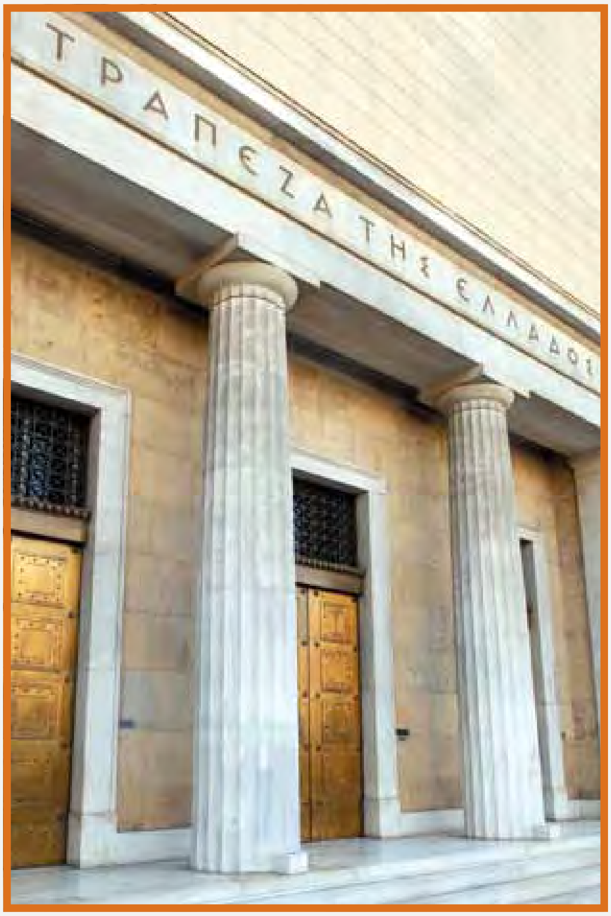
THE ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPACTS OF CLIMATE CHANGE IN GREECE



Climate Change
Impacts Study Committee

JUNE 2011

BANK OF GREECE
EUROSYSTEM

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Foreword

George A. Provopoulos

Governor of the Bank of Greece

Two years ago, when the Bank of Greece announced its ambitious plan to set up a Climate Change Impacts Study Committee and work was begun, the need for action on the impacts of climate change was already pressing. It is even more pressing today. In the course of these two years, we have all been witness not only to unfolding climate change and its significant global effects, but also to an economic crisis that has the tendency to divert our attention from the long-term benefits of investing in measures to adjust to climate change.

With this Report, the Bank of Greece, in keeping with its broader institutional role and its long-standing tradition of addressing structural problems of the Greek economy, aims at meeting the need in Greece for well-documented scientific analysis and information on climate change, its impact and effective ways of tackling it.

The study, which began in March 2009 and was designed specifically for Greece, provides detailed forecasts of climatic and environmental changes, assesses the implications of these changes for the Greek economy and estimates the cost of action as part of the EU framework of policies addressing climate change. The Bank of Greece is hopeful that this knowledge will serve as a valuable input towards the design of appropriate policies for the Greek economy.

The findings of the study point to the need not only for action to address climate change, but also for further research that will provide support and guidance to efforts aimed at adjusting to climate change in the coming decades. At the Bank of Greece, we will pursue the dissemination effort, thereby making an effective contribution in this area.

A further positive outcome of this initiative was that, for the first time, it gave experts from a wide range of disciplines the opportunity to join forces in the study of such a complex problem. This sets an example for Greece's scientific community. It is our hope that, in the future and beyond the mandate of the Committee, researchers will emulate this example, by contributing their knowledge to action against climate change.

In closing, I wish to express my deepest appreciation to all the distinguished scientists who played an active part in such an ambitious team effort, without remuneration and out of sheer dedication to this major project.

Preface and summary of the findings of the Report

The studies included in this publication of the Bank of Greece were conducted by a large number of researchers from a wide range of scientific disciplines. When the Governor and the General Council of the Bank asked my colleague at the Academy of Athens, Professor Constantinos Drakatos, and me to set up a Climate Change Impacts Study Committee, we were fully aware of the fact that producing a comprehensive report on the environmental, economic and social impacts of anthropogenic climate change in Greece would be a particularly demanding task, but also that such an endeavour would help fill an important gap in both the Greek and the international literature on the subject. Indeed, in the course of preparing the respective studies, we realised how much needed to be done and how much more would have to be done in the future.

The individual studies highlight the wealth of Greece's natural resources, but also the *dangers* to the country's natural and human environment. Greece has an extremely long coastline of some 16,300 km (equivalent to roughly one-third of the Earth's circumference), of which around 1,000 km correspond to areas highly vulnerable to climate change, due to the risk of a *rise in mean level of Greece's seas* by an estimated 0.2 m to 2 m by the year 2100. The vulnerability of our coasts is determined not only by the risk of a mean sea level rise and extreme wave events, but also by local factors (tectonics, geomorphology, etc.). About 20% of Greece's total coastline is ranked as being of moderate-to-high vulnerability to developments likely to arise on the basis of projections. Both the long-term change in sea level and extreme, transitory events will affect many sectors of the economy, including tourism, land use and transportation. The total cost of anthropogenic contribution to sea level rise will come to tens of million of euros each year, as discussed in detail in the relevant chapters.

Greece's environment, apart from its distinctive geography featuring an extensive coastline, is also characterised by great biodiversity and a variety of climates, due to the interaction between the weather systems and the country's complex topography and the distribution of land and sea areas from East to West and North to South. Thus, within just a few dozen kilometres, the climate can change from coastal Mediterranean to practically alpine in the country's central and northern regions. The varied topography combined with the trajectories of the weather systems separate Greece into a western windward area and an eastern leeward (or rain shadow) area. The country receives enough *rainfall* to meet all its needs, but unfortunately these water resources are mismanaged. The total annual volume of precipitation averages 115 billion m^3, which puts Greece at least on a par with many other European countries. However, some regions of Greece are affected by a water deficit, especially in the country's rain shadow, where the decline in water supply is, in addition to water resource mismanagement, further exacerbated by extreme climate situations, such as the one that occurred in 1989-90, when precipitation levels dropped by around 40%. On the plus side of the equation, many of these water-deficit regions have higher biogenic emissions of aromatic compounds, which, to the delight of scores of visitors, release their fragrances into the atmosphere.

Available measurements show that, in the course of the past century, *precipitation* decreased by around 20% in Western Greece and by 10% in Eastern Greece. These lower levels of precipitation have typically been attributed to natural factors, for the simple reason that the anthropogenic impact only became quantifiable in recent decades thanks to the development of high-standard climate models requiring the use of advanced computers. Based on the models used to calculate the anthropogenic component of climate change under the two extreme climate change scenarios (B2 and A2) discussed in the relevant sections of the study, it is expected that by the end of the 21st century, the decrease in precipitation levels due to anthropogenic factors will range between 5% and roughly 19% countrywide, depending on the scenario, while *air temperature* will increase by between 3.0ºC and 4.5ºC, respectively. The simulations point to significant changes in several climate parametres, such as *humidity, cloud cover*, etc. Interestingly, with regard to the future use of Renewable Energy Sources (RES), *average solar irradiation is expected to increase* (by between 2.3 W/m^2 and 4.5 W/m^2) at a national level, while *the force of the etesian winds is expected to increase* by 10% by the end of the 21st century.

As shown by one of the studies in this Report, it is estimated that, even under the intermediate scenario A1B, the Greek mainland in 2071-2100 would, compared to now, have some 35-40 more days *with a maximum daily temperature of 35ºC or more*, while even greater would be the increase (by around 50 at the national level) in the number of tropical nights (when minimum temperatures do not fall below 20ºC). At the other end of the spectrum, the number of nights with frost is expected to drop significantly, especially in Northern Greece (by as many as 40). Moreover, the rise in average temperature will *prolong the vegetation period* by 15-35 days.

One of the major impacts of global warming is that *the demand for electricity for cooling* in the summer months *will increase*. More specifically, the low-lying areas of continental Greece will have increased needs for cooling for up to an extra 40 days per year during the period 2071-2100, while the increase in needs will be smaller in the island and mountain areas. A positive aspect of climate change is that *energy needs for heating* in wintertime *will decrease*.

Changes are also expected in *precipitation extremes*. In Eastern Central Greece and NW Macedonia, the maximum amount of precipitation occurring within 3-day periods is expected to increase by as much as 30%, whereas in Western Greece it is expected to decrease by as much as 20%. By contrast, the greatest increases in drought periods are projected for the eastern part of the mainland and for Northern Crete, where 20 more *drought* days are expected per year in 2021-2050 and up to 40 more drought days are expected in 2071-2100. As a result of climate pattern changes, the number of days with a very high *risk of fire* is expected to increase significantly by 40 in 2071-2100 across Eastern Greece (from Thrace down to the Peloponnese), while smaller increases are expected in Western Greece.

On a general note, the impact of climate change on all sectors of the economy that were examined was found to be negative and, in several cases, extremely so. The impact, for instance, on fir, beech and pine *forests* would be considerable, while fire-fighting costs are expected to shoot up on account of the increasing number of *forest fires* and area affected by them. Meanwhile, species abundance and *biodiversity* are expected to decline. Furthermore, climate change, as measured by its projected impact on the tourism climatic index (TCI) by the end of the century, is expected to have serious repercussions on *Greek tourism* – mainly on the seasonal and geographical patterns of tourist arrivals. Receipts from tourism will therefore be affected. Given that tourism is such a crucial source of revenue for Greece, this Report proposes that long-term strategic planning is needed in order to upgrade the country's tourism product in the context of ongoing human-induced climate change. The consequences of climate change on the *built environment, transportation, health, mining* and other sectors are also important and are discussed in the present publication. All of the studies in the Report clearly point to the need for a well-specified adaptation policy that would cover all sectors. A foreign policy that would be revised on aspects of particular relevance for Greece should also be part of the overall adaptation policy.

With regard to *economic impact assessments*, specific studies were carried out using three different scenarios: the worst-case scenario in terms of greenhouse gas emission intensity, called the **Inaction Scenario**, corresponds to no action being taken to reduce anthropogenic greenhouse gas emissions. It was estimated that, under this scenario, Greece's GDP would drop by an annual 2% in 2050 and 6% in 2100, and that the total cumulative cost for the Greek economy over the period extending till 2100, expressed as GDP loss relative to base year GDP, would amount to €701 billion (at constant prices of 2008). The second scenario, called the **Mitigation Scenario**, presumed that Greece would achieve a consistent and drastic reduction in greenhouse gas emissions within a broader global effort and that, as a result, the average global temperature would not increase by more than 2ºC. The total cumulative cost of the Mitigation Scenario for the entire period till 2100, expressed in terms of GDP loss, comes to €436 billion (at constant prices of 2008). In other words, the total cost for the economy under the Mitigation Scenario is €265 billion less than under the Inaction Scenario, meaning that the mitigation policy would reduce the cost of inaction by 40%. Finally, given that an adaptation policy is also necessary in order to reduce the damage from climate change, an **Adaptation Scenario** was examined. Under this scenario, Greek GDP would drop by 2.3% and 3.7%, respectively, in 2050 and 2100, while the cost of adaptation policies would total €67 billion. It must, however, be stressed – as discussed in the relevant sections of the Report – that the adaptation measures do not eliminate all the damage from climate change, but simply contain it. Thus, the cumulative cost for the Greek economy of the (now reduced) damage from climate change was estimated at €510 billion (at constant prices of 2008) over the period till 2100. As a result, the total cost for the Greek economy under the Adaptation Scenario is the sum of, first, the cost incurred by the economy on account of the adaptation measures and, second, the cost of the (reduced) damage from climate change; this sum (the total cumulative cost through 2100) was estimated at €577 billion (at constant prices of 2008).

Finally, it should be noted that the estimates of the economic cost of human-induced effects on the environment, as derived at various stages of the study, all correspond to the lowest expected cost and, as such, must be taken as simply indicative of the order of magnitude. One of the important factors affecting Greece's strategic planning and adaptation policy formulation will be the issue of *poverty* and the *social problems* that human-induced climate change exacerbates. Obviously, understanding and addressing such a host of issues would require better calculations, more data, but also the formulation of domestic and foreign policies which – drawing on the indicative findings of this Report – would shield the country from things to come. Let us not forget the tenet of Hippocrates and his school *"Κάλλιον το προλαμβάνειν ή το θεραπεύειν"* ("It is better to prevent than to treat"), which is echoed in the term *'Precautionary principle'*, now of standard usage after its introduction by former Prime Minister of Norway, Bro Harlem Brundtland.

On behalf of the Climate Change Impacts Study Committee, I would like to ask our readers to excuse any errors, oversights or omissions in this Report, to be corrected in a future edition. The Study Committee would like to thank the Governor of the Bank of Greece, Mr. George Provopoulos, as well as the members of the Bank's General Council, and all those who have contributed to the success of this first, but big, effort to better prepare our country for the environmental challenges ahead.

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Chapter 1

The climate of the Eastern Mediterranean and Greece: past, present and future*

1.1 Introduction

During the four and a half billion years of our planet's history, the parameters that determine the Earth's climate have varied considerably. When the composition of our planet's atmosphere started to come close to its present-day characteristics, some three billion years ago, alternating warm and cold glacial and interglacial periods began to take place. The most recent geological period, the Holocene began 11,500 years ago, i.e. after the last ice age (18,000 years ago) and continues to this day. During the current interglacial period, the air temperature began to rise and almost reached present temperature levels in the 11th century A.D. (Luterbacher et al., 2011). This period was also marked by the so-called 'Little Ice Age' from the 15th to the 19th century, during which substantially lower temperatures prevailed both at middle latitudes and in Greece, with estimates showing that temperatures were 1.5ºC lower than today (Repapis et al., 1989; Zerefos et al., 2010; Zerefos, 2007; Zerefos, 2009; Luterbacher et al., 2006; 2010; 2011).

Since the end of the 19th century, a warming of the atmosphere, with some variations, has been ongoing. The average rate of warming of the Earth's atmosphere during the 20th century was 0.7ºC per 100 years (IPCC, 2007). The international scientific consensus is that a significant part of this warming is attributable to a change in the atmosphere's composition caused by human (anthropogenic) activity. This is commonly referred to as the 'anthropogenic component of climate change' or simply 'anthropogenic global warming'. In fact, this period is often described, quite accurately, as the 'anthropocene' a term originally coined by Eugene F. Stoermer and later popularised by Prof. Paul Crutzen. As estimated by Jones and Moberg (2003), the increase in air temperature averages in the Earth's land areas in the course of the 20th century was 0.78ºC per 100 years. It should be noted that the increase was not constant throughout the 20th century: a warming was recorded in 1920-1945 and from 1975 onwards, while many studies have tried to explain the cooling observed between 1945 and 1975, which, it was concluded,

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* Chapter 1 was co-authored by Ch. Zerefos, Ch. Repapis, Ch. Giannakopoulos, J. Kapsomenakis, D. Papanikolaou, M. Papanikolaou, S. Poulos, M. Vrekoussis, C. Philandras, G. Tselioudis, E. Gerasopoulos, C. Douvis, M. Diakakis, P. Nastos, P. Hadjinicolaou, E. Xoplaki, Juerg Luterbacher, P. Zanis, Ch. Tzedakis, D. Founda, K. Eleftheratos and K. Repapis.

could be attributed to the sun's light being blocked by anthropogenic atmospheric aerosols and volcanic dust (global dimming). In any case, the recent upward trend in temperature is statistically significant at a confidence level of 95% in almost all inhabited areas of the planet and, according to the World Meteorological Organisation, the 1995-2005 period was the warmest decade on record in the last 500 years (WMO, 2006).

According to the Intergovernmental Panel on Climate Change (IPCC, 2007) the atmospheric temperature is projected to continue to rise throughout the 21st century in most areas of the planet. In particular, on the basis of average results over a number of climate model simulations, the average atmospheric temperature is expected to increase by 1.8-4ºC by 2100, depending on developments in the concentration of greenhouse gas emissions. The increase in temperature is expected to be greater at higher latitudes and in continental regions as opposed to the oceans (IPCC, 2007). Global warming is expected to cause a decline in sea and land ice cover, and an increase in the mean sea level. In fact, in many regions the observed and expected increase in atmospheric temperature is also accompanied by an increasing frequency of extreme weather events, as mentioned in the Special Report on extreme weather events of the Intergovernmental Panel on Climate Change (IPCC, 2012). Future precipitation is more difficult to estimate because local factors including terrain affect the amount of rainfall. In the 20th century, the amount and the distribution of rainfall in continental areas tended on average to increase in a large part of middle and high latitudes, whilst, by contrast, tending to decrease in tropical regions. Similar patterns are expected in the amount of rainfall in the 21st century, according to results of climate model simulations. Precipitation is generally expected to increase at mid and high latitudes and also in the Intertropical Convergence Zone, and to decrease at tropical latitudes (IPCC, 2007).

Southern Europe and the wider Mediterranean region have been identified as vulnerable to the impact of anthropogenic climate change (Hulme et al., 1999; Giorgi, 2006; IPCC, 2007), because these regions are situated at the edge of semi-arid zones; as a result, a northward shift of baroclinic instability due to climate change could bring about drastic changes, particularly in the balance of precipitation in the Mediterranean. In particular, as shown by the results of a series of climate model simulations under various emission scenarios for the Mediterranean region, temperatures are projected to rise significantly by the end of the 21st century, while precipitation is projected to decrease (Gibelin and Déqué, 2003; Pal et al., 2004; Giorgi and Bi, 2005; Giorgi and Lionello, 2008; Zanis et al. 2009; Kapsomenakis, 2009; Douvis, 2009). Recent studies by Gao et al. (2006), Hertig and Jacobeit (2007), Zerefos et al. (2010), using statistical downscaling methods, concluded that precipitation is projected to decline substantially in SE Mediterranean regions, mostly from October to May. Other studies focusing on changes in temperature and rainfall extremes project that heat stress (Diffenbough et al., 2007; Kuglitsch et al., 2010) and the duration of drought periods (Goubanova and Li, 2007) will drastically increase in the Mediterranean region in the future, leading, inter alia, to a significant rise in forest fire risk (Giannakopoulos, 2009a). These changes are expected to have a significant impact on the region's ecosystems, as well as on a number of sectors and implications of human activity (health, agriculture, tourism, energy demand, natural disasters, loss of biodiversity, etc.). The following sections present a more detailed analysis of climate change in the Eastern Mediterranean and in various regions of Greece, at different time scales in the past, present and future.

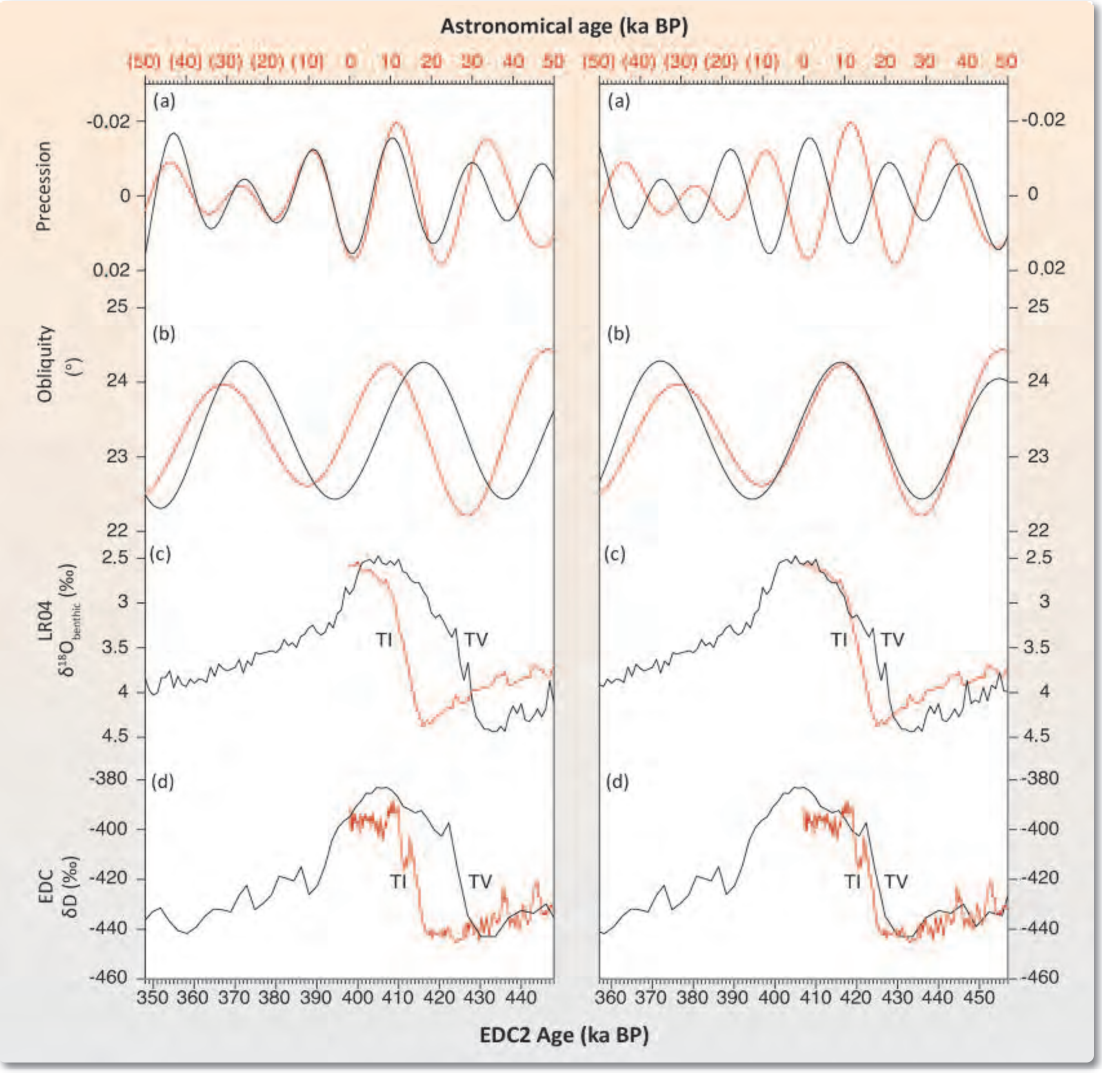
1.2 Paleoclimatic changes

At the beginning of the Eocene, fifty-five million years ago, the Earth's climate was warmer than it is today (The Geological Society, 2010), with deep-sea paleotemperature estimates derived from the analysis of benthic foraminifera oxygen isotopes (Zachos et al., 2001; Miller et al., 2005) suggesting that temperatures were about 6ºC higher. Evidence also points to a subsequent long-term downward trend in temperature over the last 50 million years (Zachos et al., 2001). Antarctic ice sheets formed 34 million years ago (Barrett, 1996), while Northern Hemisphere glaciation started 2.6 million years ago (Maslin et al., 1998). This marked the beginning of the Quaternary, i.e. the most recent geological period, characterised by alternations between relatively short interglacial periods (lasting 10-30 thousand years), and prolonged glacial ones. The sequence of alternating glacial/interglacial periods became distinctly more intense, but also less frequent during the last one million years (Middle and Late Pleistocene).

In brief, climate is determined by both external and internal factors (Bradley, 1999; Alverson et al., 2003). External factors include Earth-Sun orbital parameters, i.e. eccentricity, obliquity and precession, as well as solar activity. Internal factors include volcanic activity, feedback processes between the hydrosphere – atmosphere – lithosphere – biosphere – cryosphere (e.g. albedo, cloud cover, etc.), variations in ice-sheet volume, changes in speed and circulation of ocean currents, changes in atmospheric greenhouse gases (e.g. CO_2, CH_4) and their impact on incoming and outgoing thermal radiation, and anthropogenic forcing.

The impact of variations in the Earth's orbital parameters on long-term climate change was first described by Adhemar (1842), Croll (1875) and Milankovitch (1941); since then, numerous studies have documented the effect of the three orbital parameters, occurring at periodicities of 400 and 100, 41 and 19-21 thousand years (ka), on various paleoclimatic indices. Astronomical solutions and calculations of the Earth's orbital parameters in the past (Berger and Loutre, 1991) and the future (Berger et al., 1998) are important tools in a range of paleoclimatic studies. For instance, they allow for comparisons between the current interglacial period —which started 11.5 thousand years before present (ka BP)— and past ones marked by similar orbital parameters and, then, for an estimate of the current phase of the climate cycle, as well as of its future development. According to estimates from the 4th IPCC assessment report (2007), at least 30 thousand

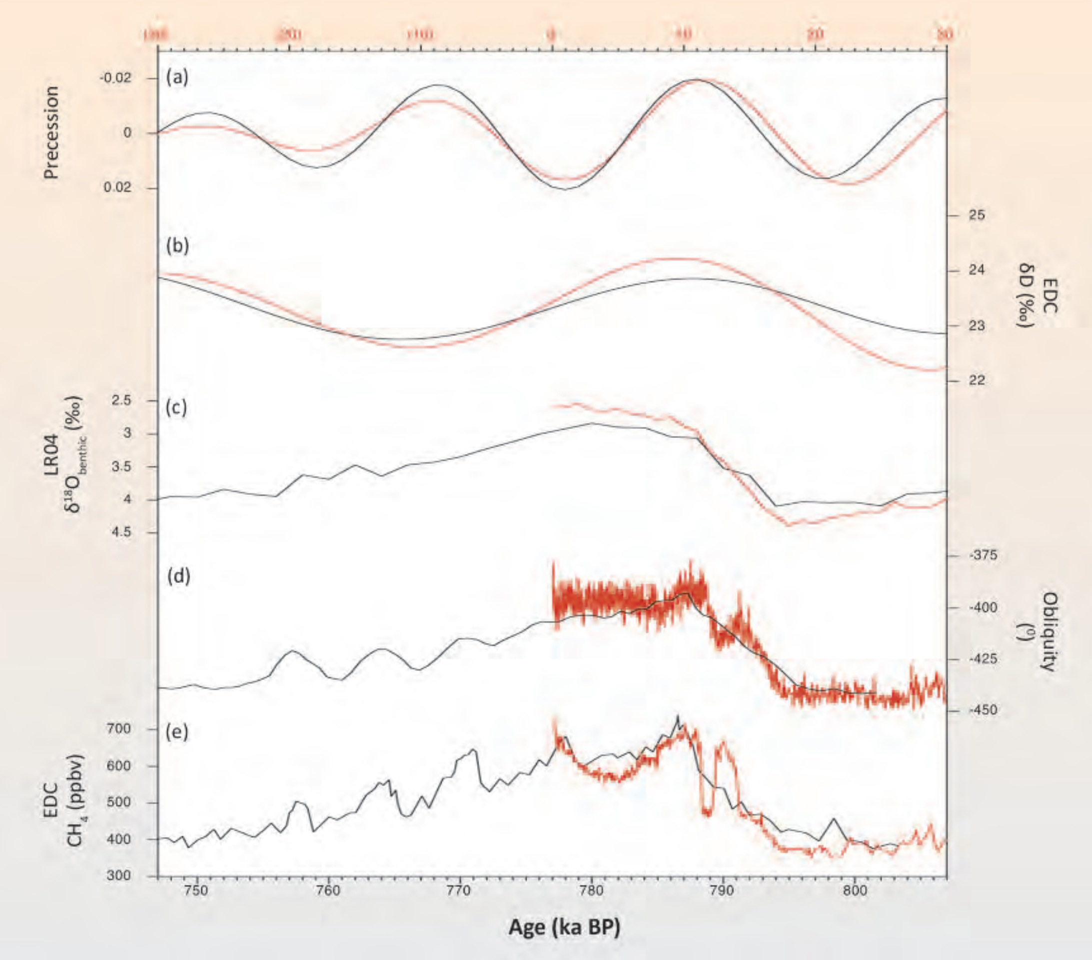
Figure 1.1 **Alignment of past isotopic records, based on precession and obliquity parameters, with those of the present and the future. Comparison of the two alignment schemes**



The bottom horizontal axis (in black) refers to a 100-ky interval in the past, namely 350-450 ka (MIS 11) (according to Masson-Delmotte et al., 2006). The upper horizontal axis (in red) refers to the past 50 ka, but also extends 50 ka into the future (ages in parentheses denote thousand years after present, ka AP). Left panel shows synchronization of the precession signal between MIS 1 and 11 and right panel synchronization of the obliquity signal. (a) precession index (Berger and Loutre, 1991); (b) obliquity (Berger and Loutre, 1991); (c) $\delta^{18}O_{benthic}$ record from the LR04 stack (Lisiecki and Raymo, 2005); (d) Deuterium (δD) composition of ice in EDC ice core (EPICA Community Members, 2004). The EPICA data in this figure are plotted on the EDC2 timescale used in the EPICA Community Members (2004) paper. Chart from Tzedakis (2010).

years would have to pass before the Earth's orbital configuration would favour the occurrence of very cold summers in the Northern Hemisphere, similar to the ones that occurred 116 ka BP at the beginning of the last glacial period). However, the scientific community remains sceptical today both about which specific past interglacial period to choose for comparison with the current warm period, and about which analogue to use for such a comparison. For instance, if we were to compare the current interglacial period (isotopic stage 1, or MIS 1) with MIS 11 (~ 400

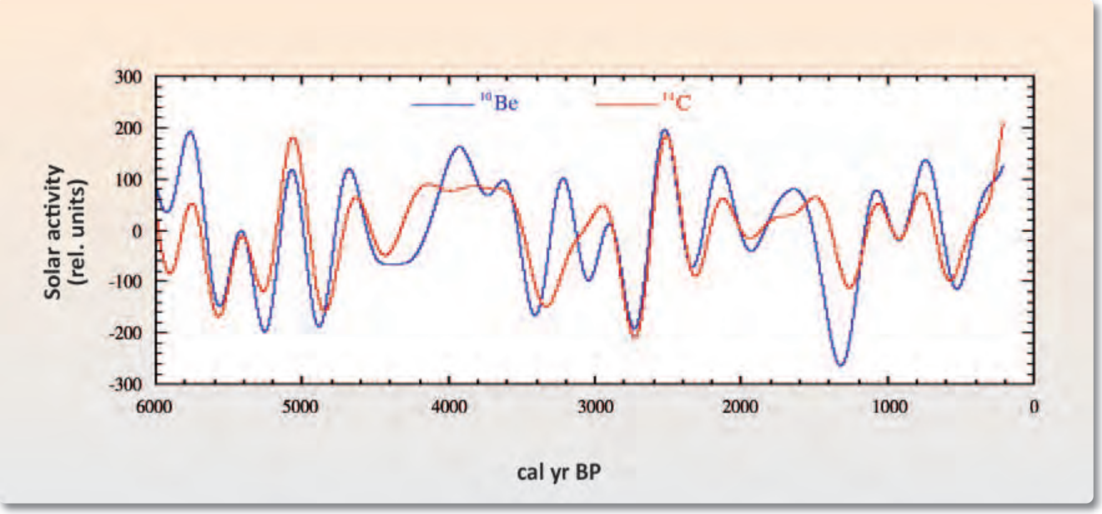
Figure 1.2 **Alignment of past isotropic records, based on precession and obliquity parameters, with those of the present and future. Comparison of the two alignment schemes**



The bottom horizontal axis (in black) refers to a 60-ky interval in the past, around 800 to 750 ka BP (MIS 19). The upper horizontal axis (in red) refers to the past 30 ka, but also extends 30 ka into the future (ages in parentheses denote thousand years after present, ka AP). (a) Precession index (Berger and Loutre, 1991); (b) obliquity (Berger and Loutre, 1991); (c) δ^{18}Obenthic(‰) record from the LR04 stack (Lisiecki and Raymo, 2005); (d) δD composition of ice in the EDC ice core, Antarctica (Jouzel et al., 2007), plotted on the EDC3 timescale; (e) atmospheric CH_4 concentration from the EDC ice core (Loulergue et al., 2008), plotted on the EDC3 timescale.

ka BP) —which had a long duration (28 ka) and similar insolation and CO_2 values— and if we aligned the precession curves of the two interglacial periods, we would probably deduce that the current interglacial period must be nearing its end (Figure 1.1) (Loutre and Berger, 2000; 2003; Ruddiman, 2007; Tzedakis, 2010). However, the alignment of the obliquity curves of the two warm periods (Masson-Delmotte et al., 2006; Broecker and Stocker, 2006) indicates that the current warm period should continue another 12 ka, before conditions could favour the onset of the next glacial period (Figure 1.2). On the other hand, if we compare the current MIS 1 period with MIS 19 (~770 ka BP), which also has similar orbital parameters, then we would deduce that the current warm period could last another 9 ka (see Loutre and Berger, 2000; and Figure 1.2).

Figure 1.3 Reconstruction of solar activity based on ^{10}Be and ^{14}C



The ^{10}Be production rate was derived from ^{10}Be concentrations measured in the GRIP ice core, Greenland (Vonmoos et al., 2006). The ^{14}C production rate was calculated with the Bern3D dynamic ocean carbon cycle model (Müller et al., 2006) by prescribing the tree-ring records of both hemispheres (Reimer et al., 2004; McCormack et al., 2004). Chart from Wanner et al. (2008).

Climate variability can, depending on the observed frequencies of variability, be broken down into (a) periodicities of 400 to ~20 thousand years, closely associated with astronomical forcing, (b) periodicities of 1,500 years and its multiples (i.e. 3,000 years, etc.), related to rapid global cooling events, known as 'Dansgaard-Oeschger events' and non-periodical 'Heinrich events' and, lastly, (c) shorter decadal or even annual periodicities, attributable to interactions between the atmosphere – biosphere – cryosphere – hydrosphere, such as 'El Niño', the North Atlantic Oscillation, the Arctic Oscillation, the Quasi-Biennial Oscillation, etc.

Measurements of solar activity based on sunspot number observations date back to the 17th century and show periodic variations at cycles of 11, 22 and 75 years. Solar activity in the historical and geological past can be reconstructed using such proxies as changes in cosmogenic isotope concentrations (^{10}Be in polar ice cores and ^{14}C in tree rings, where strong production rates of isotopes are associated with lower solar irradiation). Reconstructions of this sort were made by Wanner et al. (2008) for the past 6,000 years and by Vonmoos et al. (2006) for the past 10,000 years. The discrepancies between ^{10}Be and ^{14}C records over the last 6,000 years are visible in Figure 1.3

The scale of solar activity impacts on climate variability is also suggested by the correlation of changes in cosmogenic isotopes with changes in various climate proxies, such as oxygen isotopes (Karlén and Kuylenstierna, 1996; Bond et al., 2001; Fleitmann et al., 2003; Wang et al., 2005). Scafetta and West (2006) calculated that 75% of the global warming during the period 1900-1980 came from solar contribution, a proportion that falls to 30% for the following two decades (1980-2000). Others, like Wanner et al. (2008), are more sceptical both about how to physically interpret the climatic impact of solar activity and about how marked the effect of solar activity variations may have been on Quaternary climatic change (glacier advances and retreats) and on current global warming (Bard and Frank, 2006), claiming that the effect of solar activity is probably only secondary. It is, in other words, possible that solar activity may contribute to small climatic variations on a timescale of a few centuries (Steinhilber et al., 2009), like the climatic variations that took place over the last millennium, e.g. the medieval climate anomaly (a relatively warm period between 900 and 1400 A.D.) and, the ‘Little Ice Age’ (1500-1800 A.D.). Given the considerable uncertainty within the scientific community as to the impact of solar activity at small timescales, solar activity will not be discussed further in the present study (IPCC, 2007).

1.3 Climate change in the Holocene

The high-resolution study of the climatic evolution over the last 11.5 thousand years (Holocene) is important for estimating the trends, patterns, ranges and rates of change in various climate proxies. The climate regime of the elapsed part of the Holocene is comparable to today’s and provides high-resolution sediment records containing potentially valuable biological and paleoclimatic indicators. The dating of these records can, depending on the case, be achieved quite accurately, using either absolute dating (e.g. radioactive isotopes ^{14}C, ^{210}Pb) or relative dating methods (e.g. tephrostratigraphic markers, sapropel stratigraphy, etc.). The availability of high-resolution records of climate parameters (e.g. temperature, salinity, precipitation) either from instrumental measurements (for the last two centuries) or from sediment records (on a millennial or centennial timescale) point to a strong variability on a decadal and centennial timescale. Meanwhile, adequate instrumental climate measurements are available only for the past 150 years, while the combination of various parameter datasets from tree rings, ice cores, speleothems, historical records, etc. barely covers the last two millennia in the Mediterranean (e.g. Luterbacher et al., 2011).

The present and following two sub-chapters aim to compare the duration, range and rate of past climate change with present-day data, focusing primarily on the Eastern Mediterranean and Greece.

The Holocene, the most recent warm interglacial period, is currently in its final stages. However, a significant number of studies point to substantial climatic variability, in the form of abrupt global cooling events. It is absolutely essential to determine the characteristics (duration, intensity, and rate) of these events, as well as the driving forces behind them, and to compare the findings with respective data for the last millennial-to-centennial timescale. Mayewski et al. (2004) in their extensive review of global Holocene proxy records identify six major periods of rapid climate change, i.e. cooling events within a generally warm period.

The first severe climatic disruption of the Holocene occurred 9-8 thousand years ago. Also called the ‘8.2 ka event’ (Alley et al., 1997), this cooling event coincided with:

- at least one large pulse of glacier meltwater into the North Atlantic (Barber et al., 1999), probably enhancing the production of sea ice, providing a positive feedback on climate cooling;
- a decline in summer insolation;
- no clear evidence of variations in solar activity (^{10}Be remains unchanged in ice cores, while the pronounced depressions in $\Delta^{14}C$ probably reflect a change in thermohaline circulation because of increased meltwater production) and high rates of SO_4, suggesting a possible contribution of volcanic eruptions to both cooling in the Northern Hemisphere and aridity in low latitudes (as a result of weakened Afro-Asian monsoons circulation).

The 9-8 ka event was followed by other abrupt climate events that occurred during the time periods 6-5 ka BP, 4.2-3.8 ka BP, 3.5-2.5 ka BP, 1.2-1 ka BP and 600-150 a BP (Mayewski et al., 2004). The climate regime and the driving forces associated with these cooling events are different from the ones of the earlier 9-8 ka BP event, in the sense that these later (post 9-8 ka BP) cooling events provide no evidence of massive freshwater releases or significant ice growth in the Northern Hemisphere. Also, there are no systematic changes in the concentrations of volcanic aerosols and atmospheric CO_2. Although during 9-8 ka BP event, Northern Hemisphere glaciers still played a significant role in climate change, some of the more recent events seem to be largely determined by solar variability. Cooling at high latitudes in the Northern Hemisphere generally coincides with aridity at low latitudes (Mayewski et al., 2004; Staubwasser and Weiss, 2006), including the Mediterranean. More specifically, the 6-5 ka BP and the 3.5-2.5 ka BP intervals are associated with:

- a decline in solar output, as suggested by the maxima in the ^{10}Be and $\Delta^{14}C$ records; and
- a steady rise in atmospheric methane concentrations after ~5 ka BP .

The subsequent abrupt climate events of 4.2-3.5 ka BP and 1.2-1 ka BP are more difficult to attribute to specific forcing mechanisms: the 4.2-3.5 ka BP interval, for instance, coincides with a maximum in ^{10}Be, but only little change in $\Delta^{14}C$ to suggest a solar association. On the other hand, the aridity at low latitudes may be attributable to the southward displacement of the Intertropical Convergence Zone (ITCZ, Hodell et al., 2001), which would be consistent with the strengthening of the westerlies over the North Atlantic. The drought of the 4.2-3.5 ka BP period seems to have been a factor in the collapse of the Akkadian civilisation (deMenocal et al., 2000a). The 1.2-1 ka BP event coincides with a slight increase in atmospheric CO_2 and the drought-related collapse of Maya civilisation (Hodell et al., 2001). Under cooler conditions, tropical aridity may result from a variety of factors, including the weakening of the monsoonal system, reduced evaporation from cooler oceans, and weakened thermal convection over tropical landmasses (Mayewski et al., 2004).

The most recent cooling interval (<600 years BP) is characterised by low temperatures at high latitudes together with increased moisture at low latitudes. It has seen a drop in CO_2 and a rise in CH_4, suggestive of wet conditions. High levels of volcanic aerosols at early stages of this event may have contributed to its onset. Moreover, a distinct peak in ^{10}Be and Δ^{14}C (Beer, 2000; Stuiver and Braziunas, 1989; 1993) suggests that solar variability had a major influence on climate during this interval (Bond et al., 2001; Denton and Karlén, 1973; Mayewski et al., 1997; O' Brien et al., 1995) and may be associated with the solar activity minimum (Spörer Minimum) of the 15th century A.D. A sequence of sunspot minima, such as the Wolf Minimum (1280-1350 A.D.), the Spörer Minimum (1460-1550 A.D.), the Maunder Minimum (1645-1715 A.D.) and the Dalton Minimum (1790-1820 A.D.), can be regarded as representing the cold interval known as the 'Little Ice Age', during which volcanic activity is estimated to have contributed to a further drop in temperature (Gao et al., 2008). Between the Oort minimum (1040-1080 A.D.) and the Wolf Minimum (1280-1350 A.D.), there was an interval of nearly 200 years marked by higher solar activity, which coincides with the Medieval Climate Anomaly.

The most important conclusions to be drawn from this brief presentation are that the abrupt climate change events of the Holocene (more frequent from the Middle Holocene onward) were the result of a combination of climate forcing mechanisms and therefore did not take place at the same time or with the same intensity across the globe. Each cooling event is the outcome of a distinct and unique combination of climate forcing mechanisms (Mayewski et al., 2004).

1.4 Past rates of increase in atmospheric temperature and the role of carbon dioxide

Current climate change has been estimated to account for a temperature increase of about 1ºC (ground surface temperature) in the last 500 years (Pollack and Smerdon, 2004; Huang et al., 2000) and of 0.76ºC in the last 100 years (IPCC, 2007). Temperatures in the second half of the 20th century were, as estimated, very likely to have been higher than during any other 50-year period in the last 500 years, and likely the highest in the past 1,300 years (IPCC, 2007). However, uncertainty remains considerable as to whether the last 100 years have had a higher incidence of climate extremes than the last 400 years, due to the accuracy margin of paleoclimate data derived from paleoclimatic proxy indicators and historical records for the last 400 to 500 years BP, and to the fact that these data are not sufficiently calibrated and bridged with the instrumental records available for the last 150 years (Xoplaki et al., 2005).

Although it is difficult to assign specific numbers to the change and rate of change in global temperatures, given the considerable differences between regions, a number of temperature esti-

Table 1.1 **Global temperature change and rate during sub-periods of the present interglacial, along with the respective data sources**

Time period	ΔT (°C)	ΔT rate (°C/years)	Source
100 a BP	+ 0.7		IPCC (2007)
500 a BP	+1		Pollack and Smerdon (2004)
18 ka-11 ka BP*		+ 1/100	North Atlantic foraminifera
18 ka-11 ka BP		+ 0.6–0.8/100	Pollen from France
18 ka-11 ka BP		+ 1.7–2/100	Coleoptera from Britain
6 ka BP		+ 0.4/100	
900-1350 A.D. (Middle Ages)	+1		Greenland ice
Cold periods in the 19th century	- 0.6-0.7		Dahl-Jensen et al. (1998)
Cold periods in the 17th century (Little Ice Age)	- 0.5		Dahl-Jensen et al. (1998)
1980-1999 – 2090-2099	+ 1.8-4.0		IPCC (2007) (Meehl and Stocker, 2007) climate projections

* ka: thousand years, BP: before present.

mates have been advanced by the scientific community for different periods of the geological past, quoted below in chronological order and also summarised in Table 1.1.

The global mean surface temperature during the last interglaciation (125-120 thousand years ago, or ka BP), is estimated to have been higher (by 0ºC to 4ºC, and by 2ºC to 3ºC for northern Europe) than today (Otto-Bliesner et al., 2006). Temperature variability from the end of the last glaciation (21-18 thousand years ago) to the beginning of the current warm period (11-10 thousand years ago) is estimated to have been in the order of 4ºC to 7ºC (Jansen et al., 2007). In the course of the current warm period (i.e. the last 11,500 years), estimates show that the mid-Holocene (between 9 and 4 thousand years ago) experienced a warm peak, with temperatures 1-3ºC higher than present levels (based on surface and ice-core data, Dahl-Jensen et al., 1998; Masson-Delmotte et al., 2005). As shown by Greenland ice-core data, temperatures during the Medieval Warm Period (900-1350 A.D.) were 1ºC higher than in the hundred-year period from 1880 to 1980 (Vinther et al., 2010). All reconstructions indicate that the Middle Ages were warmer and the Renaissance and Enlightenment periods were colder, and that the 20th century presents particularly high rates of temperature increase. It should, at any rate, be noted that the maximum temperatures in the Middle Ages, for instance in Greenland, were close to 1950 A.D. temperature levels (Kobashi et al., 2010).

The rates of temperature increase during the transition from the last glaciation (21-18 thousand years ago) to the beginning of the Holocene warm period (11,500 years ago) have been estimated at around 1ºC/100 years based on data from deep-sea foraminifera in the North

Atlantic (Austin and Kroon, 1996), 0.6-0.8ºC/100 years based on the analysis of pollen time series from France (Guiot, 1987) and 1.7-2ºC/100 years based on the analysis of coleoptera remains from Britain and France (Atkinson et al., 1987; Ponel and Coope, 1990). Even higher rates of temperature increase have been advanced on the basis of the Greenland ice sheet, with the temperature estimated to have increased by 5-10ºC in less than 1,500 years (Severinghaus et al., 1998) and in some extreme estimates even by as much as 5-10ºC/100 years (Alley, 2000).

The rate of temperature increase in the Mid-Holocene (6 thousand years ago) is estimated to have reached no more than 0.4ºC/100 years at mid-latitudes.

At this stage, it should be noted that, as estimated by the Intergovernmental Panel on Climate Change, the anthropogenic component in the temperature increase over the next 80 years is projected to be between 1.8ºC and 4.0ºC (IPCC, 2007).

The high temperatures, the glacier retreat and the rise in sea level to higher-than-current levels during the Early- to Mid-Holocene are consistent with higher insolation, which peaked at the beginning of the Holocene (~11 ka BP) and then began to trend downward. Given that current insolation levels are low, one would expect temperatures to be lower and glacier volume to be greater than the observed values. Furthermore, the rates of temperature increase of 0.6-0.8ºC and 1ºC/100 years mentioned above concern the transition from a glacial to an interglacial period, during which higher rates of increase can be expected, whereas the current rate of increase of 0.76ºC/100 years likely corresponds to the final stages of the current interglacial period.

The global warming of the last 150 years has been largely attributed to the increase in anthropogenic greenhouse gas emissions (Hegerl et al., 2011). As for the changes of the last few decades, human forcing, e.g. air pollution, but also natural variability and processes in the atmosphere-hydrosphere system have played their part (IPCC, 2007). As noted by The Geological Society of London in a recent report (November 2010), evidence from the geological record is consistent with the physics that shows that adding large amounts of CO_2 to the atmosphere causes the temperature to rise (‘greenhouse effect’), which in turn leads to higher sea levels, changed patterns of rainfall (Alverson et al., 2003), increased acidity of the oceans (Barker and Elderfield, 2002; Caldeira and Wickett, 2003) and decreased oxygen levels in seawater (Keeling et al., 2010).

As shown by the analysis of air bubbles trapped in the Antarctic ice sheet, atmospheric CO_2 concentrations have fluctuated over the last 800 thousand years. Temperature and CO_2 concentration time-series evolved in parallel during earlier glacial-interglacial cycles of the Quaternary, with CO_2 concentrations ranging from 180 to 280 ppm, respectively. However, since the end of the previous glacial period, the increase in CO_2 has been lagging behind the rise in temperature by a few centuries, more likely suggesting that CO_2 is not the only culprit in climate change during this interval. Scientists believe that the continued global cooling from the end of the Eocene (34 million years ago) to the Holocene is probably associated with a decline in CO_2 values from ~1000 ppm to 180-280 ppm during the Quaternary. CO_2 is currently at 390 ppm, having increased by almost 35% in the last 200 years, with half of this increase having occurred in the last 30 years. As mentioned in the aforementioned report of The Geological Society of London (2010), similar rates of increase in CO_2 have been found for 183 million years ago (Lower Jurassic) and for 55 million years ago (Paleocene-Eocene), although the calculations of the rate of CO_2 increase are fraught with considerable uncertainty (sediment dating, rate of sedimentation, estimates of total CO_2). Similarly high CO_2 levels are estimated to have existed during the Pliocene (at times between 5.2-2.6 million years ago), with CO_2 concentrations in the atmosphere reaching 330-400 ppm. During those times, global temperatures were 2-3ºC higher than now (Seki et al., 2010), and the mean sea level was higher than today by 10-25 m.

Evidence preserved in a wide range of geological settings (e.g. ice sheets, marine and lake sediments, speleothems, etc.) has helped to establish that the Earth has undergone a number of warming periods in the past. Each warming event/episode can be explained by, or related to, geological events, such as orbital forcing, the breakdown of methane hydrates beneath the seabed, changes in ocean circulation, variations in volcanic activity, continental displacement and changes in the energy received from the sun. The concern about current global warming (since 1970) stems from the fact that it cannot be related to anything recognisable as having a geological cause, like the events mentioned above. For one, a rise in temperature as a result of internal climate variability (e.g. El Niño) should cause regional rather than global warming (Hegerl et al., 2007). The recent increase in temperature coincides with a sharp increase in anthropogenic CO_2 emissions which, based on geological analogues and physical theory, is likely to raise global temperatures (Solomon et al., 2007). It has been estimated that a doubling of CO_2 concentrations in the atmosphere translates into a temperature increase in the order of 2ºC to 4.5ºC, with a best estimate of about 3ºC (climate sensitivity).

1.5 Paleoclimatic changes in the Eastern Mediterranean during the Holocene

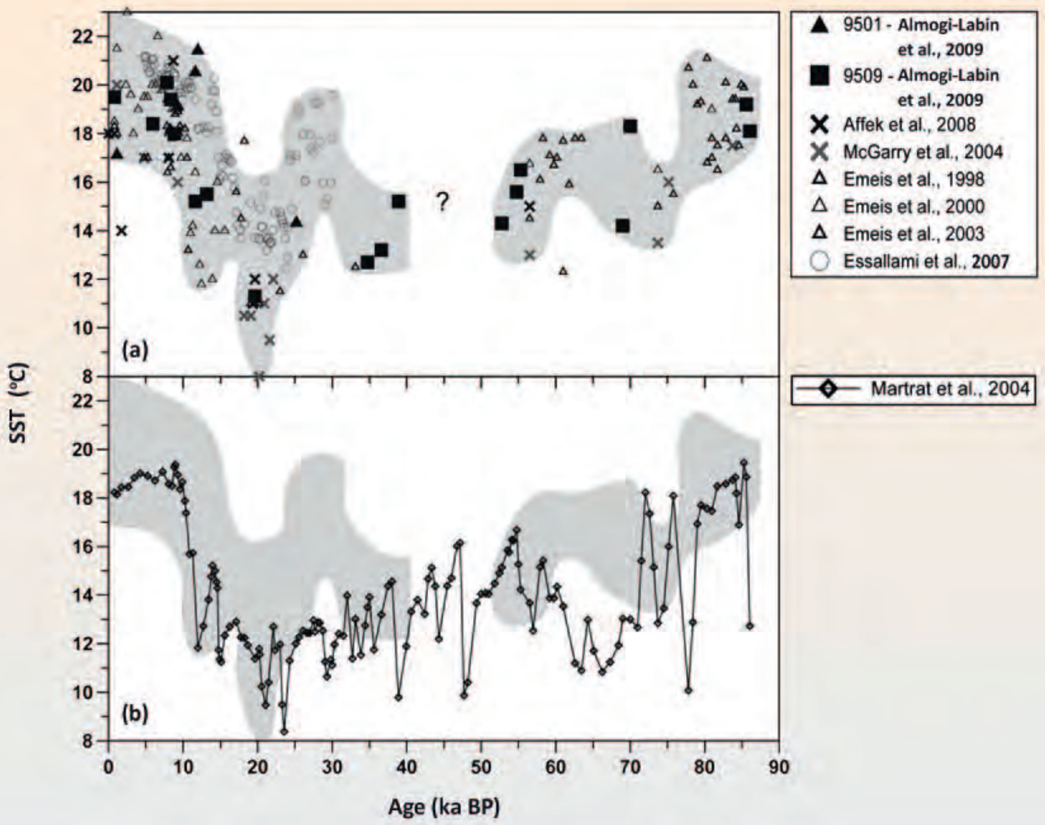
The Mediterranean climate is influenced by the subtropical high pressure system over the arid zones of North Africa's deserts, the westerlies from central and northern Europe, the African and Asian monsoons (Lionello and Galati, 2008), the Siberian High Pressure System, the North Atlantic Oscillation (NAO) and the Southern Oscillation (SO) (Lionello et al. 2006; Xoplaki, 2002). Apart from atmospheric circulation in the Mediterranean, the NAO can also have an impact on river runoff and thermohaline circulation in the region (e.g. Tsimplis et al., 2006). Specifically, according to the patterns of at least the last 500 years (Luterbacher et al., 2006), a negative NAO index is associated with wet (low-pressure anomalies) and usually cooler conditions in the Mediterranean, whereas a positive NAO index is linked with strong westerlies at high- and mid-latitudes and dry (anticyclonic), warm conditions in the Mediterranean. Heavy rainfall from the African and Asian monsoons contributes to the inflow of freshwater, mostly into the Eastern Mediterranean, from the Nile and other river systems, while precipitation variability is also affected by the El Niño Southern Oscillation (ENSO); Alpert et al. (2006); Brönnimann et al. (2007); Karabörk and Kahya (2009). Thus, the reconstruction of the Mediterranean paleoclimate and interpretation of climatic changes, whether gradual or abrupt, often involve correlating with variations in monsoon intensity, periodicity of the Earth's orbital parameters, solar activity, as well as the North Atlantic Oscillation (NAO).

The main physico-geographical factors that determine climatic conditions in the Mediterranean region are atmospheric circulation, latitude, altitude/orography, Atlantic and Mediterranean sea surface temperatures, land-sea interaction (distance from the sea), as well as smaller-scale processes. Oceans have a direct influence on the atmosphere, through the continuous exchange of heat and moisture, and through the significant role they play in the atmosphere's chemical balance. Sea Surface Temperature (SST) is an important geophysical parameter, capable —via the air-sea interaction mechanism— of shaping local weather conditions, but also of affecting the long-term climate (IPCC, 2007).

Both the marine geological record (paleotemperature reconstruction using e.g. foraminifera, coccolithophores, alkenones) on a multi-millennial to centennial timescale and the proxy-based reconstruction of temperature, precipitation and atmospheric pressure for the past 500 years point to the existence of different climatic sub-regions in the Mediterranean, the clearest demarcation being between the Eastern Mediterranean, on one hand, and the Western and Central Mediterranean (Luterbacher and Xoplaki, 2003). Thus, winter air temperature in the Eastern Mediterranean appears to be negatively correlated with the NAO index, in contrast with the Western and Central Mediterranean where there seems to be a small positive correlation. Evidence of these regional differences is also found in the geological record in the paleotemperatures of marine surface waters estimated from long-chain alkenones (i.e. the Uk′37 index) in the coccolithophorid *Emiliania huxleyi* that blooms in spring. According to Emeis at al. (2003), sea surface temperatures over the last 300 ka are estimated to have ranged between 9ºC and 21ºC in the Western Mediterranean and between 17ºC and 25ºC in the Eastern Mediterranean. Comparable sea surface temperature data for the past 90 thousand years are graphically represented in Figure 1.4 (Almogi-Labin et al., 2009).

A combined analysis of the fossil coral record from the northernmost Red Sea and of simulations using the coupled atmosphere-ocean climate model ECHO-G reveals an impact of the NAO on both seasonal variability and on inter-annual long-term mean values during the Late Holocene (2.9 ka BP) and the previous interglacial (122 ka BP) in the Eastern Mediterranean and the Middle East (Felis et al., 2004).

Figure 1.4 **Sea surface temperatures (SST) derived from alkenones**



(a) From the Eastern Mediterranean, (b) from the Western Mediterranean. Figure taken from Almogi-Labin et al. (2009).

Present-day winter conditions in the Aegean are influenced by dry polar/continental northelies that are orographically channelled through the Axios, Strymon and Evros river valleys, lowering the SSTs to 12-14ºC in the Northern Aegean and to 16ºC in the Southern Aegean (Theocharis and Georgopoulos, 1993; Poulos et al., 1997). The SST range in the Mediterranean is 3.6ºC in spring (from 16.6ºC to 20.2ºC) and 3.4ºC in winter (from 13.9ºC to 17.3ºC) (Brasseur et al., 1996). The temperature difference between the Western and the Eastern Mediterranean is in the order of 2-3ºC (Emeis et al., 2000).

Paleoceanographic data from the Aegean suggests that short cooling events during the Holocene are associated with intense northerly winds superimposed on the tropical/sub-tropical influence on the regional hydrography and ecosystems (Rohling et al., 2002b; Casford et al., 2003; Gogou et al., 2007; Marino, 2008). These findings suggest that the NE Mediterranean climate was more variable during the last climate cycle than generally believed.

After the last glacial maximum (LGM, 21 ka BP) and until 13 ka BP, Mediterranean SSTs averaged 11-15ºC based on the alkenone Uk′37 index (Emeis et al., 2000), while the total temperature change during the transition to the 'warm' Holocene (11.5 ka BP) is estimated at about 10ºC (Emeis et al., 2003). Significant during this period was the brief episode with relatively high SSTs (e.g. 22.9ºC in the Northern Aegean; Gogou et al., 2007), between 15 and 13 ka BP and corresponding to the Bølling-Allerød event (Bar-Matthews et al., 1997; Geraga et al., 2000; Sbaffi et al., 2001). Distinct and abrupt cold events, known as the Older and Younger Dryas, then followed between 14.7 and 11.7 ka BP, with SSTs as low as 13-14ºC at ca 14 ka BP in the Ionian Basin (Emeis et al., 2000) and 14.5ºC in the Northern Aegean (Gogou et al., 2007) and throughout the Mediterranean (Vergnaud-Grazzini et al., 1986; Rossignol-Strick, 1995; Geraga et al., 2000; Sbaffi et al., 2001; Asioli et al., 2001; Aksu et al., 1995; Bar-Matthews et al., 1997; Zachariasse et al., 1997; De Rijk et al., 1999).

During the early to mid-Holocene, the enhancement of Northern Hemisphere monsoons, resulting from orbitally induced changes in the latitudinal and seasonal distribution of insolation created substantially wetter conditions over much of NE Africa (Jolly et al., 1998). This resulted in a periodic intensification of the African summer monsoon, with increased precipitation along the northern African and the Sahel and possibly an increased discharge of freshwater from the Nile (Rossignol-Strick, 1985; Rohling et al., 2002). At the same time, the northern fringe of the Mediterranean may also have experienced increased precipitation in autumn/winter (Tzedakis, 2007) due to significant regional atmospheric pressure variations (Duplessy et al., 2005). The greater discharge of freshwater into the Eastern Mediterranean affected thermohaline circulation and inhibited deep water formation processes. This resulted in bottom water oxygen depletion and stagnation, which, combined with increased organic material productivity and deposition on the sea floor, led to the formation and preservation of the most recent sapropel,[1] S1 (Rohling and Hilgen, 1991; Rohling, 1994). In the Aegean, sapropel formation began at ca 10-9.6 ka BP (Perissoratis and Piper, 1992; Aksu et al., 1995; Zachariasse et al., 1997; De Rijk et al., 1999; De Lange et al., 2008) and continued until ca 6.5 ka BP, with an interruption between 7.9 and 7.3 ka BP (see e.g. Figure 1.7).

The period preceding sapropel S1 formation, i.e. before 9 ka BP, was characterised by low SSTs. More specifically, the SST has been estimated at 13-14ºC in the Ionian Basin at ca 11 ka BP (Emeis et al., 2000), 17ºC in the SE Aegean between 10.8 and 9.7 ka BP (Triantaphyllou et al., 2009a, b) and ~16ºC in the Northern Aegean at 10.5 ka BP (Gogou et al., 2007) (Figure 1.7). During sapropel S1 formation (9.5-6.6 ka BP), the SST reached 16-19ºC in the Eastern, Central and Western Mediterranean (Emeis et al., 2000, Figures 1.5 and 1.6) and 17.5-22.9ºC in the Northern Aegean (Gogou et al., 2007, Figure 1.7). A characteristic interruption in sapropel S1 formation is signalled by the global cold event of 8.2 ka BP, with markedly lower SSTs (Ger-

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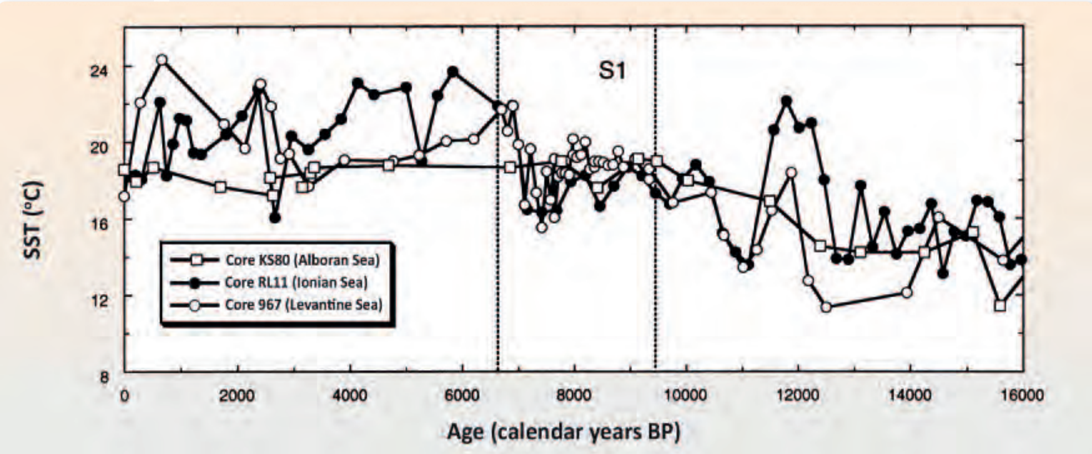
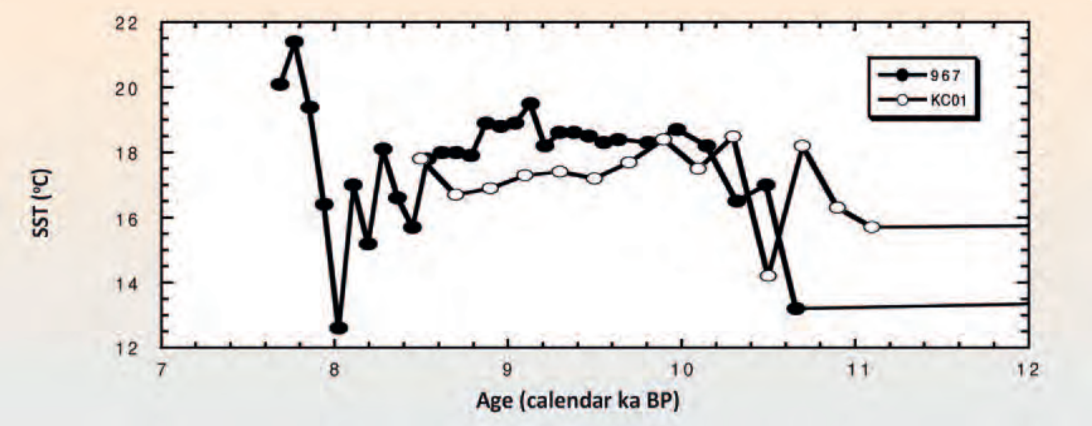
[1] Sapropel is a dark-coloured sediment, rich in organic material and thought to develop during episodes of reduced oxygen availability.

Figure 1.5 Sea surface temperature (SST) estimates derived from alkenones



Emeis et al. (2000).

Figure 1.6 Sea surface temperatures (SST) derived from alkenones in cores ODP 967 in the Levantine Basin and KC01 in the Ionian Sea



Emeis et al. (1998).

aga et al., 2008) in the Eastern Mediterranean (de Rijk et al., 1999; Geraga et al., 2000; 2005) and arid conditions, as suggested by the sedimentary record of the Aegean sea (e.g. Rohling et al., 2002; Triantaphyllou et al., 2009a, b). This cold dry event has also left archaeological imprints, for instance in Knossos (Crete), where a Neolithic age settlement between ca 9.8-8 ka BP, as confirmed by pottery finds, seems to have been partly abandoned between 9 and 7.5 ka BP (Efstratiou et al., 2004). The absence of material remains from human activity during this period has also been noted in a number of other locations, such as the Cyclops' Cave in the Northern Sporades, the Theopetra Cave (Thessaly), Sidari (Corfu, Berger and Guilaine, 2009) and elsewhere in the Mediterranean.

Table 1.2 **Sea surface temperature (SST)* and its rate of change during various time intervals (ka BP)** in Greece**

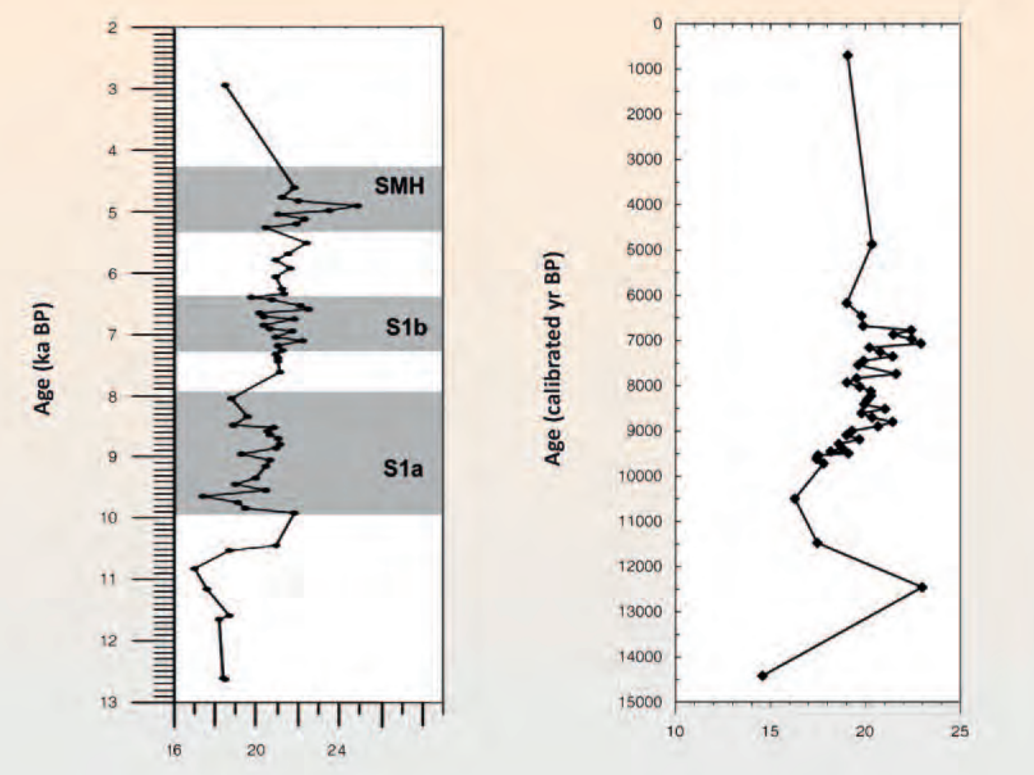
Time period	SST rate of change (°C/yr)	SST (°C)	Region
13 ka	+ 8/1000	from 14 to 22	Ionian Sea (Emeis et al., 2000)
9.8 ka	- 1.6/91		SE Aegean (Triantaphyllou et al., 2009)
9.7 ka	- 2-3/70		SE Aegean (Triantaphyllou et al., 2009)
9.7 ka	+ 3/92		SE Aegean (Triantaphyllou et al., 2009)
8.2 ka	- 2/50		Southern Aegean (Rohling et al., 2007)
2.8 ka	+ 6/~250	from 16 to 22	Ionian Sea (Emeis et al., 2000)
2.9 ka	- 4/~250	from 20 to 16	Ionian Sea (Emeis et al., 2000)
1500-1850 A.D.	- 2		Sicily (Silenzi et al., 2004)
1860-2000, with 1961-1990 as reference period	0.9/90		IPCC (2001)

* Based on alkenones (except for Silenzi et al., 2004, which is based on Vermetidae shells).
** ka BP: thousand years before present.

Following the S1 sapropel deposition (less than 6.6 ka BP), SSTs ranged around 20ºC in the Ionian Sea and Levantine basin, reaching a maximum of 24ºC (Emeis et al., 2000) at ca 6 ka BP and averages of 19ºC in the Northern Aegean (Gogou et al., 2007), i.e. levels similar to the current annual SST (Worley et al., 2005) at the same location. The Mid-Holocene (4.9 ka BP) saw the highest SST recorded in the SE Aegean, i.e. 25ºC (Triantaphyllou et al., 2009).

The abrupt changes in Holocene SSTs in the Eastern Mediterranean are summarised in Table 1.2. Specifically, during the Allerød period (ca 13 ka BP) core RL11 in the Ionian Basin (Emeis et al., 2000) saw a sharp increase in SST from 14 to 22ºC in less than 1,000 years, followed during the Younger Dryas by a decrease in SST over the next 1,000 years (Figure 1.5). This variation may be associated with seawater density changes and a shift of intermediate and deep water formation to the Ionian Basin during the Younger Dryas. At 9.8 ka BP, core NS-14 in the SE Aegean (Figure 1.7) saw a decrease of 1.6ºC in SST within 91 years, followed at 9.7 ka BP by a rise of 3ºC within 92 years. The fact, however, that these high-amplitude and abrupt changes are not observed throughout the Aegean underscores the importance of local hydrologic and bathymetric conditions. Subsequently, during the cold and dry '8.2 ka event' and based on paleotemperature proxies (e.g. oxygen isotopes and foraminifera concentrations), temperatures in the LC21 core in the Southern Aegean dropped by 2ºC in roughly 50 years (Rohling et al., 2002a, b), likely associated with fierce NW polar winds prevailing in the area. According to the LC21 record, the decrease in temperature continued for about 150-250 years, while several centuries elapsed before temperatures resumed an upward trend. Rohling and Pälike (2005) note that the 8.2 ka BP cold event was part of a longer anomaly spanning 400-600 years (based for

Figure 1.7 **Sea surface temperatures (SST), Uk/'37 index**



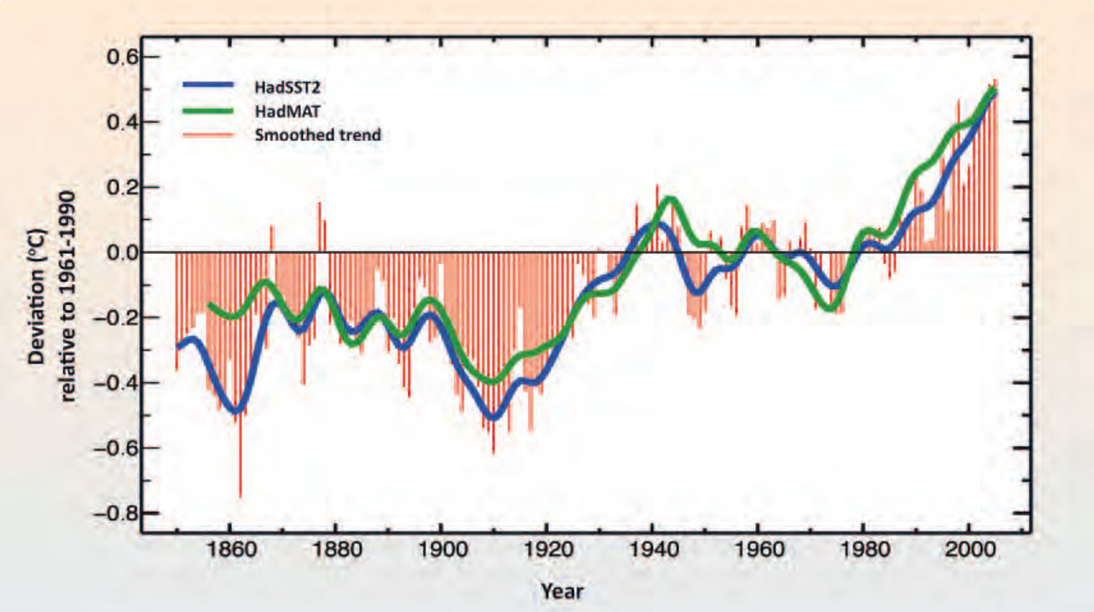
Derived from the alkenone Uk/'37 index, (a) in NS-14 core, south of Nissyros (Triantaphyllou et al., 2009), left panel, and (b) in MNB3 core in the Northern Aegean (Gogou et al., 2007), right panel.

instance on records from Asia), but in Greenland lasted only 150 years (based on temperature records derived from ice cores).

At about 2.9-2.8 ka BP, records from the RL11 sediment core in the Ionian basin (Emeis et al., 2000) indicate that SSTs dropped sharply from 20ºC to 16ºC, and then rose from 16ºC to 22ºC in less than 500 years (see Figure 1.5). A decrease in SSTs (from 21-24ºC to 18.5ºC) is also recorded in the NS14 core in the Southern Aegean (Triantaphyllou et al., 2009a, b) during the same period.

As can be seen in Figure 1.8 representing the annual anomalies of Northern Hemisphere sea surface temperatures relative to the 1961 to 1990 mean, the decadally smoothed annual values indicate a total temperature deviation of about 1.0°C within 150 years. This rate of change does not seem to exceed estimated paleotemperature SST changes (e.g. a drop of 2-3ºC in 70 years at 9.7 ka BP, or a rise from 21ºC to 23.4ºC in 72 years at 5 ka BP, Triantaphyllou et al., 2009a, b), derived from alkenone measurements for specific periods in the Aegean.

Figure 1.8 **Annual sea surface temperature (SST) deviations relative to the 1961-1990 reference period in the Northern Hemisphere**



Source: IPCC, 2007.

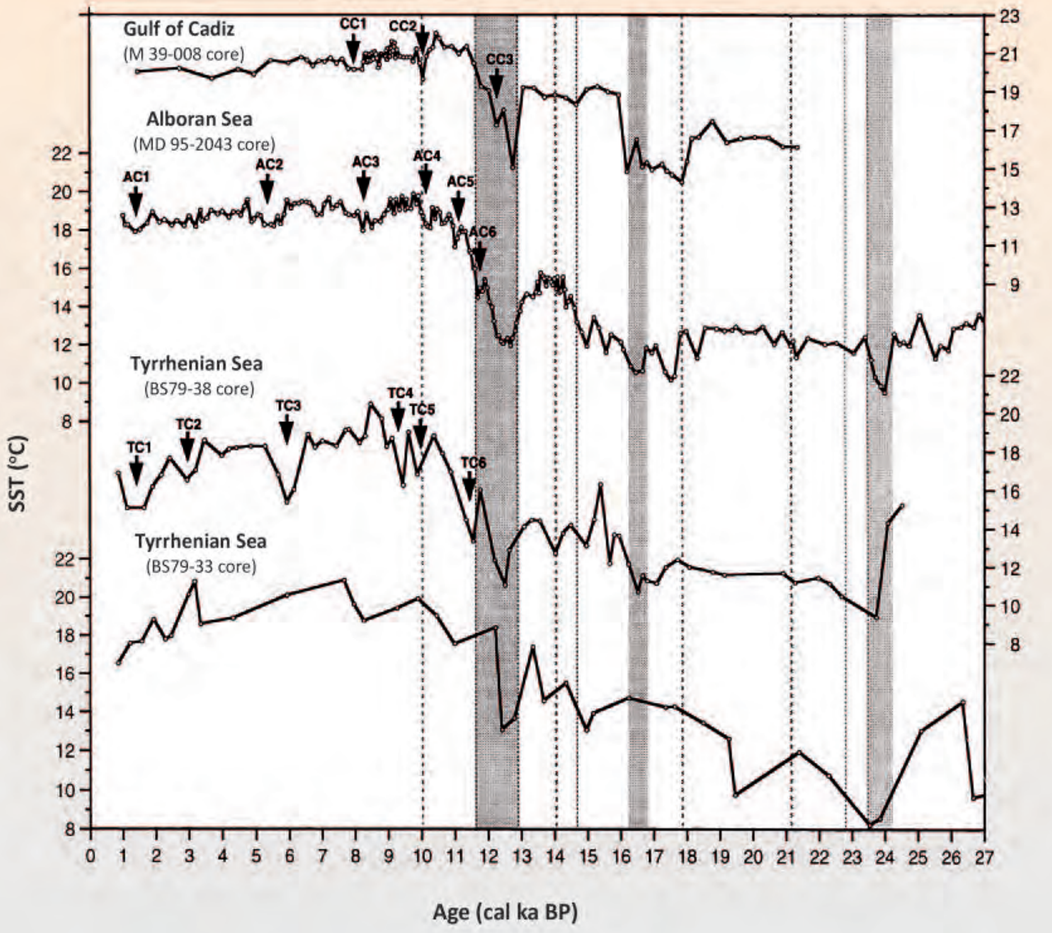
Table 1.3 **Total range of change in sea surface temperature (SST) in the Mediterranean during the Holocene (11.5 ka BP until before the industrial revolution)**

SST variation (°C)	Region	References
2-6	E Mediterranean	Emeis et al. (2000, 2003), Triantaphyllou et al. (2009)
8	N Aegean	Gogou et al. (2007)
4-12	SE Mediterranean, north of the Nile	Castaneda et al. (2010)
4	W Mediterranean	Cacho et al. (2001)
5	Tyrrhenian Sea	Sbaffi et al. (2001)

As shown by the recapitulation in Table 1.3, Holocene climate variations are reflected in SST variations of about 2-6ºC in the Eastern Mediterranean (Emeis et al., 2000; 2003; Triantaphyllou et al., 2009a, b), up to 8ºC in the Northern Aegean (Gogou et al., 2007), 4-12ºC in the SE Mediterranean (north of the Nile; Castañeda et al., 2010), 4ºC in the Western Mediterranean (Cacho et al., 2001; Figure 1.9) and about 5ºC in the Tyrrhenian Sea (Sbaffi et al., 2001).

There are indications that the periodicity of these changes was 2,300 years for the Aegean Sea (Rohling et al., 2002a, b) and ca 730 years for the Western Mediterranean (Cacho et al., 2001).

Figure 1.9 **Sea surface temperatures (SSTs) in the Western and Central Mediterranean**



Source: Cacho et al., 2001.

Estimates about the variation in temperature and rainfall during the Holocene have been made possible by analysing the calcite formations (speleothems) of karstic caves in the Eastern Mediterranean for stable oxygen and carbon isotope ratios ($\delta^{18}O$ and $\delta^{13}C$). The Soreq Cave in central Israel, situated at an altitude of 400 m and 40-50 m below ground, has been the focus of many paleoclimate investigations, such as the ones by Bar-Matthews et al. (2003) and Bar-Matthews and Ayalon (2005). The analysis of these stable isotope data revealed a similarity in temperature variation between sea surface water (Emeis et al., 2000; McGarry et al., 2004) and atmospheric air, while a reconstruction of precipitation for the past 10 ka showed that there was 50% more rainfall at the beginning of the Holocene than today. The 8.2 ka BP cold event corresponds, at low latitudes, to an arid period within a humid period (i.e. the African humid period of 15-5 ka BP, deMenocal et al., 2000a, b). Maximum rainfall values prevailed until 7 ka BP, while 6-5 ka BP marks the end of the tropical African humid period (Gasse, 2000; 2001), with evidence of a gradual decrease in precipitation in the Eastern Mediterranean at ca 6.2 to 5.8 ka BP (Bar-Matthews et al., 1997; 2003; Frisia et al., 2006) and increased aridity in the Aegean (Rohling et al., 2002a, b). A period of increased precipitation followed between 5 and 4 ka BP, reflected in a sapropel-like layer, possibly younger than S1, called SMH (sapropel mid Holocene) and found in the Southern Aegean (Triantaphyllou et al., 2009a, b).

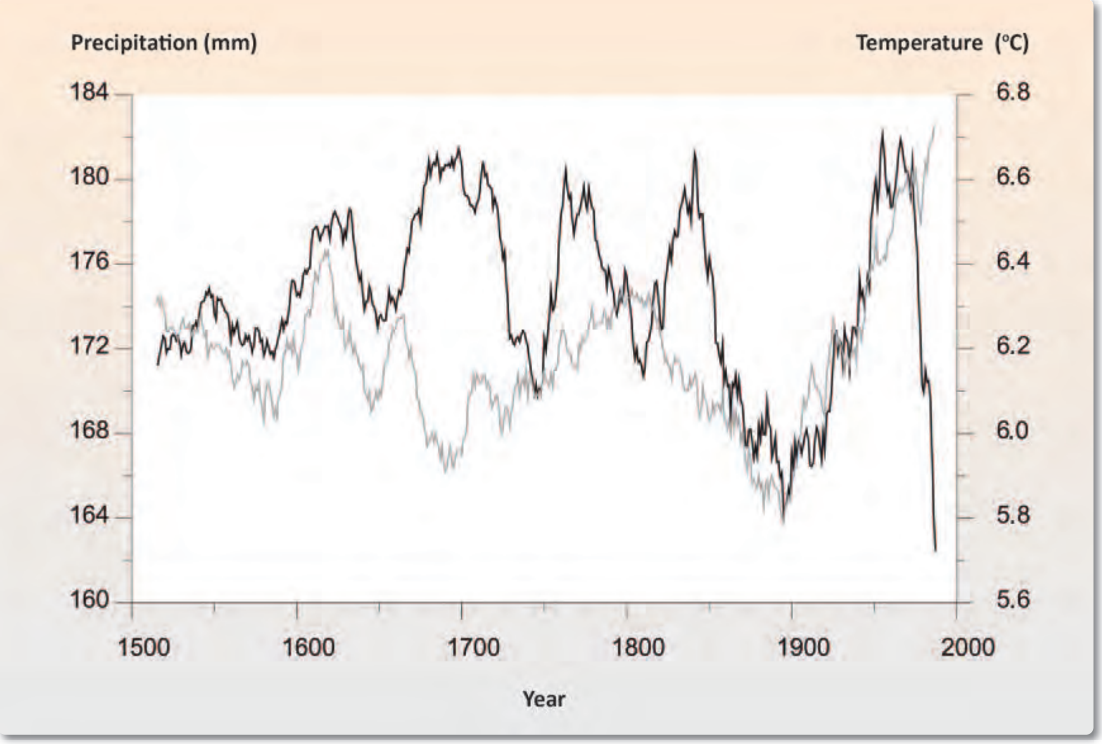
Subsequently, between 4.6 and 4.2 ka BP, precipitation levels in northern Italy (Drysdale et al., 2006), the Levant (Bar-Matthews et al., 1997; Enzel et al., 2003) and the northern Red Sea (Arz et al., 2006) decreased significantly from 600 to 400 mm and then remained below current levels for a long period of time. The late Holocene (from 4 ka BP to present) is characterised by a general cooling trend, coupled with progressive aridity (Cacho et al., 2001; Sbaffi et al., 2001; Marchal et al., 2002; Rohling et al., 2002a, b). The arid period is in line with the general aridity trend, suggested by theory, for North Africa and the Middle East, more likely driven by earth orbital variations (e.g. precession), (deMenocal et al., 2000a).

1.6 The last millennium

A series of distinct climatic episodes have occurred during the last millennium in the Mediterranean, including the Medieval Warm Period (also known as the Medieval Climate Anomaly, 900-1350 A.D.), the cold Little Ice Age (1500-1850 A.D.) and other cold events of shorter duration. The latter, which comprise the Late Maunder Minimum (LMM, ca 1675-1715 A.D.) and the Spörer Minimum (SM, ca 1460-1550 A.D.), appear to be associated with solar activity minima, although there remains considerable scepticism among the scientific community about long-term solar irradiance changes (Jansen et al., 2007, etc.). Atmospheric circulation during the LMM, for instance, was also affected by volcanic activity, internal climate variability and changes in the North Atlantic Ocean circulation (Luterbacher et al., 2001; Luterbacher and Xoplaki, 2003).

Turning to Greece, documentary data (historical documents, manuscript monastic sources) provide evidence of severe winter extremes during the period 1200-1900 (Repapis et al., 1989). Repapis et al. conclude that the coldest periods occurred in the first half of the 15th century (concurring with the cold period reported by Mayewski et al., 2004), the second half of the 17th century and the mid-19th century. Indices of temperature, precipitation, drought and flooding for Greece and Cyprus during the period 1675-1830 have been reconstructed on a monthly discontinuous basis (Xoplaki et al., 2001). The wettest weather during the Little Ice Age was recorded during the periods 1650-1710 and 1750-1820 (Figure 1.10), while the SST, based on the $\delta^{18}O$ analysis of vermetid reefs (formed by thermophilic gastropods) in NW Sicily (Silenzi

Figure 1.10 **Reconstruction of low-frequency temperature and precipitation variations in winter**



Mean values (for every 31 years) of winter temperatures (grey line) and precipitation (black line) in the Mediterranean during the 1500-2002 period (Luterbacher et al., 2006).

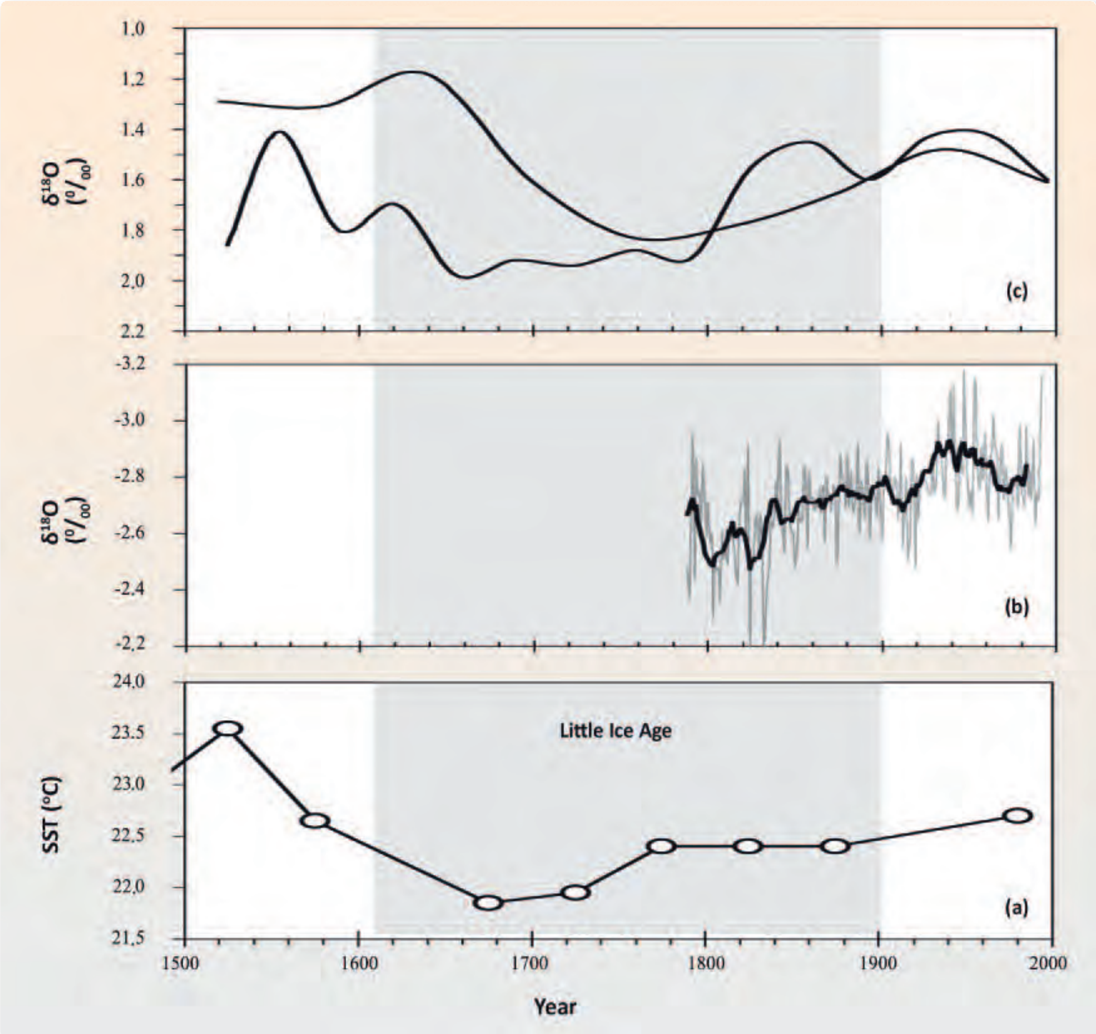
et al., 2004), is estimated to have been 1.99±0.37ºC lower during the Little Ice Age than today. As can be seen from Figure 1.11, the SST based on the reconstruction by Silenzi et al. (2004) was higher in the early 1500s A.D. than today, an observation also corroborated by the SST records from the Bermuda Rise in the Sargasso Sea (Keigwin, 1996).

Evidence dating back to the Middle Ages and the beginning of the Little Ice Age in the Eastern Mediterranean has been collected by the University of Thessaloniki, the Patriarchal Institute for Patristic Studies and Utrecht University.

It should be noted that the period between 1500 and 1900 saw intense volcanic activity throughout the Mediterranean, but also across Europe.

Regarding the last few centuries, there is a considerable shortage of high-resolution (annual, seasonal) SST data for the Mediterranean, due to a lack of appropriate indices (such as the coral reef indices available for tropical-subtropical seas). One exception, though, is the annually-banded coral reefs of the Red Sea (Felis and Rimbu, 2010). New paleoenvironmental indicators are being sought in vermetid reefs (for the last 500-600 years; 30-50 year resolution; Silenzi et al., 2004; Montagna et al., 2008; 2009; Sisma-Ventura et al., 2009), non-tropical corals (for the last 100-150 years; seasonal to weekly resolution; Montagna et al., 2009) and deep-water corals (similar to non-

Figure 1.11 Comparison of paleotemperature indices



(a) Vermetid $\delta^{18}O$ records from Sicily (Silenzi et al., 2004), (b) $\delta^{18}O$ records from the Red Sea, and (c) sea surface temperature (SST) in the Bermuda area, Sargasso Sea (Keigwin, 1996).

tropical corals; Montagna et al., 2006; McCulloch et al., 2010). These new records could complement the paleoclimatic database derived from such key climate indicators as foraminifera, alkenones, dinoflagellates, nannofossils, as well as serpulid overgrowth in submerged speleothems (Antonioli et al., 2001). The above-mentioned marine indicators provide low-resolution information (i.e.100-200 years between samples), with the exception of areas with a high sediment accumulation rate (>80 cm/ka), such as the Southern Levantine basin, where the time resolution over the last millennium reaches 40-50 years between samples (Schilman et al., 2001). The stable isotope composition of foraminifera in this high-resolution sedimentary record clearly delimits the Medieval Warm Period from the Little Ice Age. Kuniholm and Striker (1987) conducted a large number of dendrochronological investigations, mostly in Greece and Turkey, in

Table 1.4 **Published papers on the paleoreconstruction of sea surface temperatures (SST) (Based mostly on the alkenone Uk/'37 index and for the Eastern Mediterranean in particular during the Quaternary)**

Core/location	Reference	Location	Paleotemperature index	Age range ka BP
NS-14	Triantaphyllou et al. (2009)	Nissyros (SE Aegean)	alkenones	(3) 4.5-12.7 ka
MNB-3	Gogou et al. (2007)	Skyros (N Aegean)	alkenones	(1.5) 6-10.5(14.5) ka
ODP967D ODP964 KC01/01B	Emeis et al. (1998)	Levantine, Ionian basins	alkenones	7.69 ka-3 ma
KS8230,967,RL11	Emeis et al. (2000)	Alboran, Ionian, Levantine basins	alkenones, planktonic oxygen isotopes	16 ka
M40/87, RL11, 964, M40/71, 969, M40/67, 967	Emeis et al. (2003)	Alboran, Ionian, S Aegean, Levantine basins	alkenones	340 ka
BS7933, BS7938,MD952043, M39008	Cacho et al. (2001)	Tyrrhenean, Alboran Sea, Gulf of Cadiz	alkenones	25 ka
9509, 9501	Almogi-Labin et al. (2009)	N and S Levantine Basins	alkenones	0.240-86 ka
	McGarry et al. (2004)	Peqiin cave, Israel	speleothemes	0-140 ka
GeoB 7702-3	Castaneda et al. (2010)	E Mediterranean, north of the Nile	alkenones and TEX86	27 ka
BS79 38/33/22, MD 95-2043, GISP2, GRIP	Sbaffi et al. (2001)	North of Sicily, Alboran Sea, Greenland	Forams, pteropods, d^{18}O, alkenones	0-34 ka

order to date archaeological sites. The various investigations of tree-ring data from Turkey showed that drought periods typically lasted 1-2 years and rarely more than three. By combining the results of different studies, it appears that 1693, 1735, 1819, 1868, 1878, 1887 and 1893 were the driest years in the Eastern Mediterranean basin (Akkemik and Aras, 2005; Büntgen et al., 2008; 2010; Till and Guiot, 1990; Serre-Bachet et al., 1992; Glueck and Stockton, 2001; Esper et al., 2007; Touchan et al., 2008; 2010; Touchan et al., 2003; 2005; 2007).

The data and characteristics of leading published studies of paleo-sea surface temperature reconstruction in the (Eastern) Mediterranean over the past 340 thousand years, based mostly on the alkenone Uk'37 index, are recapitulated in Table 1.4.

1.7 A comparison of current climate change to earlier changes in the Earth's history

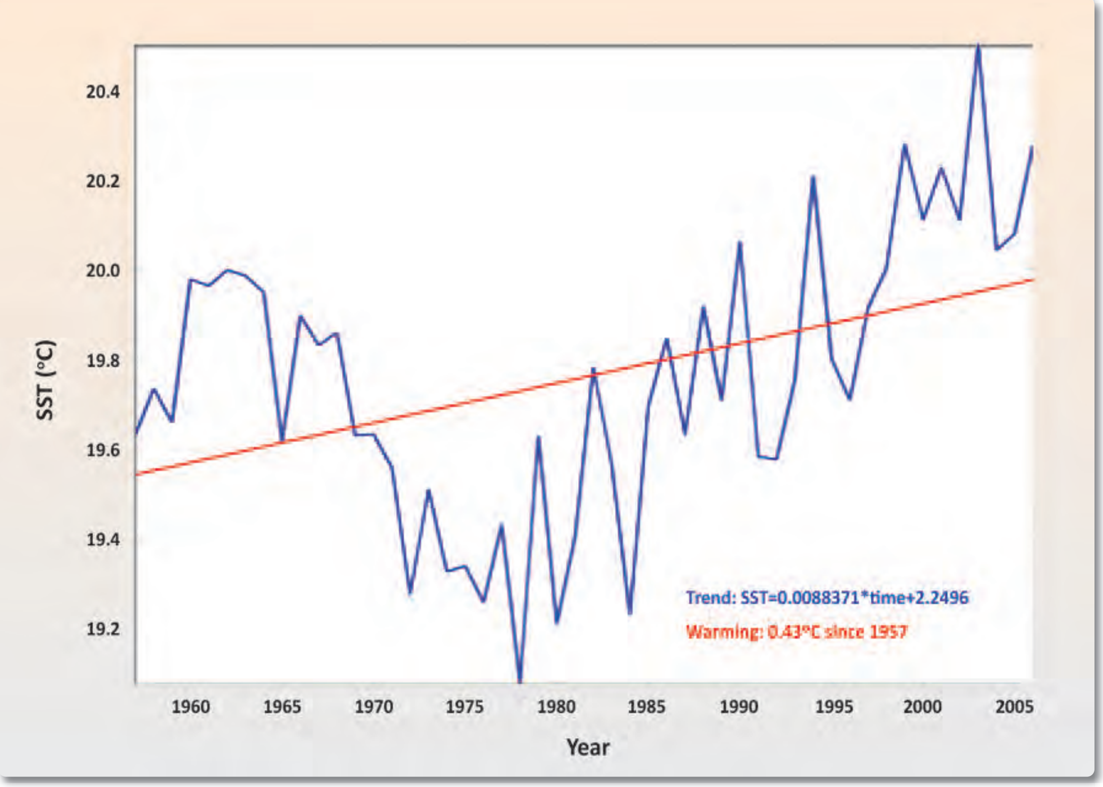
Comparisons of the relative and absolute changes in SST in the Mediterranean over the last 21 thousand years with current temperature changes (assuming that the current mean SST of the

Mediterranean is 19.4ºC, within a range of 18.4-20.5ºC) reveal that, based on the alkenone Uk′37 index for paleotemperature estimation (considered to reflect spring SSTs), lower but also higher temperatures have been recorded in the recent geological past. More specifically, an SST of 25ºC has been estimated for the SE Aegean at 4.9 ka BP (Triantaphyllou et al., 2009a, b), when comparable current spring values for the Southern Aegean are <9ºC (Skliris et al., 2010). Similarly, an SST of 24ºC has been estimated for the Ionian Basin at 6 ka BP (Emeis et al., 2000), when current mean SSTs for the Ionian Sea are <18ºC (Malanotte-Rizzoli et al., 1997). The Northern Aegean is estimated to have had an SST of 22.9ºC at 13 ka BP (Gogou et al., 2007), while current spring values are <8ºC (Skliris et al., 2010), and the Ionian Basin is estimated to have had an SST of 22ºC at ca 1000 A.D. (Emeis et al., 2000), while estimates based on oxygen isotope data from Vermetid reefs show that the SSTs in the Tyrrhenian Sea were higher in the early 1500s A.D. than today (Silenzi et al., 2004).

The mean rate of SST change in the Mediterranean from the early-19th century to 2008 was +0.04ºC/decade, but much lower, in the order of +0.01ºC/decade, in the Aegean (Axaopoulos and Sofianos, 2009). However, since the mid-1980s, the SST of the Aegean has shown a much stronger rate of increase, in the order of 0.024ºC/decade (Axaopoulos and Sofianos, 2009). As discussed in Sub-chapter 1.5, the following rates of SST change (using alkenone-based reconstruction) have been estimated for the Mediterranean during the Holocene (11.5 ka BP): a decrease of 1.6ºC in approximately 90 years (at 9.8 ka BP), followed by an increase of 3ºC in 92 years (at 9.7 ka BP) (Triantaphyllou et al., 2009a, b) in the SE Aegean; a decrease of 2ºC in 50 years in the Southern Aegean at 8.2 ka BP (Rohling et al., 2002a, b); an increase of 2.4ºC (from 21ºC to 23.4ºC) in 72 years at 5 ka BP in the SE Aegean (Triantaphyllou et al., 2009); and an increase from 16ºC to 22ºC at 2.8 ka BP in the Ionian Sea (Emeis et al., 2000, see Figure 1.5).

As also noted in Sub-chapter 1.5, the annual deviations of mean SSTs in the Northern Hemisphere available for the period 1860-2000 relative to the reference period 1961-1990 (Figure 1.8) recorded a total change of an order of 0.9ºC in the course of a 90 year-interval (namely 1910-2000 A.D.), which is less than other changes observed during the last 21 thousand years. However, a more recent record (1957-2006) of mean SSTs for the Mediterranean shows a stronger change in temperature, i.e. of 1.2ºC in 28 years (Figure 1.12), which is consistent with the rate of increase of 0.067ºC/year derived from satellite measurements for the period 1990-2006 (Del Rio Vera et al., 2006). Unfortunately, the inevitably low time resolution (over the last 21 ka) and poor spatial distribution of available paleoclimatic data do not allow for a more valid comparison of current and past SST variability in the Mediterranean. Based on high-resolution ocean circulation models, it is estimated that that SSTs could increase by 3ºC by 2100 (Somot et al., 2006), i.e. at a rate not unheard of in the recent geological past, for instance at 9.7 ka BP in the SE Aegean.

Figure 1.12 Mean annual sea surface temperature (SST) in the Mediterranean during the 1957-2006 period
(Based on Hadley climatology, Belkin, 2009)



A comparison of the global warming signal of 0.7ºC over the past century (IPCC, 2007) with respective rates of warming during the last 21 thousand years indicates that similar or even greater changes occurred in the recent geological past. However, these earlier cases of warming coincided with glacial-interglacial transitions, during which higher rates of warming are to be expected. The rate of warming during the Mid-Holocene (6-4 ka BP) dropped to 0.4ºC/100 years, i.e. a rate that reflects a period of more stable background climate state, as the climatic transition had essentially been completed. The current rate of warming (0.7ºC/100 years) therefore exceeds that of the Mid-Holocene, despite the fact that the estimated paleotemperatures are, in absolute terms, 1-3ºC higher than today's temperatures.

The difference between current climate change and earlier episodes of climate warming is that the rate of increase is now higher, when our position in the climate cycle is taken into account. It should be noted that the projections of a temperature increase of 1.8-4.0ºC over the next 80-90 years (Meehl and Stocker, 2007, IPCC), exceed the average warming rates recorded in paleoclimatic data. The highest estimated rate of warming during the initial stages of the current interglacial reached the extremes of 5-10ºC/100 years; however, this estimate comes from

Arctic ice core measurements during the transition period from 18 ka BP to 11.5 ka BP, and therefore has limited spatial significance. The paleoclimatic record for the last 500 years in the Mediterranean consists of an instrumental record that goes back 150 years and compilations of proxy data for the period prior to 1860. The inconsistency and lack of homogeneity of this record does not allow safe conclusions, as to the change in frequency of extreme weather events during the past 100 years relative to the previous 400 years.

An overview of the paleoclimate of the last 21 ka in the Mediterranean shows that although all regions usually experienced a similar climate change trend (i.e. warming or cooling), they did not experience the same range or rate of temperature change (Tables 1.2 and 1.3). This is also evidenced by the modern instrumental SST record, which shows that during the recent warming period 1975-1990, the temperature increase was 0.8ºC in the Western Mediterranean, 0.6ºC in the Ionian Sea and almost nil in the Levantine Sea (Belkin, 2009). This suggests that the anticipated increase in SST based on the respective scenario will vary in intensity and duration across the different sub-basins of the Mediterranean, due to their distinct hydrological, climatic and oceanographic features. For instance, Eastern Mediterranean basin SSTs display stronger seasonal variability, most likely due to the deep water mass temperatures that are consistently lower than those of the other Mediterranean sub-basins (Berman et al., 2003). Moreover, the Eastern Mediterranean is strongly influenced by the Indian Monsoons, whereas the Western Mediterranean is more affected by the North Atlantic climatic variability.

In conclusion, today's rate of warming is indeed high, given the current climate background (phase of the climate cycle), but it remains within the range observed at other times during the past 21 thousand years. The contribution of CO_2 to current global warming seems to be significant, as this increased rate of warming cannot be explained or directly associated with specific geological events, such as changes in the Earth's orbital parameters, breakdown of methane hydrates, ocean circulation changes, volcanic activity, continental drift and changes in solar activity, each one of which has, in the geological past, been a cause of global warming and climate change.

1.8 Greece's present-day climate

1.8.1 Climate type and sub-types

The regions around the Mediterranean basin have a particular type of climate, known as 'Mediterranean', characterised for the most part by mild to cool wet winters and warm to hot dry summers.

Situated at the southern end of the Balkan Peninsula (Aemos Peninsula), Greece has a complex topography which, together with the prevailing weather systems, accounts for a strong spatial variability of climate conditions. As a result, the climate can vary from Mediterranean to alpine within just a few dozen kilometres. Another predominant feature is Greece's extensive coastline, which along with the topography influences a number of local climate characteristics, sometimes causing significant differences from what is considered a typical Mediterranean climate. Three facts worth mentioning at this stage are the average altitude of the Greek mainland (close to 600 m), the gradient in elevation (typically between 100 m and 200 m per km), and —as mentioned— the impressively lengthy total coastline (16,300 km, i.e. more than a third of the Earth's equatorial circumference). Broadly speaking, Greece's climate can, according to Mariolopoulos (1938, 1982), be broken down into four main sub-types:

i) a maritime Mediterranean climate, with pleasant temperate characteristics, encountered along Greece's western coast and on the Ionian Islands;

ii) a lowland Mediterranean climate, found in SE Greece, part of Eastern-Central Greece, parts of the Eastern Peloponnese, the islands and coastal areas of the Central Aegean and Crete, with drier summers and colder winters than at respective latitudes around the Ionian Sea;

iii) a continental Mediterranean climate, over the larger part of Thrace, Macedonia and Epirus and part of Thessaly, with some of the continental climate characteristics typical of Balkan regions further north; and

iv) a highland Mediterranean climate, encountered in the mountain ranges running through Greece. These mountain ranges include woodlands with a forest climate, as well as small high-altitude areas with an alpine climate during winter.

The islands of the Northern Aegean have a transitional type of climate (continental-to-lowland), whereas the climate of the Dodecanese islands has temperate maritime characteristics.

1.8.2 Seasonal climate characteristics

The weather patterns over the Southern Balkans and the Eastern Mediterranean are affected by high pressure systems (anticyclones) and low pressure systems (depressions) that determine air mass movement. These centres of atmospheric activity, whether permanent or temporary/seasonal, are influenced by local factors and therefore take on characteristics specific to the region they move over and whose climate they in turn also affect.

The atmospheric circulation systems and centres of atmospheric activity that directly affect the winter weather patterns in the region are the Azores High, the Siberian High, and primary and secondary low pressure systems in the Mediterranean. The southward movement of the Azores High enables storm systems from the Atlantic to penetrate over the Mediterranean, while other low pressure systems also form over the Mediterranean as a result of the interaction between a low pressure trough in the upper atmosphere and the topography. The low pressure systems are mostly driven by the polar jet stream, in the upper troposphere, in trajectories roughly corresponding to the polar front. As the polar front moves south-east in winter, the tracks of the low pressure systems also move south-east, causing the Eastern Mediterranean to become a centre of low pressure activity. This activity results in subtropical air masses moving over Greece and accounts for the mild temperatures and the seasonal rainfall.

The effects that these low pressure systems moving over Greece have on the weather and the climate depend on both the track of these systems and the topography. Because of the presence of mountain ranges in Western Greece, the low pressure systems coming in from the west produce large amounts of rainfall on the windward side of the ranges and lose strength by the time they reach the Aegean; there, they gather strength again and moisture as they rotate over the warm sea, causing new rainfall in Greece's eastern islands and on the Asia Minor coast. The impact of the Siberian High results in very low temperatures and severe winter cold, due to the advection of continental polar air masses into the region. The southward movement of the high pressure systems that form over the North Atlantic and northern Europe and the fact that they can remain stationary for extended periods of time cause very cold, albeit sometimes sunny days.

Spring in Greece is usually short, as winter generally lasts through March, with short frequent cold spells. The onset of summerlike weather is fairly rapid, rainfall declines as the atmospheric stability increases, especially toward end-March. From April onward, the average air temperature increases markedly throughout the country, paving the way to a generally warmer May, the prelude to summer.

Summer sets in during the month of June, with stable, fair and dry weather, abundant sunshine throughout the season and only brief rainy interludes in the form of thermal storms. Low pressure systems are, of course, not non-existent, but they are usually weak. More specifically, although the Balkan Peninsula and Anatolia are both regions where thermal low pressure systems form, the temperature of the sea at this time of the year is generally cooler than the surface temperature of the land it surrounds. As a result, the upward movement of the overheated air, which would normally be conducive to summer rainfall, is inhibited. The summer heat is rather intense throughout the country, with heat waves, known since ancient times, usually associated with atmospheric stability and calm.

In many areas of Greece, the heat, though severe, is tolerable due to the dryness of the air and the cooling effect of sea and land breezes. In Eastern Greece and in the Aegean in particular, the seasonal, but intermittent strong dry winds from the North (known formally as 'Etesians' and colloquially as 'meltemia') temper the heat considerably. In Western Greece, where the humidity is higher and the low-lying inland areas are too far for the sea breezes to cool and where the Etesians are rare, the heat can be unbearable. The temperature in Greece's mountainous areas, on the other hand, is quite tolerable. Summer nights are pleasant, especially in Eastern Greece, owing to the dryness of the atmosphere mentioned previously, the light land breeze and the more subdued Etesians at night. Summer weather, with its high temperatures, often lasts through September, particularly in the southern regions and on the islands.

Autumn is one of the more pleasant seasons in Greece, especially in the southern regions and on the islands where it can last well into December. The mean temperature is higher in autumn than in spring. The first rains of autumn come around mid-September/early October, when the eastward expansion of the Azores High ceases rather abruptly, and the southward shift of the high pressure zone brings the first incursion of cold air masses. The high pressure systems that form in eastern Europe often around mid-autumn are responsible for the Indian summers with calm fair weather encountered in SE Europe, including Greece.[2]

1.9 Greece's climatic parameters

1.9.1 Solar radiation

The amount of solar radiation that reaches any given spot on the Earth's surface depends on such factors as location latitude, season, local climate and local topography.

In theory, the geographical distribution of insolation follows the annual cycle of solar declination.[3] In the Northern Hemisphere, maximum incident solar radiation occurs at the time of the summer solstice (June 21st), and minimum incident solar radiation at the time of the winter solstice (December 21st).

However, atmospheric factors (such as absolute humidity, cloud cover, suspended particles) can account for considerable deviations from the theoretical values of incident solar radiation. In Athens, for instance, direct solar radiation, i.e. the solar radiation energy to reach the Earth's surface, measured on a surface perpendicular to the sun's beam, is stronger in spring than in summer. The reason for this is simple: despite the fact that the sun is at its maximum altitude in summer, the amounts of water vapour and (because of the etesian winds) dust in the atmosphere, i.e. two factors that absorb and scatter solar radiation, are greater in summer than in spring. The mean annual cycle of global solar radiation in a given region, i.e. the sum of the direct and diffuse radiation it receives, generally follows the annual variation in solar altitude, with maximum values in summer and minimum values in winter. Indicatively, the mean values of global solar radiation for Athens are 200-250 W/m^2 in winter and 800-850 W/m^2 in summer, while diffuse radiation averages between 90-100 W/m^2 in winter and 190-200 W/m^2 in summer.

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[2] The Indian summer phenomenon is sometimes still referred to in Greece as the 'little summer of St Demetrius' (e.g. Mariolopoulos, 1982; Kotini-Zambaka, 1983). Note: the feast of St Demetrius is celebrated in October.

[3] Interestingly, the Greek word for climate ('κλίμα'), derived from the verb 'κλίνειν' (to slope, to incline), denotes the relationship between the angle of the sun's rays and air temperature.

1.9.2 Cloud cover and sunshine

Average annual cloud cover in Greece is greater in the inland regions, where the air masses are forced upward by the orography, causing water vapour convergence and condensation to take place. On average, maximum cloud cover (i.e. the fraction of the sky covered by clouds) is slightly above 50% inland and progressively declines the closer one moves to the coast, where maximum cloud cover falls below 40%. During the course of the year, cloud cover evolves roughly in parallel with rainfall, with maximum values in winter and minimum values in summer. In SE Greece, cloud cover is close to zero.

The number of mostly clear days (cloud cover under 20%) is rather high in all seasons, while the number of overcast days (cloud cover over 80%) is small.

The highest average annual sunshine durations in the country (around 3,000 hours) are recorded in the Southern Aegean, the southern coast of Crete and the Southern Dodecanese, while durations of over 2,800 hours are recorded in the Southern Ionian, the southern coast of the Peloponnese, the Argolis region (Eastern Peloponnese), the Saronic Gulf and the Central Aegean. The number of annual sunshine hours progressively decreases as the distance from the coast increases, with annual sunshine falling to its lowest levels (under 2,300 hours) in the country’s north-western mountainous regions. As can be expected, during the course of the year, sunshine duration varies inversely with cloud cover, with maximum sunshine of about 300-400 hours/month recorded in July and minimum sunshine of about 90-100 hours/month in winter.

1.9.3 Air temperature

Air temperature in Greece varies not only with latitude, but also with the topography. Winters are milder in regions where the mountain configuration blocks the inflow of cold winds from the North, and much colder in areas where the geomorphology allows these cold air masses to penetrate. The tempering influence of the sea also accounts for the milder climate (milder winters and cooler summers) of the coastal regions and islands, compared with nearby regions situated inland. The annual isotherms (i.e. the contour lines that connect points of equal mean annual air temperature on a geographic map) run almost parallel to latitude, with the 19ºC isotherm following the western coast of the Peloponnese, the 20ºC isotherm the SE coast of Crete, and the 15ºC isotherm the lowlands of Macedonia and Thrace. The mean annual temperature is about 10ºC in the mountains of the Peloponnese and about 5ºC in the mountains of Northern and Central Greece. The coastal areas of the Ionian and the islands of the Eastern Aegean enjoy a milder climate than regions in Eastern Greece at similar latitudes, with differences of about 0.5-1.0ºC in mean annual temperature, while winters on the western coast are almost 3ºC warmer. The winter isotherms again run almost parallel to latitude and temperature differences in various regions are more pronounced than in summer, when the air temperature is regulated by land-sea distribution.

In high summer, i.e. July and August, the daily maximum air temperature ranges between 32ºC and 36ºC, but can climb above 40ºC, as daily absolute maximum temperatures of over 45ºC have been recorded in certain areas of Central and Southern Greece. The climate of the Aegean is tempered by the etesian winds and summer sea breezes. In most parts of Greece, minimum air temperatures are recorded between end-January and February, indicating the prevalence of a continental climate and occurring earlier in the inland regions than on the coasts. Daily absolute minimum temperatures of -20ºC are not unheard of in certain areas in Northern Macedonia and Northern Thrace, as well as at high altitudes in Central Greece. From March onwards, the air temperature gradually increases, peaking between end-July and August, later along the coast than inland. The temperature slowly begins to drop countrywide by end-September, earlier in the north than in the south.

The mean annual temperature range (the difference between the monthly mean temperature of July or August and the monthly mean temperature of January or February) is more than 20ºC in Northern Greece, characteristic of a continental climate, but much smaller in the southern regions. In the southern islands, in fact, it is typically below 15ºC. The diurnal air temperature variation in most parts of the country reaches a high in the afternoon, at around 2 pm (a little later in summer, at around 3 pm), and a low at around 7 am in winter (5 am in summer). The mean daily temperature range (the difference between the mean maximum and the mean minimum daily temperature) ranges from 8ºC in summer to 4ºC in winter.

Northern Greece sees days with total frost, i.e. days when the temperatures never climbs above 0ºC, a phenomenon quite rare for Southern Greece, especially the coastal regions and Aegean islands. In fact, not a single day with total frost has ever been recorded in the low-lying areas of Crete since instrumental observations began. Days of partial frost, when the air temperature dips below 0ºC at some point during the day, are common in winter and early spring. The air temperature drops by 0.6-0.8ºC for every gain of 100 m in altitude. Ground surface temperature, like air temperature, varies on an annual and daily basis, but on a much larger scale, as the ground heats up more than the air in summer and also cools more in winter. Ground temperature variation evens out at greater depths, and at depths exceeding 1 m daily fluctuations are inexistent.

1.9.4 Air humidity

The annual course of absolute air humidity, i.e. the quotient of the mass of water vapour in a given volume of air, expressed by partial water vapour pressure, follows the annual temperature cycle, with maxima in summer and minima in winter. In maritime Mediterranean climates, the absolute humidity maxima and minima, just like the sea-surface temperature, lag slightly behind the corresponding air temperature maxima and minima. The mean annual absolute humidity shows maximum values of 11-12 mm Hg along the coast of Western Greece, and decreases as one moves inland with minimum values of 8-9 mm Hg; the values then increase again towards the coast of Eastern Greece and on the Aegean islands, but remain lower than in Western Greece. The daily course of absolute air humidity presents a double fluctuation year-round, just as in the case of continental climates.

Relative humidity is expressed in percentage terms as a ratio of water vapour mass in the air to water vapour in the air at saturation (the maximum vapour mass that would be present in the air at a given temperature) or as a percentage ratio of partial water vapour pressure (absolute humidity) to maximum water vapour pressure (at saturation point). The concept of relative humidity is of particular bioclimatic interest, as low relative humidity makes summer heat waves and winter cold more tolerable. Mean annual relative humidity ranges around 60% in Attica-Boeotia and Argolis and around 75% along the coast of Western Greece and the islands. The climate is, generally speaking, more humid in Western Greece than in the SE regions. Relative humidity evolves conversely to air temperature on both an annual and a daily basis, as relative humidity is, by definition, inversely proportional to maximum water vapour pressure, which depends on air temperature. Mean relative humidity shows a simple annual variability pattern throughout Greece, with a maximum in December and a minimum in July-August. The annual range in atmospheric water vapour content is greater in continental Greece and Crete than that of temperate climates, approaching the typical range for continental climates; the annual range for Western Greece is somewhere between that of continental and marine climates, while the range for the coastal regions of the Peloponnese and Crete and the islands is close to that of maritime climates. Similarly, mean atmospheric relative humidity presents a simple daily variation, conversely to temperature variation, with a maximum near sunrise, between 4 am (in summer) and 7 am (in winter), and a minimum —almost always— at 2 pm.

1.9.5 Precipitation

Rainfall and air temperature are major determinants of regional climate. As already mentioned, the topography of Greece plays an important part in the shaping of its climate, especially with regard to the amount of rainfall. Greece’s geographic position, the fact that the country is on most sides surrounded by sea, together with the presence of high mountains and mountain ranges spanning in different directions make for considerable regional differences in rainfall distribution and levels. The rainfall pattern typical of Mediterranean coastal areas is, of course, predominant, with dry spells in summer and a rainy season from mid-autumn to mid-spring. Rainfall distribution throughout the year tends to be more even in Northern Greece. Mean annual precipitation for Greece as a whole is roughly estimated at 800 mm, but the geographical distribution of the annual amount of precipitation and of the yearly rainy season generally follows Greece’s geomorphology. As in the Iberian and the Italian peninsulas, annual precipitation in Greece generally declines from west to east and from north to south. The warm, moist, rain-producing air masses of depressions moving in from the west, and the warm moist air masses coming in from the south butt up against almost perpendicular mountain ranges (the bulk of Greece's mountain ranges run north-south). These air masses, thus uplifted, subsequently cool and release most of their moisture on the windward side. Once over the mountain ridges, the air masses descend and heat by compression, producing some rainfall on the leeward side (rain shadow).

The mean annual precipitation received by Greece's mountain ranges is as follows: >2,200 mm in the Pindos range (continental Greece); 1,800 mm in Crete's White Mountains (Lefka Ori); and 1,600 mm in the mountains of the Peloponnese. The lowest amounts of annual precipitation, i.e. <400 mm, are recorded in the Saronic Gulf, Argolis (Eastern Peloponnese) and the islands of the Southern Aegean. Mean annual precipitation reaches 1,000-1,400 mm in the Ionian Islands, 1,000-1,200 mm on the western coast of Epirus, and increases progressively with the gain in altitude up to 2,000 m, but then decreases sharply on the leeward eastern slopes of the mountains and on the Greek peninsula's eastern side. Annual precipitation increases again somewhat, further east, in Euboia and the Northern Sporades Islands, and in the mountains of Macedonia and Thessaly, but once again decreases over the Aegean coast. Finally, annual precipitation increases over the islands and coast of Asia Minor. In Greece's NE regions, Eastern Macedonia and Thrace, annual precipitation increases as the distance from the coast increases, reaching its highest level in the region's northern mountains. Similarly, in Crete, annual precipitation declines from west to east, with levels of almost 800 mm recorded in the NW and of below 500 mm in the SE.

The temporal distribution of annual precipitation is fairly even in the cold months of the year, although precipitation levels increase from autumn to winter and decrease towards spring. In summer, the scarce rainfall events to interrupt the protracted dry spell are usually brief local thermal thunderstorms, which, without major differences between west and east, can produce substantial amounts of rain within just a few hours. In most parts of Greece, the summer drought begins in May, as the depressions over the Eastern Mediterranean become less frequent. The duration of the drought increases from north to south, from 2 months (July-August) in Northern Epirus, Macedonia and Thrace to as many as 4-5 months in the country's SE regions. The annual pattern of precipitation can present particularities in terms of maxima and minima depending on proximity to the sea, altitude, latitude, etc., without ever deviating too much from the typical characteristics of a Mediterranean climate, i.e. a cool wet winter and an arid summer. July and August are the driest months. The first autumn rains usually come in September, first at the higher altitudes, and later (October) in the lowland regions and the Aegean islands. The highest monthly rainfall is, on average, recorded in November and especially December. Annual precipitation levels can vary considerably from year to year, while consecutive years of dry or wet weather are also recorded. Annual precipitation in Athens has, for instance, ranged from minimums of 115.7 mm (1898), 150.6 mm (1989), 199.3 mm (1990) and 206.2 mm (1891) to maximums of 987.3 mm (2002), 846.4 mm (1883), 713.0 mm (1885), 612.0 mm (1955) and 601.9 mm (1910). It should be noted that, based on the observations of the National Observatory of Athens, the mean annual precipitation of Athens during the period 1891-2010 was close to 400 mm.

The spatial distribution of the annual number of rainy days is similar to the spatial distribution of precipitation amounts. More specifically, the annual number of rainy days exceeds 110 days in the western coastal regions, increases farther inland, peaks in the central mountain ranges, and then decreases towards the Aegean coast, before increasing again in the coastal regions of Asia Minor. The smallest annual number of rainy days (below 80) is observed in the same region as the smallest amount of annual rainfall, i.e. in certain Cyclades islands and in the region of Argolis and the Saronic Gulf.

The amount of 24-hour precipitation and rainfall intensity, i.e. the amount of rain divided by its duration, are important data to be taken into consideration, especially at the designing and construction phases of public works. 24-hour precipitation levels in excess of 150 mm are not unheard of, even in regions with low annual precipitation: Athens has had 24-hour precipitation as high as 150.8 mm (16 November 1899) and 160 mm (2 November 1977), when the mean daily precipitation in November for Athens is 1.9 mm and total annual precipitation is roughly 400 mm. 24-hour precipitation and rainfall intensity have the same geographical and seasonal distribution as annual precipitation. Mean annual rainfall intensity declines from west to east and from north to south. Rainfall intensity in most parts of Greece is highest in October and November.

The meteorological conditions that favour thunderstorm development are similar to the ones that generate rainfall, except that there also has to be a high degree of atmospheric instability. Thunderstorms occurring in the Mediterranean are generally the result of an incursion of cold polar air masses (cold fronts), particularly in the autumn when the sea is relatively warm, and in areas where warm, moist, tropical air masses converge (warm fronts). The orography plays an important role, as the uplifted air masses subsequently cool and their water vapour content condenses. In Greece, autumn and winter storms are generally more common in the coastal regions, as the sea is warmer than the atmosphere. What are known as thermal thunderstorms take place in summer in the continental regions, as a result of the very high ground surface temperatures and the conditions that favour instability in the free atmosphere. Such instability is, on the contrary, negligible in the coastal regions, as the sea is cooler than the land.

1.9.6 Winds

As already mentioned, the Mediterranean winter is determined by high pressure systems over Eurasia and the North Atlantic. These systems steer respectively cold dry or warm moist air masses towards the Mediterranean, thereby creating centres of cyclogenesis or rejuvenation of low-pressure systems. This explains why winter winds are so variable in direction and intensity. The same conditions roughly prevail in autumn and spring. The predominant wind from autumn to spring is a south-southwesterly wind, known today as *livas*.[4] Caused by high pressure systems from the Atlantic and North Africa, this wind carries warm moist air masses and is associated with depressions in the Mediterranean. When forced by the topography over a mountain range, it becomes katabatic on the leeward side, warms up and moves further away from saturation, thus giving rise to warm dry winds with Foehn characteristics, particularly warm and dry in summer. The combination of a high pressure system over the Balkans and a low pressure system over the Aegean gives rise to the cold northerly wind, Vardar, in the Axios valley. As mentioned previously, winter is sometimes marked by an incursion of very cold air masses from the North.

Whereas the wind systems prevailing in winter are complex and variable, the winds prevailing in summer, known as “Etesians” (“meltemia”) , are predominantly northerly (northwesterly in the Ionian and Greece’s western coast, north-easterly in the Northern Aegean, becoming northerly in the Central and Southern Aegean). The intensity of the Etesians in the boundary layer of the atmosphere (from surface to 800-1,000 m) usually peaks at midday, when the mixing of upper and lower atmospheric layers reaches a maximum; these winds then subside, sometimes almost entirely, at night. Because of the lesser friction, the winds are generally stronger over sea expanses. Typically of moderate intensity (4-5B, 8-9 m/sec), the Etesians can easily gain strength over open seas (6-7B, 10-15 m/sec or more) and occasionally reach gale force (over 9B, >20 m/sec). The Etesians reach their highest intensity and frequency in July-August, particularly in certain channels of the Aegean, such as the one between the islands of Naxos and Paros (Repapis et al., 1977). On summer days without Etesians, the air in the inland areas is quite still, with light mountain and valley breezes, while the coastal areas and the islands enjoy sea breezes at daytime, alternating with land breezes at night. The velocity of sea breezes is of the order of 5-6 m/sec, while the velocity of land breezes is much lower.

1.9.7 Evaporation, dew, frost, fog, snow and hail

Evaporation, i.e. the amount of surface water that evaporates into the air, depends on a combination of factors: firstly, the water temperature, but also on air temperature and humidity, as well as the wind. Evaporation in Greece broadly follows the annual and daily air temperature range, with lower rates recorded in the west and north and higher rates in the south and east. Average annual evaporation amounts to roughly 1,650 mm in Athens and 1,350 mm in Thessaloniki.

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[4] Formerly the Λιψ of the ancient Greeks.

Dew, i.e. the condensation of water vapour on exposed surfaces in the form of liquid droplets, is recorded almost year-round in most parts of Greece, with maximum occurrence in winter and minimum occurrence in summer.

Frost, i.e. the condensation of water vapour on exposed surfaces in the form of tiny ice crystals, is less frequent than dew and recorded only in the cold season, when ground surface temperature is below 0ºC.

Fog, i.e. the low-lying cloud caused by the cooling and condensation of moisture contained in the adjacent to the ground surface air layer of a moist and warmer than the ground air mass. Fog forms as a result of the advection of warm, humid air masses over a cold ground surface or as a result of ground surface cooling —through radiation— during cold, fair nights. More days with fog are observed in Northern Greece than in the southern regions.

Snowfall increases from south to north, from coast to inland and from low-lying to high-lying regions. The occasional incursion in winter of north-easterly cold air masses associated with the Siberian High is another cause of snowfall, mainly in Eastern Greece. The snow season can last from end-September to end-May in the mountainous regions of Northern Greece, but is far shorter —starting later and ending earlier— in the southern regions and along the coast. Snow accounts for 0 to 20% of Greece's total annual precipitation.

Hail, i.e. the precipitation in the form of spherical or irregular pellets of ice that falls during thunderstorms, is an important climate phenomenon, because of the potentially substantial damage to agriculture. The annual number of days with hail decreases from west to east, but then increases again close to the Asia Minor coast. During the cold season, hail is more common on the coast than it is further inland, mainly due to frontal storms. Conversely, hail occurrence in the warm season increases inland on account of thermal thunderstorms.

1.10 The climatic characteristics of Greece's marine regions

The warm Asia Minor current that enters the Aegean Sea from the East, after flowing northward along the Eastern Mediterranean coast, and the colder current that enters the Northern Aegean from the Black Sea through the narrow strait of the Dardanelles and then flows southward along the western coast of the Aegean explain why the sea surface temperatures (SSTs) of the Aegean are slightly colder along the western coast than along the eastern coast (Metaxas, 1973). SSTs are generally highest in August and lowest in February and, as is well established, lag behind the air temperatures over land, due to the seas' high heat capacity, while the mean annual SST is higher than the mean annual marine air temperature (MAT). From September through March the mean monthly SST is higher than the mean monthly MAT (in the Northern and Central Aegean by as much as ~3ºC in January-February), whereas from

April through August the mean monthly SST is lower than the mean monthly MAT (in the Central Aegean by ~2ºC in July). In the Northern Aegean, the SST reaches a maximum of ~24ºC in August and a minimum of 12.5ºC in February, when the respective MAT values are 24.5ºC and 9.5ºC. In the Central Aegean, the maximum (minimum) SST is 25.0ºC in August (14.5ºC in February), when the corresponding maximum (minimum) MAT is 26.0ºC in July (12.0ºC in January). In the Southern Aegean, the maximum (minimum) mean monthly SST is 25.0ºC in August (15.5ºC in February), when the corresponding maximum (minimum) MAT is 26.0ºC in August (14.0ºC in February). In the Ionian Sea, the maximum (minimum) SST is 25.5ºC (15.0ºC), whereas the maximum (minimum) MAT is 26.0ºC (13.5ºC). In the cold season, the SST of the Southern Aegean is somewhat higher than that of the Ionian, while the opposite is the case in summer. During the months of July and August, the prevailing Etesian winds cause cooler water at greater depths to rise to the sea surface (upwelling) in the Eastern Aegean. The highest mean annual SST in Greece is recorded in the region of Rhodes (~20ºC), while the lowest mean annual SST is recorded in the wider area of Alexandroupolis (~15.5ºC). The lowest mean monthly SST in Greece is recorded in the NE Aegean, just outside the Dardanelles (~11ºC in February), while the highest mean monthly SST is recorded in the Southern Ionian (~26ºC, in August).

Mean annual sea surface evaporation is estimated at ~2,000 mm on the eastern coast of the Aegean, at ~1,800 mm in the Southern Aegean, and at ~1,600 mm along the coasts of the Ionian and south of Crete. In both the Aegean and the Ionian seas, sea surface evaporation is generally more pronounced in the northern than in the southern parts, due to the prevalence of northern winds. All year round, the isoevaporation lines run almost parallel to the axis of the Aegean. The highest estimated daily values of ~7 mm/day are recorded on the eastern coast in January (where northern winds prevail and the sea-air temperature difference is greatest along the eastern coast of the Central Aegean), as well as in July-August, when strong Etesian winds prevail. The lowest estimated daily values of sea surface evaporation, under 3 mm/day, are recorded in May, due to the weak speed of winds (Metaxas and Repapis, 1977).

1.11 Urban climate and bioclimatic indexes

The settlement of human populations inevitably brings about changes to the environment. Human activity affects atmospheric conditions in three ways: i) by modifying land surface characteristics and land use (urbanisation, deforestation, draining e.g. of wetlands and swamps, etc.); ii) by releasing energy into the atmosphere (industries, heating, electric lighting, etc.); and iii) by loading the air with gaseous and particulate pollutants. Man’s impact on the atmosphere is most evident in big cities, as *urbanisation* results in a significant alteration of the urbanised environment's climate parameters. The quality of urban air, as opposed to that of rural air, is further degraded by the presence of various pollutants. Apart from the adverse effects that air pollutants and suspended particulates have on health, they also reduce visibility. This often results in the formation of a "microclimate", or "urban climate", the characteristics of which, especially as far as air quality is concerned, largely depend on the city's size, population, percentage of built-up areas and green spaces, building materials, paved surfaces, energy source use and industrial activity. The influence of all of these factors, conducive to what is known as "urbanisation-induced warming", is particularly evident in terms of the air temperature, as the energy emitted by urban human activity contributes to an increase in air temperature. The presence of buildings, pavements and roads also alters the radiation balance, as these elements absorb and re-emit heat differently than a rural environment would. The air is thus warmer on average in cities than in non-urbanised environments, with the size of the deviation basically increasing with urban population size. This phenomenon is known as the "urban heat island" effect.

Athens is a typical metropolitan area, with a high building density in the central districts and a lower building density in the suburbs (urban fringe). According to Eurostat data, the larger urban zone of Athens is among the eight most populated areas in the European Union, with a population of over 4,000,000 since 2004, i.e. nearly one third of the country's population (Note: the true figures for the population of Athens are in fact higher, given that illegal immigrants have not been taken into consideration). Despite decentralisation efforts made in the 1980s, most of the country's administrative, commercial, economic, social and cultural activities remain concentrated in Athens. Rapid population growth and the pursuit of a better quality of life have been the main drivers of urban sprawl, towards areas with more green space, associated with a higher quality of living index (Stathopoulou and Cartalis, 2006). During the period 1990-2000 alone, urbanised areas in Athens increased by 4.6% (Stathopoulou et al., 2009). This, of course, is not only a Greek phenomenon. According to a report by the European Environment Agency, during the ten year period 1990-2000 the growth of urban areas and associated infrastructure throughout Europe consumed more than 8,000 km^2, equivalent to complete coverage of the entire territory of Luxembourg or Crete. By 2020, approximately 80% of Europeans will be living in urban areas, while in some countries the proportion will be 90% or more. Greece's growth model has led to a distorted overcrowding of both people and activities in five major areas: the wider urban areas of Athens (with Piraeus), Thessaloniki, Patras and Herakleion and the zone between the two cities of Volos and Larissa. In the specific case of Athens, the transfer of the main airport to Spata (some 20 kms east of Athens) and the construction of high-speed motorways have in the past few years accelerated the relocation of Athenians to the city fringe, mostly to the north-east and south-east. As a result, former resort/secondary residence areas have evolved into primary residence areas and have undergone a considerable growth in urban activity. Today, the predominant trend sees immigrants moving into the run-down neighbourhoods of central Athens and Piraeus, while veteran city dwellers move out, in pursuit of a better living environment in the burgeoning suburbs to the north and east. It should also be noted that this urban sprawl has been accompanied by considerable illegal construction activity, across all classes of society. With the continuous expansion of the urban fabric, motorways and paving, the urban environment encroaches ever increasingly upon the natural environment. This only exacerbates the urban heat island effect, as well as the changes to the climatic conditions in the area.

As mentioned earlier, the urban heat island effect is primarily due to the different thermal properties of commonly used urban building materials, as opposed to those of the natural environment (Park, 1986). Asphalt and cement, for instance, have different thermal and reflective properties than the natural environment. These materials alter the energy balance, as they absorb solar radiation, instead of reflecting it, thereby causing an increase in temperature. The lack of trees and natural vegetation in urban regions also affects the energy balance, as it inhibits evapotranspiration and the associated cooling effect provided. Moreover, air pollution, altered wind patterns (low winds), waste heat and the geometry of a city further intensify the urban heat island effect (Hassid et al., 2000; Santamouris et al., 2001; Livada et al., 2002; Mihalakakou et al., 2004). The urban heat island effect is seen during both the warm and the cold season (Santamouris et al., 2001), but is much higher in intensity (expressed as the difference in maximum air temperature between urban and rural areas) in the summer, when it approaches 10ºC in the day and 5ºC at night. The lack of urban green areas seems to be a key culprit in the development of the urban heat island effect in Athens, given that the phenomenon is considerably mitigated in areas of the city with tall, dense vegetation, such as the National Gardens at the heart of the city (Livada et al., 2002). The cooling effect of this public park vanishes within just a few metres, on the adjacent avenues with their dense traffic (Zoulia et al., 2008).

As a result of the urban layout, the traffic load, waste heat and the overall balance of each area, the temperature difference between the National Gardens and other parts of the city can range between 0ºC and 13ºC during the day (mean temperature difference between ~7 ºC and 8ºC). The smallest temperature difference is recorded with the central pedestrian zone on Ermou Street, as opposed to other parts of the city, such as Ippokratous Street. During the day the temperature is generally much higher in the city centre than in the suburbs (roughly 7-8ºC higher). However, in areas with a high traffic load such as Ippokratous Street (where a monitoring station is located), the temperature difference can reach as much as 12-13ºC. The increases in temperature in the Athens are not consistent throughout the different districts, but depend on the heat load.

Human health and well-being are directly dependent upon the weather and climate, in particular on such factors as air temperature and humidity, sunshine, wind and atmospheric pressure. According to many climatologists, a comfortable climate (for humans) corresponds to a temperature range of 18-22ºC, with a relative humidity of 30-60% and mild winds up to 2 m/sec. A number of bioclimatic indexes have been devised to quantify human discomfort due to various climate parameters, starting with Thom's very simple 'Discomfort Index', first proposed in 1959, that provides a combined index of the air temperature and relative humidity, to the far more elaborate 'Physiological Equivalent Temperature' (PET), an indicator of thermal comfort based on meteorological parameters, but also on the energy balance of the human body. An analysis of PET index values for Greece showed that winter afternoons in the low-lying regions and the islands were perceived as thermally neutral, i.e. comfortable (18-23ºC), whereas in the highland regions the bioclimatic conditions were perceived as cold (4-8ºC). In contrast, on July and August afternoons, the thermal environment was perceived as hot (35-41ºC) in the low-lying regions, but as slightly warm (23-29ºC) in the islands and highlands. According to climate model forecasts, bioclimatic conditions in Greece are expected to change substantially. Especially in the summer, the PET value for the period 2071-2100, compared with the reference period 1961-1990, is likely to move up three levels on the physiological stress scale in the southern regions and two levels in the northern regions. During the remainder of the year, the PET value is likely to move up one to two levels on the physiological stress scale (Matzarakis and Nastos, 2011). In addition, an analysis of the projected changes in the 'humidex' discomfort index showed a significant increase in the future in the number of days with index values of over 38ºC (Sub-chapter 1.16, Figure 1.39).

1.12 Sources and emissions of air pollutants in Greece over the period 1990-2008

The deterioration in urban air quality as a result of human activity warrants particular interest. Air pollution can be defined as the perturbation of the atmosphere's natural chemical composition, due to increased concentrations of some of its components and/or to the introduction of additional substances, mainly of anthropogenic origin. Almost all megacities have some degree of air pollution, due to the activities of their populations (industry, traffic, energy and heat production, etc.; Gurjar et al., 2007), with pollutants classified as primary or secondary. Primary air pollutants are emitted directly into the atmosphere from the pollutant source and can include soot, sulphur dioxide, carbon monoxide, nitrogen oxides, hydrocarbons and other organic gases, lead oxides and various suspended particles of organic and inorganic compounds of anthropogenic or natural origin. Secondary air pollutants are not directly emitted as such, but form when primary pollutants react in the atmosphere (physico-chemical transformation), especially in areas and time periods with abundant sunshine. One such secondary pollutant is tro-

Table 1.5 **Emissions of the most significant primary pollutants in Greece in kilotonnes (kt) and statistical data on the share (%) of Greece in total European emissions, as well as per capita emissions in kilograms per year in Greece**

Pollutant	1990 emissions (kt)	2008 emissions (kt)	Percentage change	Ranking in EU-27 in 2008	Percentage share in total emissions in EU-27	Kg per inhabitant (2000-2008)	Source
NO_x	296.0	356.9	20.6	7	3.5	31.8	EEA
SO_2	493.0	447.6	-9.2	7	7.6	39.9	EEA
NMVOC	255.0	218.0	-14.3	8	2.6	19.5	EEA
CO	1,281.3	685.0	-46.5	8	3.0	61.0	EMEP, EEA
NH_3	79.0	63.1	-20.1	14	1.7	5.6	EEA
PM2.5	49.3*	62.81	22.0	-	-	-	EMEP
PM10	26.1*	37.2	31.0	-	-	-	EMEP

EEA: European Environmental Agency, http://www.eea.europa.eu/
EMEP: European Monitoring and Evaluation Programme, http://www.emep.int/
* Emissions since 2000.

pospheric ozone. Immediately below is a brief outline of the prevalent primary air pollutants encountered in Greece (see also Table 1.5).

Nitrogen oxides – NOx

Nitrogen oxides play an important role in atmospheric chemistry, particularly in the formation and destruction of tropospheric ozone. Two of the most prevalent oxides of nitrogen —nitrogen oxide, NO, and nitrogen dioxide, NO_2— are essentially formed from the breakdown of nitrogen gas and its reaction with oxygen during combustion processes.

Certain nitrogen oxides, for instance NO_2, are particularly toxic. Short-term exposure to concentrations of less than 3 ppm can cause irritation to the respiratory tract, while concentrations of over 3 ppm may lead to pulmonary dysfunction. Prolonged exposure to low concentrations can affect lung tissue, causing emphysema. Certain groups, such as asthmatics and young children, are particularly vulnerable to the effects of nitrogen oxides. Nitrogen oxides also contribute to the formation of fine suspended particles and to ozone production, which costs billions of dollars on a global scale in terms of morbidity and mortality.

The main sources of NOx emissions in Greece are energy production (fossil fuel combustion) which accounts for 59% of the total, road transport (29%) and other types of transportation (11%).[5] As can be seen in Figure 1.13,[6] the highest NO_2 emission levels are recorded in the

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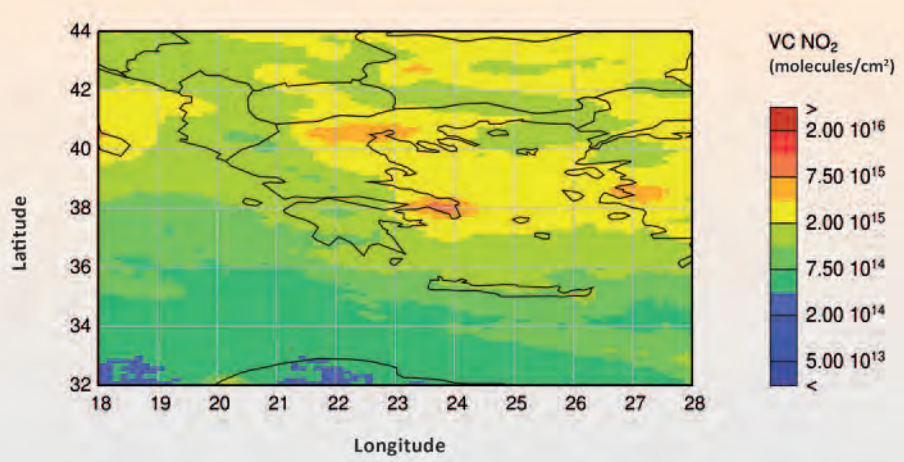
[5] http://www.eea.europa.eu/ (see file: greece-air-pollutant-emissions-country-factsheet.pdf, 2008)

[6] http://www.doas-bremen.de/

Figure 1.13 **Tropospheric column density of NO_2 over Greece in the 2003-2009 period, based on satellite observations from SCIAMACHY spectrometer**



In the colour range, blue represents the lowest values of NO_2 and red the highest.

Attica Basin and in Central/Western Macedonia (Thessaloniki/Ptolemais), i.e. regions with intense anthropogenic activity.[7]

From 1990 to 2008, total NOx emissions in Greece increased by 21%, putting Greece in the 7th position among the EU-27.[8] It should be stressed that Greece is one of the few countries whose NOx emissions increased, whereas emissions in the EU-27 as a whole decreased by 31%.[9] For the period 2000-2008, NOx emissions in Greece were estimated to have risen by 0.9 kg/capita to reach 31.8 kg/capita.

Sulphur dioxide – SO_2

Sulphur dioxide is released into the atmosphere mostly from anthropogenic activities, although one-fourth of total emissions come from natural sources, such as volcanic activity. The presence of SO_2 in the atmosphere is important to monitor because of the compound's high water solubility. When combining with water, sulphur dioxide forms sulphuric acid (H_2SO_4), a constituent of acid rain, the deposition of which has adverse effects on ecosystems. Sulphur dioxide is an oxidising agent that can cause pulmonary dysfunction, especially in asthmatics. It poses an even greater health risk when combined with increased concentrations of particulate matter and other gaseous pollutants.

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[7] http://prtr.ec.europa.eu/

[8] The EU-27 consists of Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom.

[9] http://www.eea.europa.eu/ (file: greece-air-pollutant-emissions-country-factsheet.pdf, 2008)

Energy production, mainly from fossil fuel combustion, is the predominant source of SO2 emissions in Greece (93%), with the rest coming from non-road transport and industrial processes.[10] From 1990 to 2008, total SO_2 emissions in Greece declined by 9%, which, however, was far less than the average reduction (66%) achieved by the EU-27. With annual emissions of 448 kilotonnes in 2008, Greece ranked 7th among the EU-27.[11] Another fact worth noting is that Greece accounts for roughly 8% of total EU-27 SO_2 emissions. Lastly, in 2008 SO_2 emissions were estimated at 39.9 kg per capita.

Non-methane volatile organic compounds – NMVOC

Volatile organic compounds (VOCs), together with nitrogen oxides, are precursors of tropospheric ozone, high concentrations of which cause toxic photochemical smog with adverse effects on vegetation and human health (Williams, 2004). In addition, volatile hydrocarbons also have a significant effect on the oxidative capacity of the atmosphere (Vrekoussis et al., 2004; Monks, 2005), i.e. the atmosphere's ability to convert various gases and to cleanse itself of air pollutants. Lastly, VOCs are primary precursors for the formation of particulate matter in the atmosphere, as well as of cloud condensation nuclei (CCN) (Roberts et al., 2002).

VOCs are emitted into the atmosphere from anthropogenic and natural processes (Vrekoussis et al., 2009; 2010). The production of fossil fuels, the use of solvents and biomass burning are the main anthropogenic sources, while the main biologically generated source of VOC is isoprene, a compound released by plants. The sources of NMVOC in Greece can be divided into four categories: energy production and consumption (26%), road transport (23%), industrial processes (25%), while the remaining 25% comes from a number of other sources (farming, solvent use and waste management).[12]

Over the period 1990-2008, the EU-27 was able to reduce NMVOC emissions by a substantial 41%, while Greece, with a contribution of 2.6% to total EU-27 NMVOC emissions, reduced its emissions by 14%. The 218 kilotonnes of NMVOC emitted in Greece correspond to emissions of 19.5 kg per capita.[13]

Carbon monoxide – CO

Carbon monoxide, produced from the incomplete combustion of carbon-containing substances, is toxic to humans because it acts as an antagonist to haemoglobin, i.e. the protein in the bloodstream that transfers oxygen from the lungs to the rest of the body. It is present in the natural environment in very low concentrations of 100 ppbv (part per billion per volume). Emis-

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[10] http://www.eea.europa.eu/ (file: greece-air-pollutant-emissions-country-factsheet.pdf, 2008)
[11] http://www.eea.europa.eu/ (file: greece-air-pollutant-emissions-country-factsheet.pdf, 2008)
[12] http://www.eea.europa.eu/ (file: greece-air-pollutant-emissions-country-factsheet.pdf, 2008)
[13] http://www.eea.europa.eu/ (file:greece-air-pollutant-emissions-country-factsheet.pdf, 2008)

sions from natural sources, such as volcanoes and wildfires, are relatively low compared with emission levels in urban centres. CO concentrations in urban areas, typically at 10 ppmv (parts per million per volume), are 100 times higher than in non-urban areas.

Most CO emissions in the EU-27 come from road transport, followed by household activities and industrial processes.[14] Between the years 1990 and 2008, CO emissions in Greece were reduced by a substantial 47% (from 1,302 kilotonnes in 1990 to 685 kilotonnes in 2008), with per capita emissions (2000-2008) estimated at roughly 61 kg. Greece accounts for some 3% of total CO emissions in the EU-27.[15]

Ammonia – NH_3

Ammonia has recently become the focus of much debate because of the effects that the deposition of atmospheric nitrogen can have on ecosystems, thereby leading to eutrophication and increased acidity. Ammonia is also associated with the formation of secondary particulate matter with adverse effects on human health and the climate. Agriculture remains the major source of ammonia emissions in Greece (96%), with the remaining 4% associated with road transport. Between the years 1990 and 2008, ammonia emissions in Greece were reduced by 20%, with emissions in 2008 estimated at 5.6 kg per capita. Greece accounts for 1.7% of all NH_3 emissions in the EU-27.[16]

Particulate matter – PM

Particulate matter (PM) is a collective term used to describe solid or liquid particles suspended in the atmosphere, such as dust, pollen, soot, smoke, liquid droplets. Distinctions are made between coarse particulate matter (PM10) which is less than 10 microns in diameter and fine particulate matter (PM2.5) which is less than 2.5 microns in diameter, including ultrafine particulate matter (PM1) which is less than 1 micron in diameter. Long-term exposure to high PM concentrations, especially fine particles, can cause severe respiratory and cardiovascular disorders.[17]

Primary particulate matter arises from both anthropogenic activity (agriculture, industry, fossil fuel combustion) and natural processes (windblown dust, wildfires and volcanoes). Secondary particulate matter comes from the oxidation of precursor gaseous compounds, such as nitrogen oxides, sulphur oxides, ammonia and VOCs. In the specific case of Greece, secondary particulate matter stemming mainly from NOx and SO_2 account for the bulk of airborne particulate matter.[18] Their main sources in 2007 were industrial processes, road transport and energy

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[14] http://www.eea.europa.eu/ (file: LRTAP1990-2008.pdf)
[15] http://www.eea.europa.eu/ (file: LRTAP1990-2008.pdf)
[16] http://www.eea.europa.eu/ (file: greece-air-pollutant-emissions-country-factsheet.pdf, 2008)
[17] http://www.who.int/en/
[18] http://www.ekpaa.greekregistry.eu/

production industries. Between the years 2000 and 2008, PM emissions in Greece increased both for fine particulate matter (PM2.5) and coarse particulate matter (PM10), by 22% and 31%, respectively.[19] In contrast, EU-27 emissions decreased by ~10% in both PM categories over the same period.[20]

1.13 Climate change trends in Greece

From the late 19th century to the 1970s, the mean air temperature time series for the Eastern Mediterranean and Greece has been consistent with the upward trend recorded for the Northern Hemisphere – NH (Repapis and Philandras, 1988; see also Figures 1.14 and 1.15). However, the cooling recorded in the NH in the period 1940-1970 was more pronounced in the

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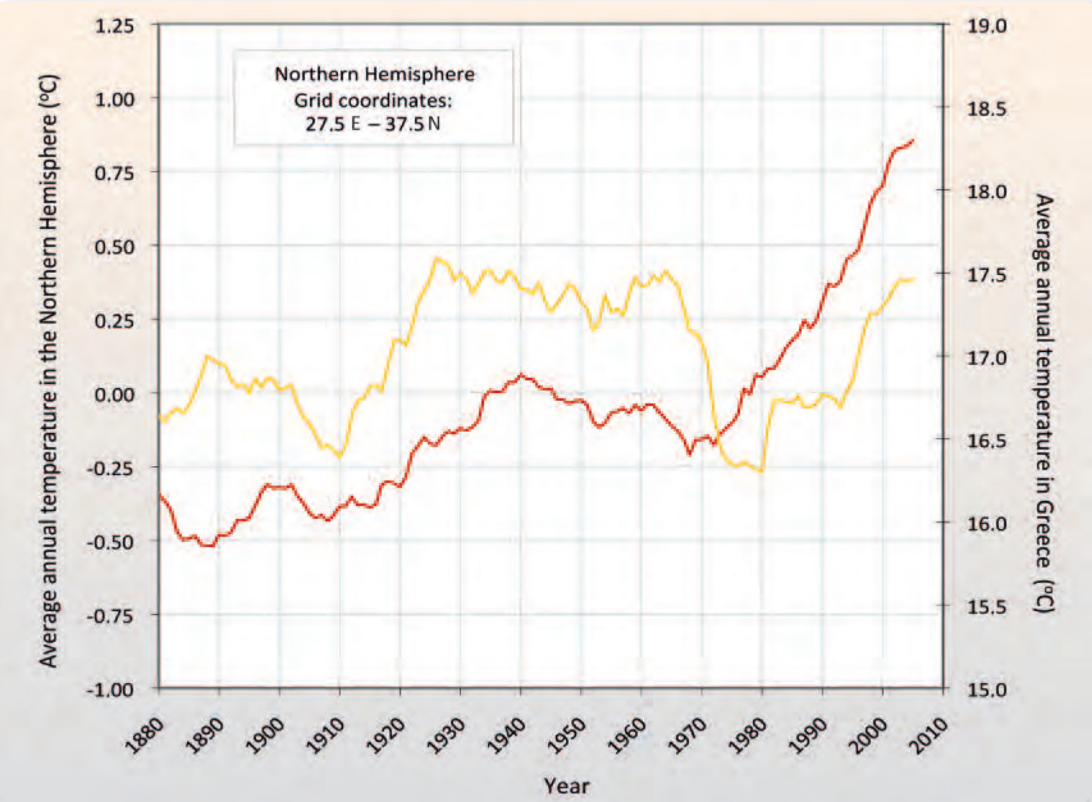
[19] http://www.emep.int/

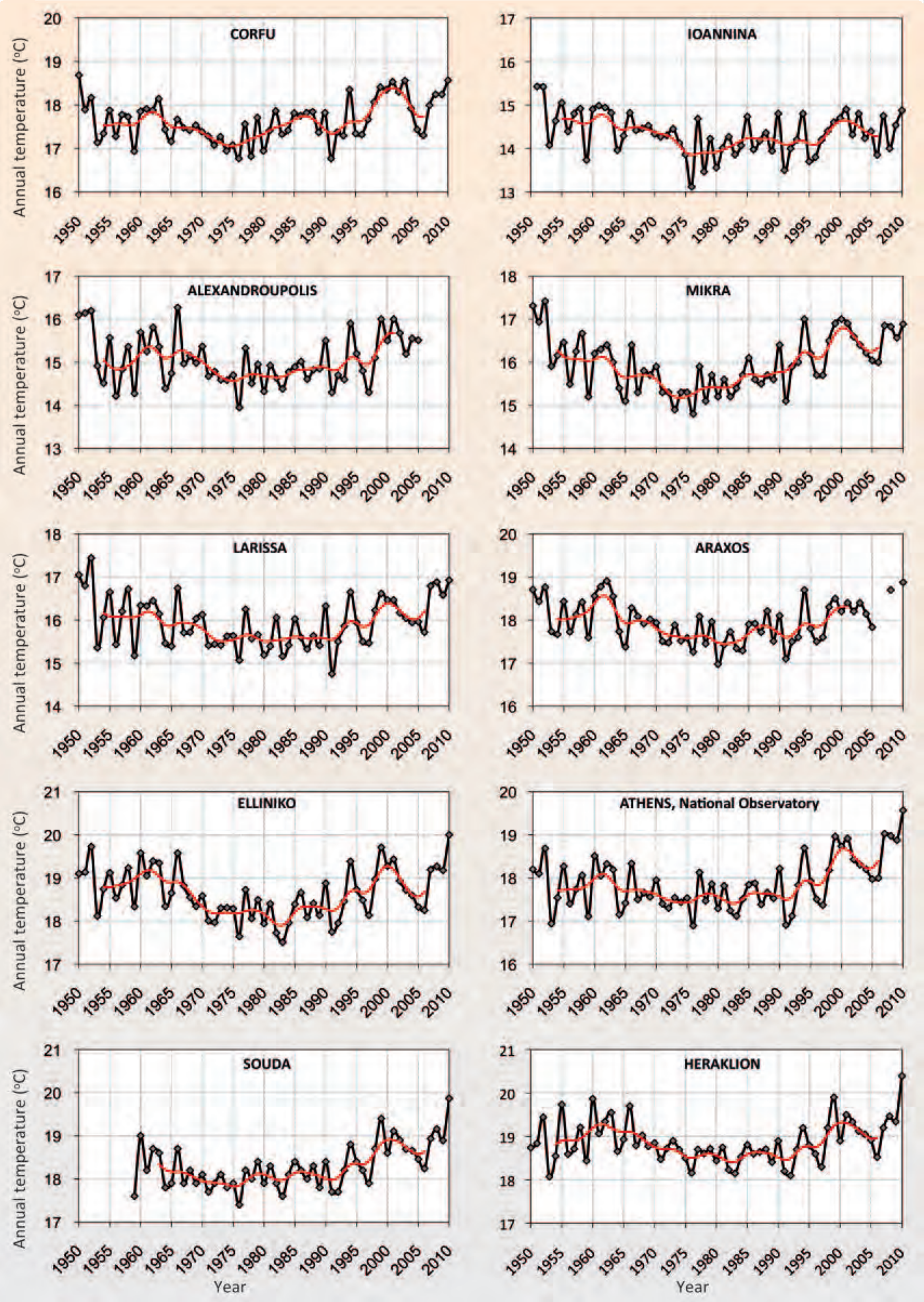
[20] http://www.eea.europa.eu/ (file: LRTAP1990-2008.pdf)

Figure 1.14 Mean annual temperature time series, 1880-2000 (Values smoothed with 10-year moving average)



(a) in the Northern Hemisphere (red line), and (b) in the grid box which includes Greece (yellow line).

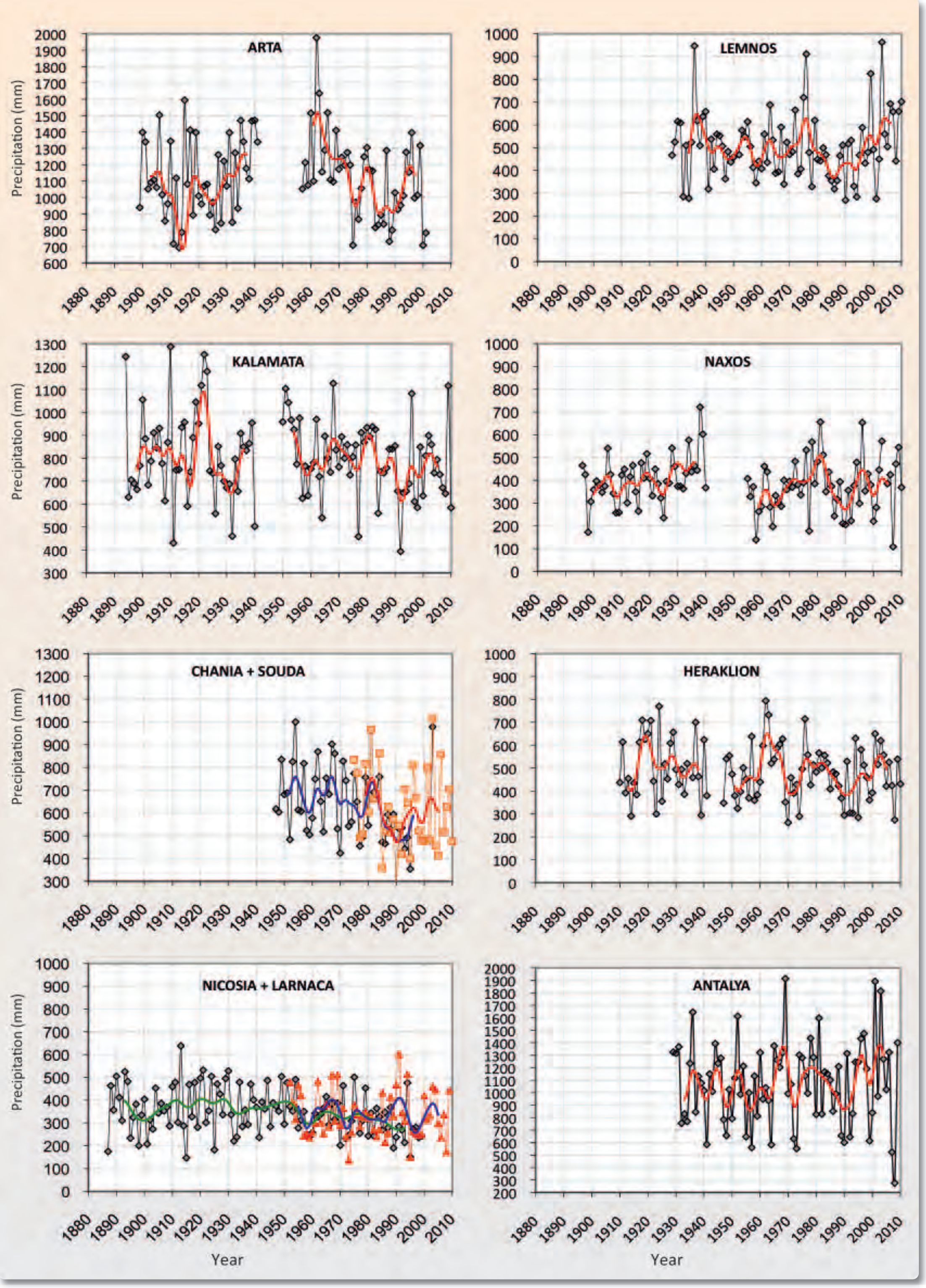
Figure 1.15 Mean annual air temperature time series observed at selected Greek stations (1950-2010)



The red line represents values smoothed with Gaussian 9.

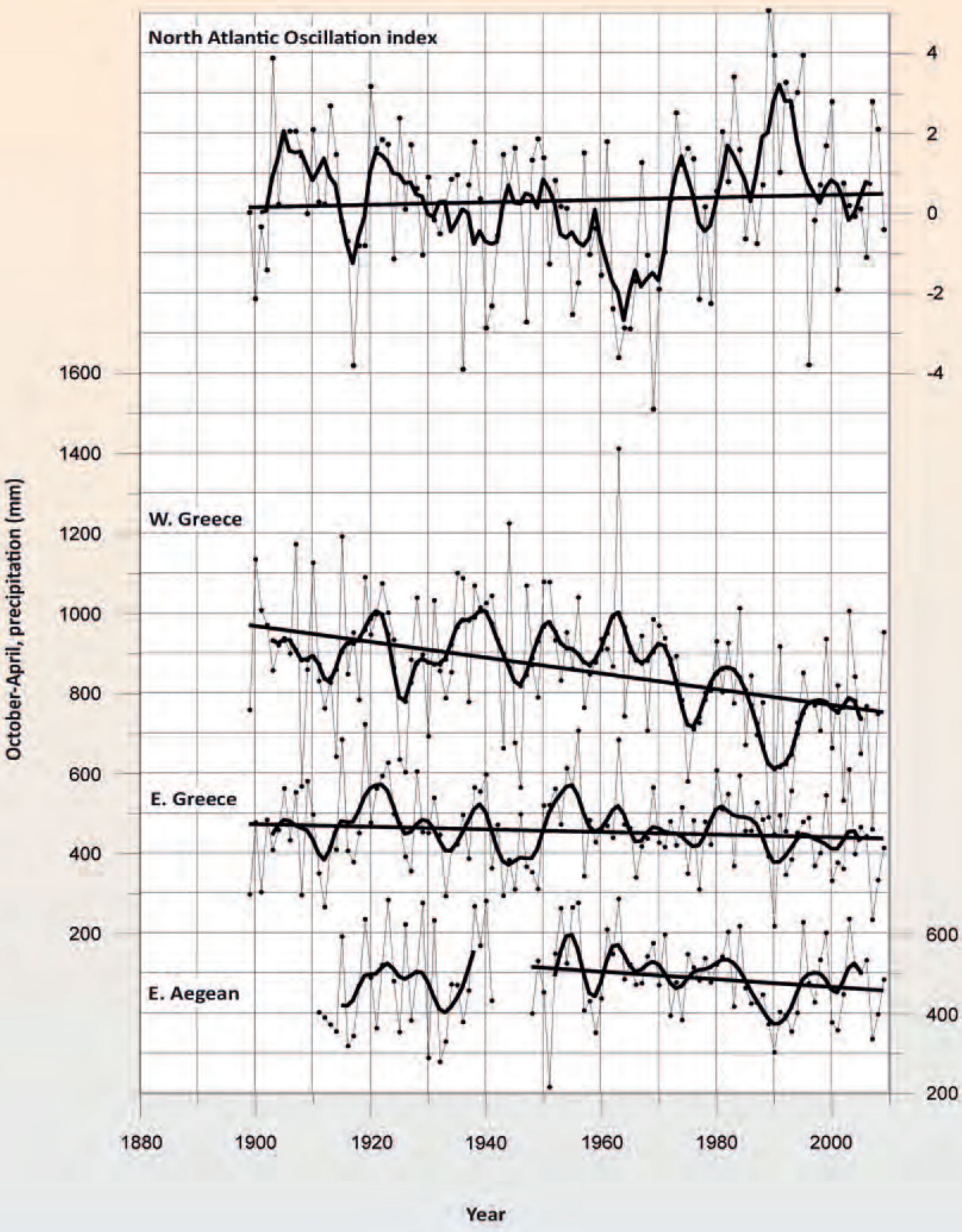
Figure 1.16

Time series of precipitation at selected stations in Greece, Cyprus (Nicosia) and Turkey (Antalya)



The orange time series for Chania and the red time series for Nicosia were completed with data from adjacent stations (Souda and Larnaca, respectively). Smooth lines were created using Gaussian filter with σ=9.

Figure 1.17 North Atlantic Oscillation (NAO) index time series and April-October precipitation (rainy season) time series in Western Greece, Eastern Greece and the Eastern Aegean Islands



The bold curves represent values smoothed with Gaussian 9. The straight lines show regressions.

Eastern Mediterranean: thus, whereas mean temperatures in the NH soon rebounded and from the early 1980s exceeded the values of the previous 100 years, in the Eastern Mediterranean they only began to rise again in the 1980s and 1990s (Repapis et al, 2002; Saaroni et al., 2003; Feidas et al., 2004; Repapis et al., 2007).

In terms of precipitation levels, a clear positive trend in annual precipitation was recorded for northern Europe, with the exception of Finland, in contrast with a clear negative trend recorded for southern Europe and the Mediterranean (ECSN, 1995; IPCC, 1996; 2001). Rainfall in the Eastern Mediterranean decreased, with sizeable differences across regions and intense variability from year to year, depending on the topography and the tracks of passing low pressure systems. As far as Greece is concerned, most regions experienced a negative trend in rainfall in the second half of the 20th century, statistically significant in some regions (Kandylis et al., 1989; Mantis et al., 1997; Hatzioannou et al., 1998; Paz et al., 1998; Maheras et al., 2004; Xoplaki et al., 2004; Feidas et al., 2007; Zanis et al., 2009).

In Greece, the negative trend in annual rainfall in the course of the 20th century ranges from 20% in Western Greece to 10% in Eastern Greece, and can be attributed partly to the trend observed in the North Atlantic Oscillation (see Figures 1.16 and 1.17; Zerefos et al., 2010).

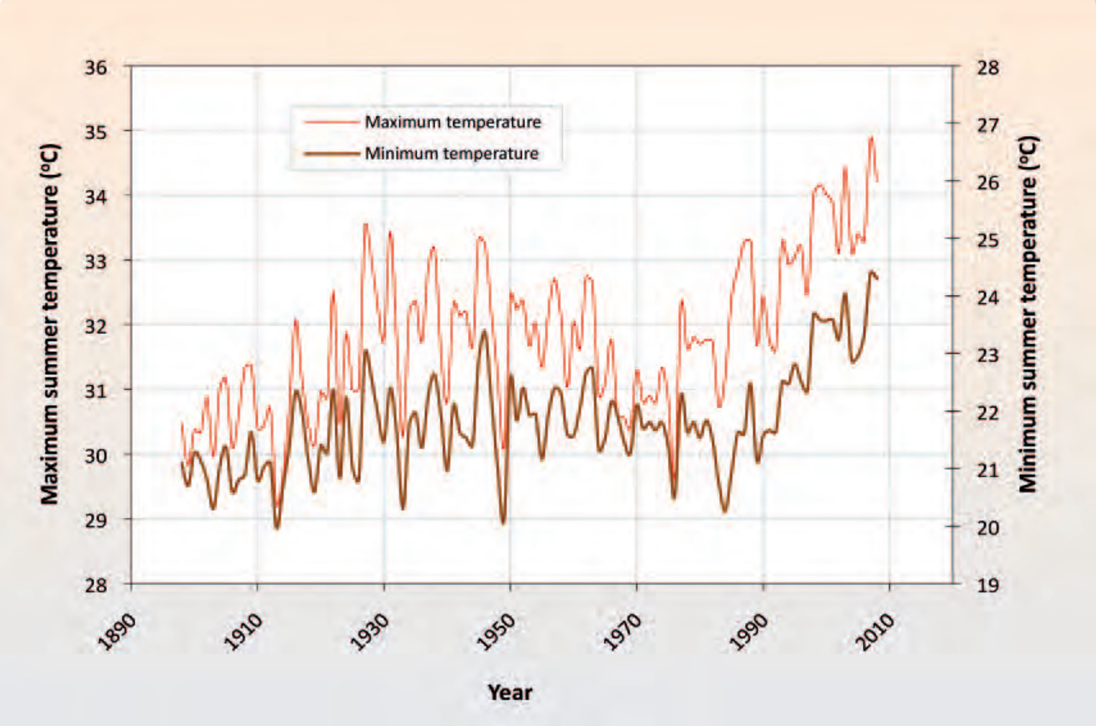
1.14 Climatic trends in the Athens region

Athens has undergone particularly acute climatic changes over the past decades, due to the combined influence of various —mostly anthropogenic— factors, including:

- intensified urbanisation, leading to a greater 'urban heat island' effect;
- global climate change, due to the greenhouse effect;
- loss of peri-urban green areas to forest fires; and
- natural climate variability.

In order to determine the climatic influence of the above factors, it is necessary to have a continuous record of meteorological observations (time-series) that are long-term, reliable and homogeneous. The case of Athens can be considered ideal, as the meteorological observations (time-series) kept on record by the historic meteorological station of the National Observatory of Athens (NOA), in the city's central district of Thisseion, go back more than a century and were all made at the exact same location, amid surroundings that have remained unchanged within a radius of several hundred meters (Founda et al., 2004). The area where the NOA station is located has no urban traffic, considerable green areas, and low-density low-height construction, i.e. features that are more typical of a suburban station (Livada et al., 2002). The temporal temperature variations, as recorded at the NOA station, seem to be predominantly attributable to the combined effects of global climate change (natural and anthropogenic) and intensified urbanisation in the wider area (Philandras et al., 1999; Founda et al., 2004).

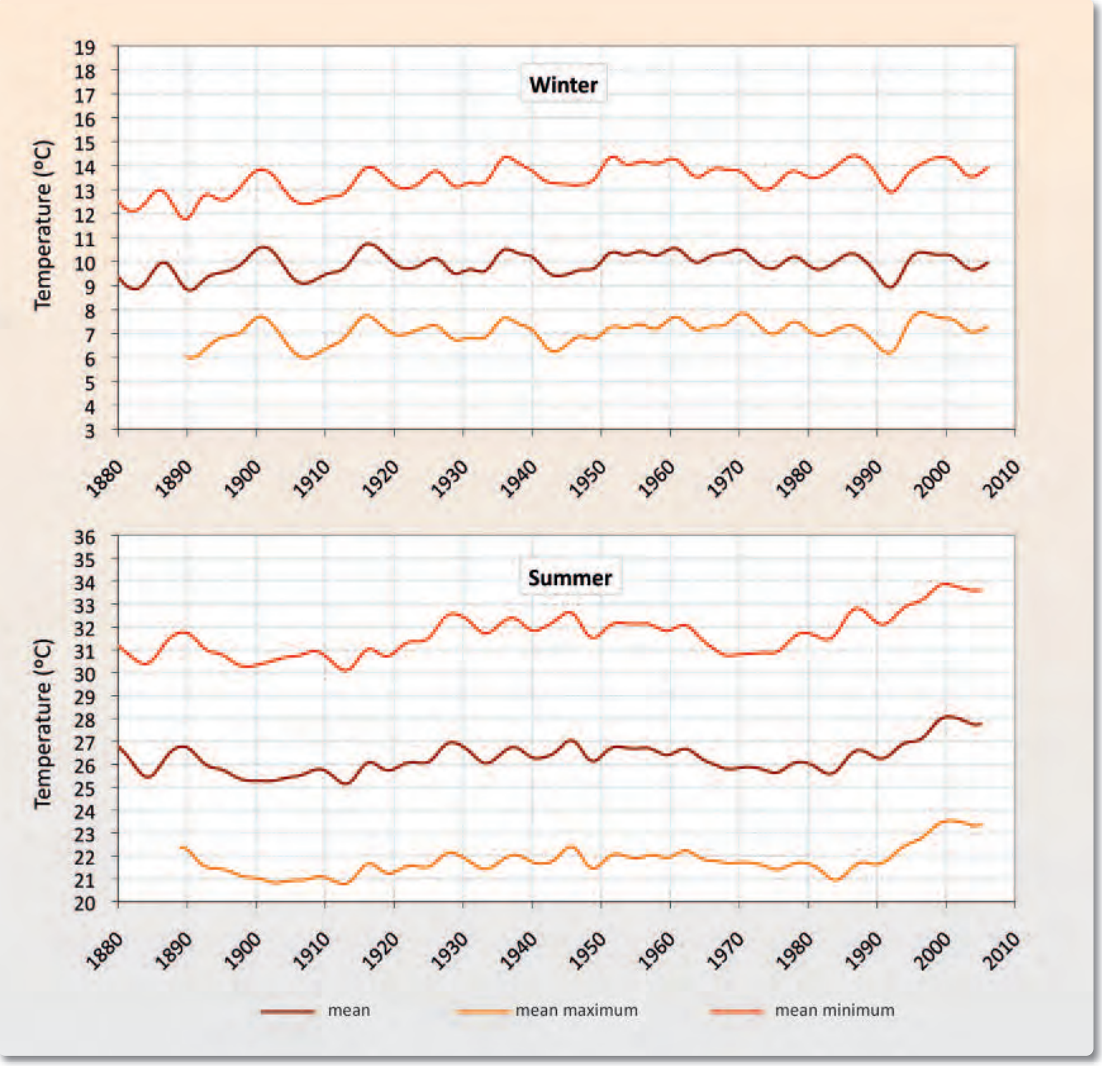
Figure 1.18 **Variation of the mean maximum and mean minimum summer temperatures in Athens (1900-2008/Thisseion Station, National Observatory of Athens)**



Based on NOA observations, the time-series of the annual mean air temperature for Athens has qualitatively followed the time-series for the Northern Hemisphere from the beginning of the previous century till today, with alternating warm and cooler periods, along a generally upward trend in the order of 0.5ºC over the long term (1900-2008). Since the mid-1970s, however, the overall trend in annual mean temperature has, despite yearly variations, been clearly upward (+1.3ºC from 1976 to 2008). Similar and concurrent has been the overall upward trend in annual mean maximum temperature (i.e. also starting in the mid-1970s), whereas the upward trend in annual mean minimum temperature (night temperature) began with a lag of several years, but has been faster paced (+1.8ºC from 1984 to 2008; Founda, 2011).

Particularly striking is the difference in temperature variation trends between the warm and cold seasons of the year, with the marked upward trend in summer temperature largely accounting for the upward trend recorded on an annual basis (Founda et al., 2004; Founda, 2011). Specifically, the mean summer temperature (June to August) in Athens has been trending clearly upward since the mid-1970s, with an average increase of ~1ºC per decade. Similar has been the overall trend in mean maximum temperature (+3.2ºC/1976-2008), whereas the upward trend in mean minimum (night) temperature in summer once again began with a lag of several years,

Figure 1.19 **Time series of the mean, mean maximum and mean minimum temperatures in Athens in winter and summer (1880-2008, Thisseion Station, National Observatory of Athens)**

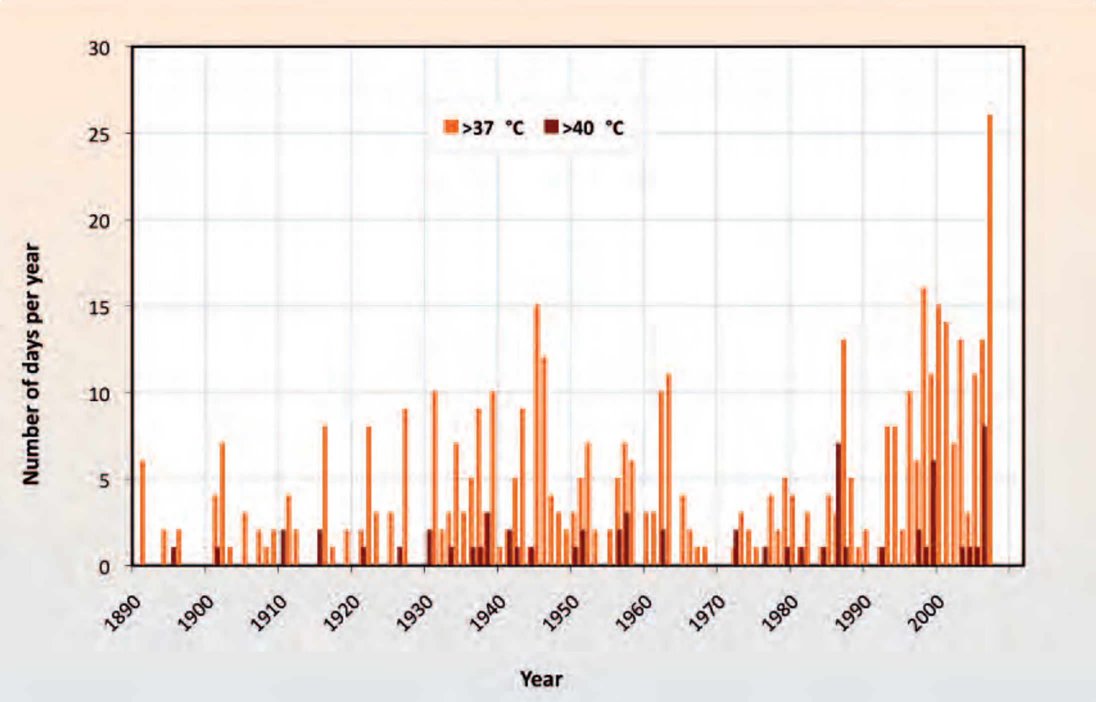


Values smoothed with Gaussian 9.

but has been faster paced (+3.3ºC/1984-2008), most probably on account of the urban heat island effect (Figures 1.18 and 1.19). Although many researchers associate the rise in summer temperatures in the centre of Athens with the weakening and warming of sea breezes as a result of higher building density (Metaxas et al., 1991; Philandras et al., 1999), interestingly similar rates of temperature increase in the summer months have also been recorded along the coast of Attica, for instance by the meteorological station of Ellinikon (Founda, 2011).

According to a recent study (Founda and Giannakopoulos, 2009), 1998-2007 was the warmest decade on record for Athens in terms of maximum summer temperatures (1937-1946 was the second warmest). On the contrary, no significant trend in temperature (either positive

Figure 1.20 Number of days per year with maximum temperature >37°C and >40°C (1890-2007/Thisseion Station, National Observatory of Athens)



In 2007, the number of days with maximum temperature >37°C exceeded 25.

or negative) has been observed during winter. According to recent records,[21] 2001-2010 was the warmest decade on record for Athens in terms of annual temperature values (mean, maximum and minimum), once again on the basis of NOA observations. Six of the warmest years on record belong to this decade, with 2010 the warmest year ever with a mean temperature of 19.6ºC and a departure from the climatic mean of almost 2ºC. This is attributable for the most part to the months of August and November 2010, which were respectively 3.8ºC and 3.5ºC warmer than their climatic monthly mean.

Apart from the long-term trends in mean temperatures, another interesting change in the climate of Athens over the past few years concerns the incidence of extreme weather events (particularly high temperatures) in the summer months. This change in warm spells is characterised by:

- higher frequency (both in the number of separate days with extremely warm weather and in the number of warm spells (heat waves) lasting at least three consecutive days, Figures 1.20 and 1.21, Founda and Giannakopoulos, 2009);
- higher intensity (higher absolute maximum temperatures);

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[21] Climatological Bulletin, National Observatory of Athens.

Figure 1.21 **Number of extreme hot spells (at least 3 consecutive days with temperatures >37°C) per year (1900-2007/Thisseion Station, National Observatory of Athens)**

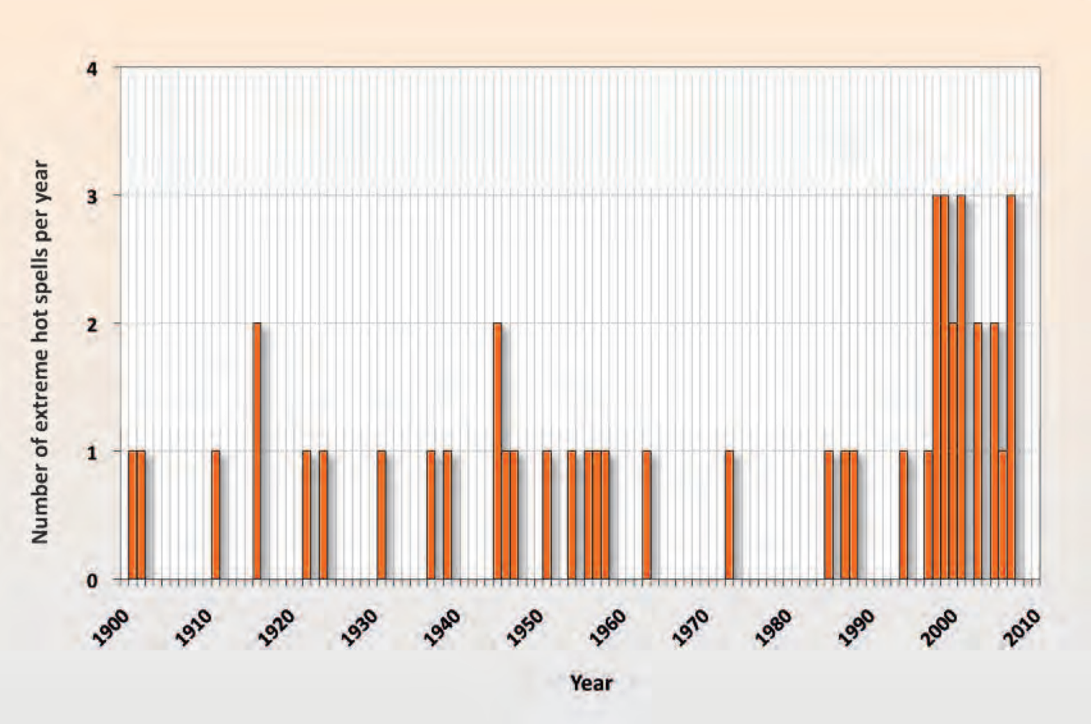
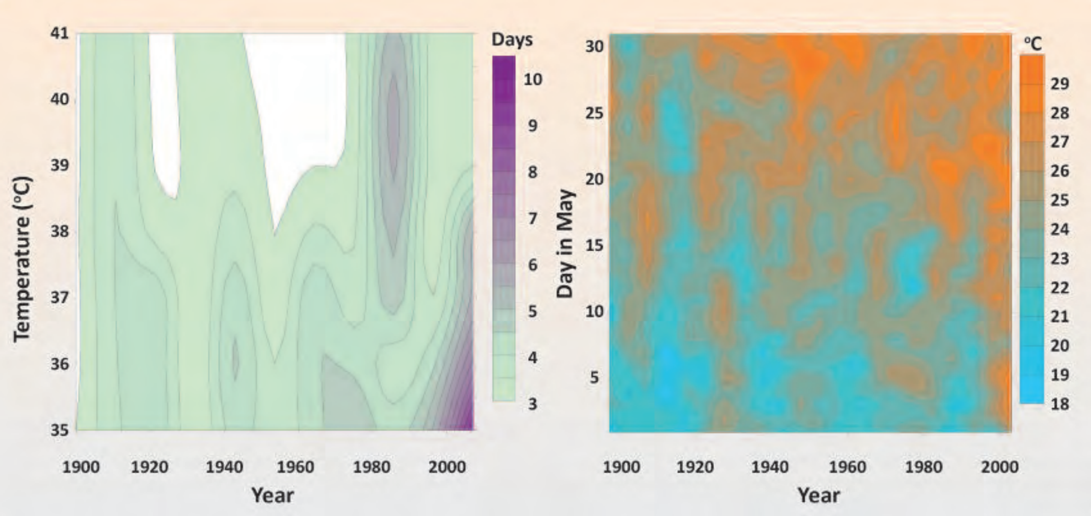


Figure 1.22 **Average duration of extreme hot spells per year for various temperature thresholds (1900-2005/Thisseion Station, National Observatory of Athens, left panel) and maximum daily temperatures in May (1900-2005, National Observatory of Athens, right panel)**



A shift towards earlier high temperature occurrences can be observed.

- longer duration (persistence) (Figure 1.22, left panel; Founda, 2009); and
- first occurrences earlier in the year (Figure 1.22, right panel, Founda, 2009).

As can be seen from Figure 1.20, the number of days with temperatures above 37ºC/40ºC has increased markedly since the mid-1990s, accounting for more than 35% of the entire time series. The increase in heat wave incidence (i.e. at least three consecutive days with temperatures above 37ºC) has been of a similar order (Figure 1.21). According to Founda and Giannakopoulos (2009), the summer of 2007 was, in terms of air temperature, the most extreme on record in Athens. The temperature of 44.8ºC recorded on 24 June 2007 at the NOA (>46ºC at neighbouring stations) was an all-time high in the 150 years of NOA records, while the heat wave of June 2007 was the earliest on record (although an even earlier, but not as extreme, heat wave occurred in 2010). As almost half of the days had a maximum air temperature that exceeded the 90th percentile of temperature in the reference period (1961-1990), the summer of 2007 felt like a continuous heat wave. As shown by comparisons with climate simulation estimates made for the future (Founda and Giannakopoulos, 2009; and Tolika et al., 2009), the temperature conditions in the summer of 2007 were found to be similar to those projected to occur at increased frequency in the latter part of the 21st century. The heat wave index increased in general throughout the country over the period 1958-2000, whereas the frequency of cold nights both in summer and in winter declined (Kostopoulou and Jones, 2005).

Although the incidence of high temperature events in Greece is mostly associated with anticyclonic conditions and circulation anomalies in the upper atmosphere (Xoplaki et al., 2003), their effects are amplified in large urban centres by the urban heat island effect. Anticyclonic conditions have the general effect of exacerbating the urban heat island effect throughout the year, although less so in winter, due to cyclonic circulation and to the wind patterns that prevail during the cold season (Livada et al., 2002; Mihalakakou et al., 2002).

As for the future of Athens' climate over the next few decades, the outlook, based on projections, seems rather bleak. The region of the Eastern Mediterranean, to which Athens belongs, is considered one of the most vulnerable to the anthropogenic component of climate change (Giorgi and Lionello, 2008). It should be noted that, even though climate model projections developed by different research institutions often present considerable divergences, they are generally consistent with each other when it comes to the Mediterranean region, which significantly increases confidence in the specific projections. Researchers studying the effects of climate change on extreme weather events have concluded that the climate of the Mediterranean basin will become significantly warmer, with prolonged heat waves, less rainfall, but also more intense extreme rainfall events (Diffenbough et al., 2007; Goubanova and Li, 2007; Tolika et al., 2008).

After combining the results of three Regional Climate Models (RCMs) for the Athens area, the mean maximum summer temperature is projected to increase by 2ºC in the period 2021-

2050 (with respect to 1961-1990) and by 4ºC in the period 2071-2100 (Founda and Giannakopoulos, 2009). In parallel with the increase in mean temperature, the models also point to a rise in temperature variability around the mean value, resulting in a more frequent occurrence of extremely high temperatures. According to a recent study jointly conducted by WWF Hellas and NOA (WWF Hellas, 2009), Athens is projected to experience up to 15 more days a year with a maximum temperature >35ºC (compared with the reference period 1961-1990) and up to 30 more 'tropical nights' with lowest night temperatures >20ºC in the near future (2021-2050).

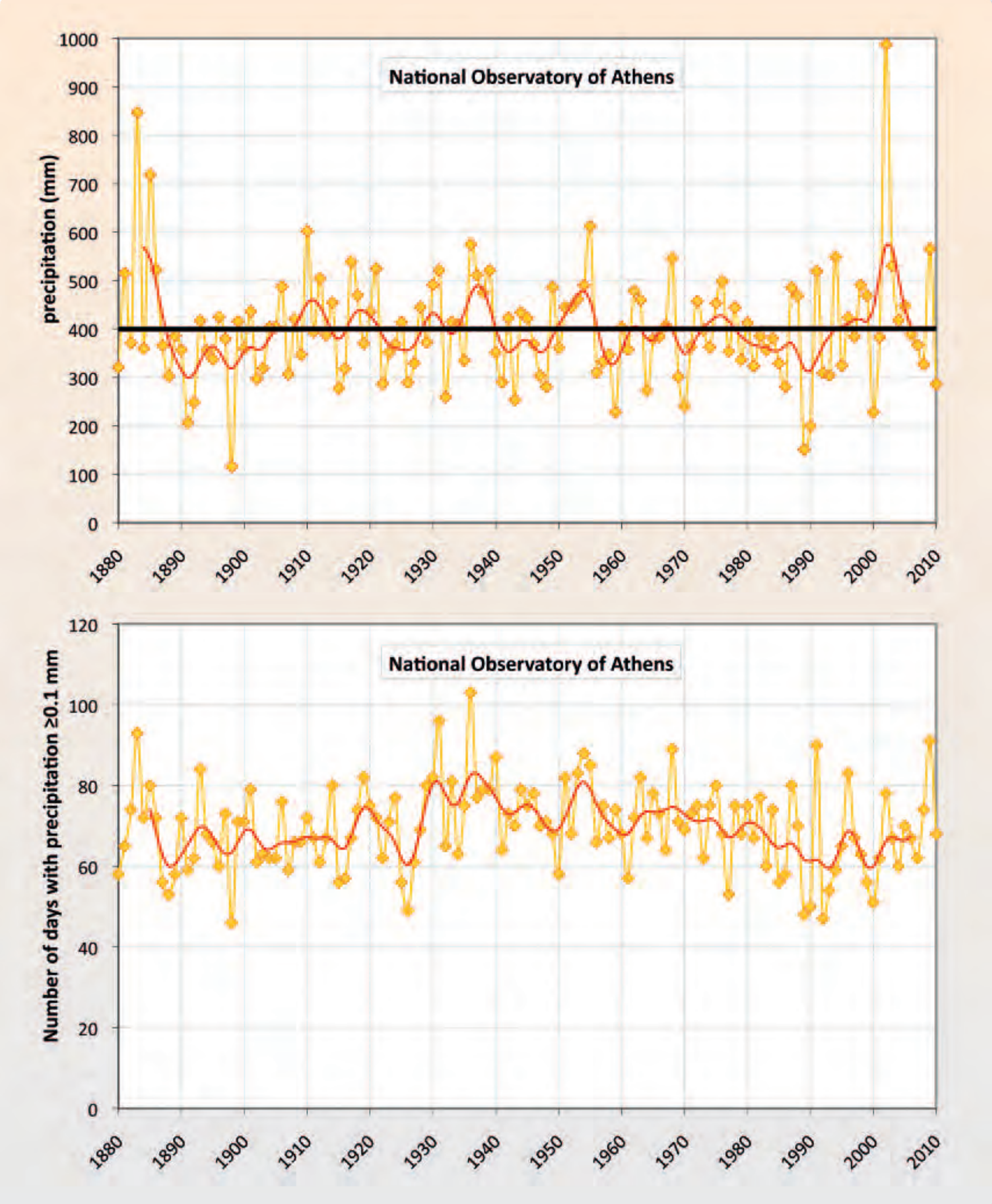
Projecting the extreme conditions of the summer 2007 into the future, it was estimated that the probability density function of the projected summer month maximum temperatures for the period 2070-2100 practically coincides with the respective one for the summer of 2007 in Athens, while similar results were obtained for minimum (night) temperatures (Founda and Giannakopoulos, 2009). In other words, the summer of 2007 was a 'foretaste' of the conditions that will prevail in the city in the future; and conditions considered today to be particularly extreme will, in the second half of this century, be typical of an Athens summer. The same approach, when applied to less urbanised areas around Athens, produced similar results with regard to maximum temperatures. However, the results in terms of minimum temperatures varied, signalling the cumulative impact of the urban heat island effect in the presence of extreme weather events, especially at night.

In addition to the above, note should also be taken of the projected expansion of the urban fabric in the next decades, and the respective expansion and exacerbation of the urban heat island effect.

As regards extreme precipitation events, Nastos and Zerefos (2007), after studying daily precipitation records from the National Observatory of Athens (NOA) covering the period 1891-2004, reported a clear overall increase in extreme precipitation events. Maheras et al. (2004) also provide evidence that extreme precipitation events are increasing, despite the decline in total precipitation (see also Figure 1.23).

Moreover, according to a recent study (Founda et al., 2009), a decrease in total precipitation is projected for Athens in the following decades, together with a higher occurrence of extreme precipitation events. Lower precipitation would obviously have an adverse effect on groundwater quality, and will become an additional factor in expected climatic changes (Fischer et al., 2007). Decision makers must be prepared to deal with such variability and the serious effects it is likely to have in our region, as shown by recent flooding and drought spells. Interestingly, the Ancient Greeks had plans for such contingencies, as evidenced by surviving texts, involving for instance the construction of ditches and dams in the surrounding mountains and of rainwater reservoirs in the cities (Aeginitis, 1908; 1926). Plato (in his *Laws*, Book 6, Sections 761b, c) says that rural patrols "shall dam the outflows of their flooded dales

Figure 1.23 **Time series of annual precipitation (upper panel) and number of rainy days (with precipitation ≥0.1 mm, lower panel) (Thisseion Station, National Observatory of Athens)**



Values smoothed with Gaussian 9 (red line). The straight line shows regressions.

by means of walls and channels, so that by storing up or absorbing the rains from heaven, and by forming pools or springs in all the low-lying fields and districts, they may cause even the driest spots to be abundantly supplied with good water. As to spring-waters, be they streams or fountains, they shall beautify and embellish them by means of plantations and buildings, and by connecting the pools by hewn tunnels they shall make them all abundant, and by using water-pipes they shall beautify at all seasons of the year any sacred glebe or grove that may be close at hand, by directing the streams right into the temples of the gods".[22] Similarly, Aristotle (in his *Politics*, Section 1330) mentions that a city "must possess if possible a plentiful natural supply of pools and springs, but failing this, a mode has been invented of supplying water by means of constructing an abundance of large reservoirs for rain-water, so that a supply may never fail the citizens…".[23]

1.15 Estimating future climate variation for Greece's 13 climate zones until the end of the 21st century

1.15.1 Determining Greece's different climate zones

Our first task was to divide Greece into different climate zones on the basis of climatic and geographical criteria, the most significant of which are: (i) the mountain range running north to south through most of the country, dividing continental Greece into a western windward area and an eastern rain shadow area; (ii) the Eastern Aegean and the Dodecanese Islands, where precipitation levels resume an upward trend, after reaching their lowest values in the Cyclades; (iii) the north-to-south temperature gradient, as well as the temperature difference between island and continental regions; (iv) the topography and climatic homogeneity. These climatic and geographical considerations enabled us to identify the following 13 climate zones (see Figure 1.24): 1. Western Greece (WG); 2. Central and Eastern Greece (CEG); 3. Western and Central Macedonia (WCM); 4. Eastern Macedonia-Thrace (EMT); 5. the Western Peloponnese (WP); 6. the Eastern Peloponnese (EP); 7. Attica (AT); 8. Crete (C); 9. the Dodecanese islands (D); 10. the Cyclades islands (CY); 11. the Eastern Aegean (EA); 12. the Northern Aegean (NA); and 13. the Ionian (I).

1.15.2 Projecting climate variation for Greece's 13 climate zones, on the basis of four different greenhouse gas emissions scenarios

The Research Centre for Atmospheric Physics and Climatology of the Academy of Athens (RCAPC) has developed model simulation datasets for Greenhouse Gas Emission Scenarios A2, A1B, B2 and B1. Table 1.6 summarises the characteristics of each scenario, as developed

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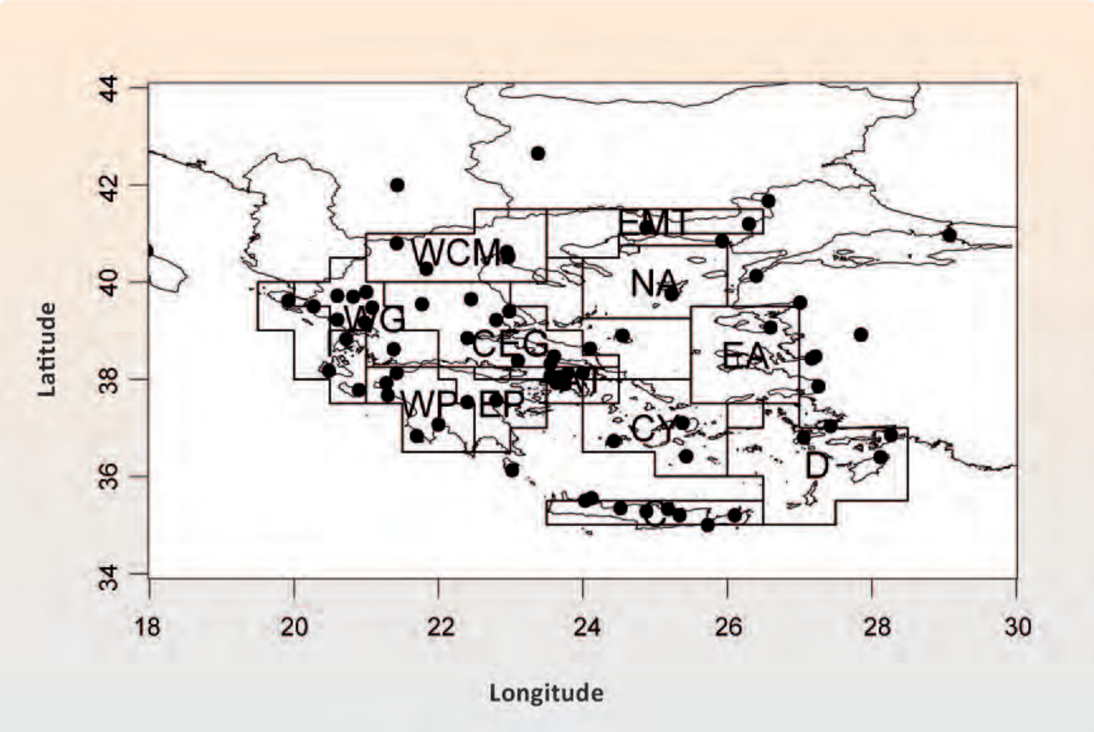
[22] As translated by R.G. Bury (Plato in Twelve Volumes, Vols. 10 & 11, Cambridge, MA, Harvard University Press; London, William Heinemann Ltd. 1967 & 1968).

[23] As translated by H. Rackham (Aristotle in 23 Volumes, Vol. 21, Cambridge, MA, Harvard University Press; London, William Heinemann Ltd. 1944).

Figure 1.24 The division of Greece into 13 climate zones



For an explanation of the initials denoting each zone, see Section 1.15.1.

Table 1.6 Greenhouse gas emission scenarios used in the present study*

Scenario A2	Moderate increase in global average per capita income. Particularly strong energy consumption. Rapid rise in global population. Slow and fragmented technological change, and modest to major changes in land uses. **Rapid** rise in CO2 concentration in the atmosphere, to **850 ppm** by 2100.
Scenario A1B	Rapid economic growth. Particularly strong consumption of energy, but also spread of new and efficient technologies. Use of both fossil fuels and alternative energy sources. Small changes in land uses. Rapid rise in global population by 2050 and gradual decline thereafter. **Large** increase in CO_2 concentration in the atmosphere, to **720 ppm** by 2100.
Scenario B2	Development of global economy at modest rates. Smaller technological change compared to Scenarios A1 and B1. Rapid rise in global population. Increase in CO_2 concentration in the atmosphere **at modest but steady rates**, to **620 ppm** by 2100.
Scenario B1	Large increase in global per capita income. Low energy consumption. Reduced use of conventional energy sources and shift towards renewable energy. Rapid rise in global population by 2050 and gradual decrease thereafter. Increase in CO_2 concentration in the atmosphere at a relatively **mild pace**, particularly as of 2050, to **550 ppm** by 2100.

* IPCC, 2007. More detailed information on the emission scenarios can also be found in the complete text on climate, in the relevant page of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr).

in the context of the United Nations IPCC Third Assessment Report on Climate Change (Nakićenović et al., 2000).

For each of the respective 13 climate zones and for the country as a whole, we estimated the anticipated variation (based on the simulations) in the seasonal mean and the annual mean values of six climate parameters for two different periods 2021-2050 and 2071-2100, for comparison with the reference period 1961-1990. The six climate parameters are:

- mean air temperature (ºC);
- precipitation (mm/year);
- relative humidity (%);
- cloud cover (%);
- total incident short-wave radiation (W/m^2); and
- wind speed at 10 m above ground (m/sec).

It should be noted that we were able to estimate the variation in all six climate parameters only under three of the four scenarios (specifically under Scenarios A2, B2 and A1B). Under Scenario B1, it was only possible to estimate the variation in mean air temperature, due to the lack of available data from high spatial resolution simulations based on Regional Climate Model simulations (RCMs).

More specifically, the variation in the six climate parameters under Scenarios A2 and B2 was assessed by analysing the results of an array of simulations with the regional climate models (RCMs) developed under the EU-financed project, PRUDENCE.[24] A recent study (Zanis et al., 2009) presented the detailed results for Greece of nine RCMs from the PRUDENCE project, as well as the projections of these models for the period 2071-2100 using Scenario A2.

Datasets from 13 simulations were used for Scenario A2, and from 8 simulations for Scenario B2. In both cases, the estimates cover 30-year time-slices for the reference climate (1961-1990) and for a future period (2071-2100). The horizontal resolution of the RCMs used in the PRUDENCE project was 0.5°x0.5° (~50 km^2). In the case of Scenario A1B: the assessment of climate variation was based on 12 simulations, conducted as part of the ENSEMBLES project.[25] The climate datasets cover 30-year time-slices for the reference climate (1961-1990) and for two future periods, 2021-2050 and 2071-2100. The horizontal resolution of the RCMs used in the ENSEMBLES project was 0.25°x0.25° (~25 km^2). Lastly, in the case of Scenario B1, the variation in mean air temperature was estimated by statistically downscaling the mean values obtained with a set of 10 simulations with Atmosphere-Ocean General Circulation Models (AOGCMs) conducted for the United Nations IPCC Fourth Assessment Report on Climate Change (AR4). The variation of the climate parameters for Scenarios A2, A1B and B2 are based on the ‘ensemble mean’ of the 13, 12 and 8 simulations, respectively. Detailed information on the simulations used in the different scenarios and on the methodology used to estimate the vari-

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[24] http://prudence.dmi.dk/

[25] http://ensemblesrt3.dmi.dk/

Table 1.7.1.a

Mean values of air temperature at 2 m above ground (T, °C), for time periods 1961-1990*, 2071-2080, 2081-2090 and 2091-2100, as well as absolute (Δ) and percentage (%) changes in these values between the periods 2071-2080, 2081-2090, 2091-2100 and the reference period 1961-1990

		T (°C)		ΔT		(%)	
Climate zones	**Periods**	**A2**	**B2**	**A2**	**B2**	**A2**	**B2**
Western and Central Macedonia	1961-1990	11.85±1.13	11.91±0.95				
	2071-2080	15.85±1.50	14.89±1.14	4.00±1.05	2.98±0.41	34.1±10.0	25.1±3.4
	2081-2090	16.40±1.54	15.11±1.23	4.56±1.07	3.20±0.51	38.8±10.3	26.9±4.0
	2091-2100	17.08±1.56	15.31±1.26	5.24±1.02	3.40±0.58	44.6±9.8	28.6±4.7
Eastern Macedonia and Thrace	1961-1990	12.24±1.39	12.36±1.06				
	2071-2080	16.29±1.74	15.42±1.15	4.05±1.06	3.05±0.41	33.5±9.8	24.8±4.0
	2081-2090	16.84±1.80	15.63±1.29	4.60±1.11	3.27±0.56	38.0±10.3	26.5±4.7
	2091-2100	17.52±1.81	15.79±1.26	5.28±1.08	3.42±0.62	43.6±10.1	27.8±5.6
Northern Aegean	1961-1990	16.37±0.65	16.19±0.66				
	2071-2080	19.63±0.76	18.82±0.73	3.26±0.19	2.63±0.11	19.9±1.0	16.3±0.7
	2081-2090	19.85±0.63	18.87±0.54	3.48±0.22	2.68±0.23	21.3±1.8	16.6±2.0
	2091-2100	20.56±0.69	19.23±0.65	4.19±0.25	3.04±0.31	25.6±1.9	18.8±2.2
Cyclades	1961-1990	17.98±0.35	17.94±0.36				
	2071-2080	20.97±0.44	20.43±0.41	3.00±0.18	2.49±0.13	16.7±1.0	13.9±0.7
	2081-2090	21.20±0.40	20.49±0.42	3.22±0.26	2.55±0.27	17.9±1.6	14.2±1.6
	2091-2100	21.91±0.45	20.86±0.36	3.93±0.33	2.92±0.34	21.9±2.0	16.3±2.1
Eastern Aegean	1961-1990	16.76±0.81	16.79±0.56				
	2071-2080	20.18±0.92	19.45±0.61	3.42±0.48	2.67±0.09	20.4±3.1	15.9±0.6
	2081-2090	20.46±0.92	19.54±0.59	3.70±0.55	2.75±0.29	22.1±3.6	16.4±1.9
	2091-2100	21.15±0.89	19.86±0.61	4.39±0.42	3.07±0.31	26.3±2.9	18.3±2.1
Dodecanese	1961-1990	18.62±0.41	18.57±0.38				
	2071-2080	21.75±0.52	21.13±0.46	3.12±0.20	2.56±0.17	16.8±1.0	13.8±0.9
	2081-2090	21.99±0.46	21.24±0.45	3.37±0.24	2.67±0.24	18.1±1.4	14.4±1.4
	2091-2100	22.65±0.57	21.57±0.57	4.03±0.34	3.00±0.40	21.6±1.8	16.2±2.2
Crete	1961-1990	17.50±0.62	17.53±0.54				
	2071-2080	20.81±0.96	20.03±0.65	3.31±0.92	2.50±0.18	19.0±5.7	14.3±0.8
	2081-2090	21.13±1.00	20.16±0.67	3.63±0.98	2.63±0.29	20.8±6.1	15.0±1.6
	2091-2100	21.86±0.86	20.51±0.70	4.36±0.82	2.98±0.32	25.0±5.2	17.0±1.8
Central and Eastern Greece	1961-1990	15.02±0.95	14.96±0.96				
	2071-2080	18.81±1.18	17.77±1.07	3.79±1.02	2.81±0.29	25.5±8.1	18.8±2.0
	2081-2090	19.26±1.25	17.97±1.21	4.24±1.09	3.01±0.45	28.5±8.6	20.1±2.8
	2091-2100	19.90±1.22	18.21±1.22	4.88±0.97	3.25±0.50	32.7±7.7	21.8±3.2
Attica	1961-1990	15.94±0.98	15.94±0.95				
	2071-2080	19.83±1.49	18.78±1.00	3.89±1.35	2.84±0.27	24.6±9.5	17.9±2.0
	2081-2090	20.29±1.55	19.02±1.15	4.35±1.42	3.08±0.46	27.5±10.0	19.3±2.9
	2091-2100	20.94±1.47	19.25±1.13	5.00±1.28	3.31±0.50	31.6±9.1	20.8±3.4
Eastern Peloponnese	1961-1990	15.41±0.85	15.36±0.75				
	2071-2080	19.17±1.26	18.11±0.94	3.76±1.14	2.75±0.29	24.6±8.4	17.9±1.6
	2081-2090	19.64±1.28	18.33±1.04	4.23±1.15	2.97±0.45	27.6±8.5	19.3±2.6
	2091-2100	20.31±1.24	18.59±1.04	4.91±1.05	3.22±0.45	32.0±7.7	21.0±2.6
Western Greece	1961-1990	12.94±1.52	13.10±1.16				
	2071-2080	16.92±1.76	16.06±1.39	3.98±1.07	2.96±0.45	31.3±10.2	22.7±3.3
	2081-2090	17.52±1.82	16.30±1.48	4.58±1.06	3.21±0.56	35.9±10.1	24.5±3.9
	2091-2100	18.24±1.87	16.54±1.53	5.30±1.01	3.45±0.65	41.4±9.6	26.4±4.7
Ionian	1961-1990	17.11±0.73	17.10±0.58				
	2071-2080	20.24±0.81	19.61±0.71	3.13±0.35	2.50±0.38	18.3±2.2	14.7±2.3
	2081-2090	20.51±0.80	19.72±0.66	3.40±0.41	2.62±0.50	19.9±2.6	15.3±3.1
	2091-2100	21.29±0.83	20.13±0.64	4.18±0.41	3.03±0.47	24.5±2.6	17.7±2.9
Western Peloponnese	1961-1990	15.69±1.14	15.81±0.77				
	2071-2080	19.26±1.40	18.53±0.96	3.57±0.60	2.72±0.34	22.8±3.8	17.2±1.9
	2081-2090	19.72±1.42	18.74±0.99	4.03±0.61	2.93±0.45	25.8±3.8	18.5±2.7
	2091-2100	20.44±1.42	19.03±0.99	4.75±0.55	3.22±0.51	30.4±3.4	20.4±3.2
Greece	1961-1990	16.17±0.68	16.14±0.56				
	2071-2080	19.58±0.80	18.81±0.67	3.41±0.42	2.66±0.19	21.1±2.8	16.5±1.0
	2081-2090	19.93±0.82	18.94±0.71	3.76±0.49	2.80±0.34	23.3±3.2	17.3±2.1
	2091-2100	20.64±0.80	19.25±0.72	4.46±0.38	3.11±0.39	27.6±2.6	19.3±2.5

Results are given as the mean value and standard deviation of 13 simulations for Scenario A2 and of 8 simulations for Scenario B2, respectively, and are based on the PRUDENCE project.
* The small differences in estimates of climate parameters in the reference period 1961-1990 for the different emission scenarios are due to the fact that climate parameters are estimated on the basis of different sets of climate simulations for the different scenarios.

Table 1.7.1.b

Mean values of rainfall (R, mm/year), for time periods 1961-1990*, 2071-2080, 2081-2090 and 2091-2100, as well as changes in these values between the periods 2071-2080, 2081-2090, 2091-2100 and the reference period 1961-1990

Climate zones	Periods	R (mm/year)		ΔR		(%)	
		A2	B2	A2	B2	A2	B2
Western and Central Macedonia	1961-1990	532.6±108.7	561.3±101.3				
	2071-2080	475.3±130.8	530.6±124.5	-57.3±51.2	-30.7±67.8	-11.4±10.2	-5.4±12.4
	2081-2090	422.9±103.0	521.4±110.3	-109.6±39.7	-39.9±50.7	-20.9±7.2	-7.1±9.8
	2091-2100	444.0±116.5	555.8±144.8	-88.5±53.5	-5.5±72.6	-17.1±10.1	-1.5±13.0
Eastern Macedonia and Thrace	1961-1990	608.3±132.4	663.6±115.4				
	2071-2080	526.8±131.1	625.6±137.2	-81.5±56.6	-38.0±92.3	-13.4±8.6	-5.3±14.4
	2081-2090	465.1±102.8	599.9±116.7	-143.2±64.0	-63.7±64.7	-23.3±8.5	-9.3±9.9
	2091-2100	487.6±126.1	652.1±159.1	-120.7±57.5	-11.5±93.8	-20.1±8.6	-1.8±14.6
Northern Aegean	1961-1990	481.8±104.4	500.7±118.7				
	2071-2080	445.5±124.8	496.1±135.5	-36.3±60.7	-4.6±84.2	-8.3±13.4	-0.4±17.1
	2081-2090	397.4±105.3	470.7±117.8	-84.4±56.8	-30.0±50.5	-17.8±10.9	-5.7±11.4
	2091-2100	451.3±134.9	532.2±151.6	-30.6±87.3	31.5±80.2	-6.9±18.1	6.2±16.3
Cyclades	1961-1990	400.6±106.0	411.7±125.2				
	2071-2080	334.3±89.6	400.6±110.1	-66.3±32.3	-11.1±27.6	-16.4±5.5	-1.7±6.1
	2081-2090	313.4±95.8	379.4±122.2	-87.3±27.0	-32.3±36.5	-22.4±6.3	-8.0±12.1
	2091-2100	361.9±106.7	436.8±138.1	-38.7±36.9	25.1±36.9	-10.3±10.1	5.6±11.1
Eastern Aegean	1961-1990	544.1±127.2	546.9±133.6				
	2071-2080	479.2±133.6	526.0±129.3	-65.0±43.4	-20.9±60.3	-12.4±8.0	-3.4±11.1
	2081-2090	431.6±125.5	500.5±127.6	-112.5±38.6	-46.4±33.7	-21.4±7.2	-8.5±6.8
	2091-2100	485.1±149.5	582.6±160.7	-59.0±63.9	35.7±65.3	-11.5±11.1	6.3±12.7
Dodecanese	1961-1990	433.2±160.8	428.4±188.0				
	2071-2080	369.7±130.7	416.8±183.1	-63.5±40.5	-11.6±37.2	-13.6±6.0	-2.7±7.8
	2081-2090	340.3±133.1	401.2±174.9	-92.9±40.8	-27.2±22.2	-22.0±5.5	-6.4±4.8
	2091-2100	376.7±152.9	450.0±207.3	-56.5±49.5	21.6±65.6	-14.8±12.3	3.8±15.3
Crete	1961-1990	351.6±187.2	315.5±144.4				
	2071-2080	280.3±151.4	287.5±127.9	-71.3±47.0	-28.1±29.8	-18.9±7.6	-7.4±9.1
	2081-2090	264.9±151.4	268.1±115.2	-86.6±47.5	-47.5±36.3	-24.7±8.1	-14.1±7.2
	2091-2100	300.2±179.6	297.9±130.9	-51.4±50.6	-17.6±34.1	-15.6±12.2	-5.1±10.1
Central and Eastern Greece	1961-1990	473.5±102.5	490.6±100.1				
	2071-2080	408.2±125.4	461.3±110.0	-65.2±43.3	-29.4±39.1	-14.8±9.3	-6.1±8.3
	2081-2090	378.3±103.6	449.3±114.3	-95.2±40.3	-41.3±45.8	-20.6±8.3	-8.8±10.7
	2091-2100	420.8±133.5	483.6±132.2	-52.6±72.6	-7.0±51.6	-11.9±15.4	-2.2±10.2
Attica	1961-1990	375.1±108.6	388.2±84.2				
	2071-2080	311.6±121.9	363.6±97.3	-63.5±36.7	-24.5±27.8	-18.1±9.1	-6.8±7.2
	2081-2090	293.9±107.7	342.8±100.0	-81.2±39.8	-45.3±41.3	-22.6±11.0	-12.3±11.9
	2091-2100	333.7±139.0	381.1±108.8	-41.4±60.2	-7.1±37.6	-12.7±15.8	-2.6±8.9
Eastern Peloponnese	1961-1990	479.9±166.6	517.4±171.5				
	2071-2080	395.4±164.1	469.4±176.7	-84.5±41.4	-48±33.9	-18.7±8.1	-9.8±7.2
	2081-2090	352.2±134.5	440.4±149.2	-127.8±53.6	-77±49.8	-27.2±7.6	-14.8±8.9
	2091-2100	392.0±166.7	483.4±177.0	-87.9±70.1	-34±32.2	-19.1±13.7	-7.1±7.4
Western Greece	1961-1990	861.1±174.2	912.4±102.0				
	2071-2080	744.0±187.8	842.2±148.0	-117.1±86.3	-70.2±126.1	-13.8±8.9	-7.5±13.8
	2081-2090	641.0±139.1	804.8±97.0	-220.1±85.0	-107.6±92.2	-25.3±8.1	-11.4±9.7
	2091-2100	654.0±164.6	842.5±165.8	-207.1±94.4	-69.9±116.8	-23.8±10.0	-7.8±12.5
Ionian	1961-1990	789.6±225.4	775.7±242.9				
	2071-2080	725.6±241.4	740.8±242.7	-64.0±83.1	-35.0±97.3	-9.2±11.5	-4.2±11.7
	2081-2090	598.6±195.9	711.3±233.0	-191±75.7	-64.5±69.7	-25.0±7.7	-8.4±9.0
	2091-2100	652.4±225.2	767.1±287.0	-137.3±89.9	-8.6±67.7	-18.6±11.9	-2.9±10.3
Western Peloponnese	1961-1990	613.5±159.6	629.4±120.8				
	2071-2080	510.2±164.9	568.6±112.4	-103.2±49.2	-60.8±66.0	-17.6±8.3	-9.4±9.9
	2081-2090	442±131.6	540.0±114.7	-171.4±52.6	-89.4±47.4	-28.4±6.4	-14.4±8.1
	2091-2100	475.6±175.7	584.5±146.0	-137.9±73.9	-44.9±46.9	-23.5±11.9	-7.9±9.0
Greece	1961-1990	510.1±108.0	524.1±113.8				
	2071-2080	442.7±112.9	497.4±108.6	-67.4±34.6	-26.7±50.2	-13.8±7.6	-4.6±9.8
	2081-2090	397.1±99.6	475.7±109.0	-113.0±29.5	-48.4±36.4	-22.6±5.5	-9.2±8.2
	2091-2100	437.7±126.6	525.2±138.0	-72.4±51.1	1.1±54.5	-15.2±10.9	-0.4±11.2

Results are given as the mean value and standard deviation of 13 simulations for Scenario A2 and of 8 simulations for Scenario B2, respectively, and are based on the PRUDENCE project.

* The small differences in estimates of climate parameters in the reference period 1961-1990 for the different emission scenarios are due to the fact that climate parameters are estimated on the basis of different sets of climate simulations for the different scenarios.

Table 1.7.1.c

Mean values of relative humidity (H, %) at 2 m above ground for time periods 1961-1990*, 2071-2080, 2081-2090 and 2091-2100, as well as changes in these values between the periods 2071-2080, 2081-2090, 2091-2100 and the reference period 1961-1990

Climate zones	Periods	H		ΔH		(%)	
		A2	B2	A2	B2	A2	B2
Western and Central Macedonia	1961-1990	61.58±9.41	61.82±11.51				
	2071-2080	57.27±7.22	59.83±12.43	-4.31±5.12	-1.99±2.85	-6.5±6.2	-3.4±4.2
	2081-2090	55.11±6.83	59.14±12.47	-6.46±4.80	-2.68±2.73	-10.0±5.5	-4.6±4.0
	2091-2100	54.73±6.90	60.2±12.23	-6.84±4.88	-1.62±2.44	-10.7±5.6	-2.8±3.6
Eastern Macedonia and Thrace	1961-1990	60.25±9.79	60.32±11.43				
	2071-2080	55.61±7.52	58.07±11.70	-4.64±5.12	-2.25±2.80	-7.2±6.3	-3.8±4.3
	2081-2090	53.59±6.99	57.12±12.28	-6.66±5.21	-3.21±2.92	-10.5±6.2	-5.6±4.3
	2091-2100	52.83±7.03	58.45±11.97	-7.42±5.21	-1.87±2.71	-11.8±6.0	-3.2±4.2
Northern Aegean	1961-1990	71.35±4.95	73.52±4.68				
	2071-2080	69.91±4.65	72.39±4.99	-1.44±0.96	-1.13±0.75	-2.0±1.3	-1.6±1.1
	2081-2090	69.34±4.87	72.38±4.82	-2.00±1.09	-1.14±0.51	-2.8±1.5	-1.6±0.7
	2091-2100	68.94±4.97	72.73±4.68	-2.41±0.86	-0.79±0.69	-3.4±1.2	-1.1±1.0
Cyclades	1961-1990	73.78±3.70	75.21±3.40				
	2071-2080	73.22±3.52	74.54±3.57	-0.56±0.48	-0.67±0.38	-0.7±0.6	-0.9±0.5
	2081-2090	73.02±3.57	74.60±3.26	-0.76±0.56	-0.60±0.30	-1.0±0.7	-0.8±0.4
	2091-2100	72.83±3.70	74.87±3.34	-0.95±0.57	-0.34±0.22	-1.3±0.7	-0.5±0.3
Eastern Aegean	1961-1990	68.92±5.16	69.97±5.22				
	2071-2080	66.74±4.68	68.86±5.43	-2.18±2.48	-1.11±0.64	-3.1±3.2	-1.6±1.0
	2081-2090	66.03±4.88	68.72±5.73	-2.89±2.57	-1.25±0.58	-4.1±3.3	-1.8±1.0
	2091-2100	65.70±4.94	69.39±5.43	-3.22±2.33	-0.58±0.73	-4.6±3.0	-0.8±1.1
Dodecanese	1961-1990	72.44±3.94	74.04±3.14				
	2071-2080	71.87±3.95	73.70±2.91	-0.57±0.74	-0.34±0.80	-0.8±1.1	-0.4±1.1
	2081-2090	71.61±3.92	73.62±3.02	-0.83±0.92	-0.42±0.70	-1.1±1.3	-0.6±1.0
	2091-2100	71.48±4.23	73.97±3.03	-0.95±0.86	-0.06±0.50	-1.3±1.2	-0.1±0.7
Crete	1961-1990	69.38±6.41	68.66±7.71				
	2071-2080	67.66±6.82	67.71±7.68	-1.72±4.10	-0.94±1.18	-2.4±5.4	-1.4±1.6
	2081-2090	67.15±6.97	67.42±7.75	-2.23±4.28	-1.24±0.94	-3.1±5.6	-1.8±1.3
	2091-2100	67.08±6.88	67.97±7.83	-2.30±4.15	-0.69±0.83	-3.3±5.5	-1.0±1.2
Central and Eastern Greece	1961-1990	62.16±6.57	62.52±7.93				
	2071-2080	58.57±4.86	61.03±8.36	-3.59±4.65	-1.49±1.57	-5.4±6.0	-2.5±2.4
	2081-2090	57.04±4.69	60.37±8.36	-5.11±4.33	-2.15±1.43	-7.9±5.3	-3.5±2.2
	2091-2100	57.11±4.78	61.29±8.16	-5.04±4.52	-1.23±1.20	-7.8±5.7	-2.0±1.9
Attica	1961-1990	59.17±8.85	58.29±10.00				
	2071-2080	55.10±8.19	56.41±9.66	-4.07±5.59	-1.89±1.65	-6.5±7.7	-3.2±2.5
	2081-2090	53.73±8.12	55.36±9.54	-5.44±5.36	-2.94±1.73	-8.9±7.2	-5.0±2.7
	2091-2100	53.90±8.42	56.62±9.59	-5.27±5.53	-1.68±1.25	-8.7±7.5	-2.8±2.0
Eastern Peloponnese	1961-1990	61.53±7.24	61.65±8.00				
	2071-2080	57.87±6.24	60.12±8.06	-3.66±4.96	-1.53±0.99	-5.6±6.6	-2.5±1.7
	2081-2090	56.35±6.13	59.26±8.36	-5.18±4.59	-2.40±1.29	-8.1±5.9	-4.0±2.2
	2091-2100	56.41±6.21	60.35±8.19	-5.12±4.86	-1.30±1.23	-8.0±6.4	-2.1±2.0
Western Greece	1961-1990	63.13±10.03	62.86±12.61				
	2071-2080	58.67±8.24	60.58±13.20	-4.46±5.29	-2.28±2.83	-6.6±6.5	-3.8±4.2
	2081-2090	56.37±7.89	60.00±13.50	-6.76±4.84	-2.86±2.90	-10.3±5.5	-4.8±4.1
	2091-2100	55.71±7.84	60.61±13.11	-7.42±4.91	-2.25±2.54	-11.4±5.7	-3.7±3.7
Ionian	1961-1990	72.07±4.83	73.67±4.18				
	2071-2080	71.77±4.20	73.40±2.84	-0.29±1.86	-0.27±1.55	-0.3±2.8	-0.3±2.4
	2081-2090	71.17±4.67	73.53±2.91	-0.90±1.90	-0.14±1.47	-1.2±2.8	-0.1±2.2
	2091-2100	70.67±5.08	73.39±2.47	-1.39±1.97	-0.27±1.96	-1.9±2.9	-0.2±3.0
Western Peloponnese	1961-1990	64.82±6.05	65.35±7.49				
	2071-2080	62.03±4.72	63.81±7.88	-2.79±3.10	-1.54±1.35	-4.1±4.0	-2.4±2.1
	2081-2090	60.51±4.81	63.22±8.09	-4.31±2.88	-2.13±1.63	-6.5±3.7	-3.4±2.6
	2091-2100	60.31±4.68	63.90±7.75	-4.51±3.02	-1.44±1.40	-6.8±3.9	-2.2±2.2
Greece	1961-1990	68.47±4.27	69.49±4.63				
	2071-2080	66.45±2.99	68.42±5.02	-2.02±2.28	-1.07±0.79	-2.8±2.9	-1.6±1.2
	2081-2090	65.50±3.04	68.14±5.03	-2.97±2.20	-1.35±0.72	-4.2±2.7	-2.0±1.0
	2091-2100	65.23±2.99	68.68±4.80	-3.24±2.09	-0.81±0.76	-4.6±2.6	-1.2±1.1

Results are given as the mean value and standard deviation of 13 simulations for Scenario A2 and of 8 simulations for Scenario B2. and are based on the PRUDENCE project.
* The small differences in estimates of climate parameters in the reference period 1961-1990 for the different emission scenarios are due to the fact that climate parameters are estimated on the basis of different sets of climate simulations for the different scenarios.

Table 1.7.2.a

Total incident short-wave radiation (S, W/m²), for time periods 1961-1990*, 2071-2080, 2081-2090 and 2091-2100, as well as changes in these values between the periods 2071-2080, 2081-2090, 2091-2100 and the reference period 1961-1990

Climate zones	Periods	S		ΔS		(%)	
		A2	B2	A2	B2	A2	B2
Western and Central Macedonia	1961-1990	183.4±19.4	188.4±21.4				
	2071-2080	186.7±17.9	192.1±17.7	3.2±4.9	3.7±5.6	1.9±3.2	2.3±3.7
	2081-2090	189.4±17.3	193.2±17.3	6.0±5.6	4.8±5.5	3.5±3.9	2.9±3.8
	2091-2100	189.7±18.0	191.6±17.2	6.3±6.6	3.2±6.3	3.6±4.4	2.0±4.1
Eastern Macedonia and Thrace	1961-1990	181.3±18.8	185.4±20.7				
	2071-2080	185.0±17.2	189.4±16.6	3.7±4.7	4±5.7	2.2±3.2	2.4±3.8
	2081-2090	187.6±16.7	190.6±16.7	6.3±5.6	5.2±5.3	3.7±3.9	3.1±3.7
	2091-2100	187.8±17.0	188.8±16.6	6.5±6.6	3.4±5.9	3.8±4.5	2.2±3.9
Northern Aegean	1961-1990	192.3±20.9	199.3±22.3				
	2071-2080	194.6±20.2	202.3±18.5	2.3±4.2	3.0±5.5	1.3±2.5	1.8±3.4
	2081-2090	196.1±19.8	203.1±18.4	3.8±4.9	3.8±5.3	2.1±3.1	2.2±3.3
	2091-2100	195.8±20.4	201.3±18.1	3.5±5.4	2.1±6.0	1.9±3.3	1.3±3.6
Cyclades	1961-1990	204.1±22.4	212.7±22.6				
	2071-2080	206.5±21.6	214.9±18.7	2.4±3.9	2.2±5.4	1.2±2.2	1.3±3.1
	2081-2090	208.0±21.2	216.3±19.2	3.8±5.0	3.7±4.9	2.0±2.9	1.9±2.9
	2091-2100	207.0±21.6	214.2±18.8	2.8±4.7	1.5±5.5	1.5±2.7	0.9±3.1
Eastern Aegean	1961-1990	200.6±21.6	207.7±21.8				
	2071-2080	203.3±20.8	210.5±17.9	2.7±4.1	2.8±5.4	1.4±2.4	1.6±3.1
	2081-2090	205.0±20.4	211.5±18.5	4.4±4.8	3.8±4.6	2.3±2.9	2±2.8
	2091-2100	204.6±20.8	209.6±18.0	4.0±5.4	1.9±5.4	2.1±3.2	1.1±3
Dodecanese	1961-1990	209.9±22.5	218.8±22.2				
	2071-2080	212.2±21.6	220.6±18.8	2.3±4	1.8±4.4	1.2±2.2	1.0±2.3
	2081-2090	213.6±21.4	221.5±19.4	3.7±4.9	2.7±4.1	1.9±2.7	1.4±2.2
	2091-2100	213.1±21.4	219.8±19.5	3.1±5.1	1.0±3.8	1.6±2.8	0.6±2.0
Crete	1961-1990	207.7±23.0	215.2±25.4				
	2071-2080	210.7±21.7	217.5±21.5	3.0±4.1	2.3±4.7	1.5±2.4	1.3±2.7
	2081-2090	212.2±21.4	219.0±21.5	4.5±4.9	3.8±5.0	2.3±2.9	2.0±3.0
	2091-2100	210.9±21.7	216.9±21.9	3.2±4.7	1.7±4.4	1.6±2.8	1.0±2.5
Central and Eastern Greece	1961-1990	192.5±20.6	199.1±21.2				
	2071-2080	195.7±19.9	202.2±17.6	3.3±4.2	3.1±5.3	1.8±2.6	1.8±3.3
	2081-2090	197.6±19.5	203.6±17.4	5.2±5.1	4.5±4.9	2.8±3.2	2.5±3.1
	2091-2100	197.1±20.4	201.6±17.3	4.7±5.4	2.5±5.5	2.5±3.3	1.5±3.4
Attica	1961-1990	198.3±21.8	205.6±21.2				
	2071-2080	201.7±21.3	208.5±17.7	3.4±3.8	2.9±5.1	1.8±2.3	1.6±3
	2081-2090	203.2±21.2	210.1±17.8	4.8±4.8	4.5±4.4	2.5±2.9	2.4±2.7
	2091-2100	202.3±21.9	208.0±17.2	4.0±4.9	2.3±5.3	2.1±2.9	1.4±3.1
Eastern Peloponnese	1961-1990	198.0±20.5	204.4±20.8				
	2071-2080	202.0±19.8	207.9±17.4	4.0±4.0	3.5±5.2	2.1±2.4	1.9±3.1
	2081-2090	204.1±19.8	209.3±17.9	6.0±4.9	5.0±4.0	3.1±3.0	2.6±2.5
	2091-2100	203.3±20.2	207.1±17.7	5.3±5.3	2.7±4.7	2.7±3.1	1.5±2.7
Western Greece	1961-1990	182.9±20.6	186.7±22.6				
	2071-2080	187.4±19.1	191.3±18.5	4.4±4.7	4.6±6.3	2.6±3.2	2.8±4.1
	2081-2090	190.7±18.5	193.0±18.5	7.8±5.6	6.3±5.4	4.5±4.0	3.7±3.9
	2091-2100	191.7±18.5	191.2±19.1	8.8±7.2	4.5±5.4	5.1±5.0	2.7±3.5
Ionian	1961-1990	188.8±19.6	195.0±22.0				
	2071-2080	191.7±19.2	198.9±18.6	2.9±4.4	3.9±5.7	1.6±2.7	2.3±3.6
	2081-2090	194.5±19.0	200.0±18.8	5.6±4.8	5.0±5.0	3.1±3.1	2.8±3.3
	2091-2100	194.7±18.8	198.1±18.8	5.9±6.3	3.1±5.4	3.3±4.0	1.8±3.3
Western Peloponnese	1961-1990	195.4±19.7	200.5±21.8				
	2071-2080	199.2±18.5	204.4±17.9	3.8±4.6	3.9±5.8	2.1±2.9	2.2±3.5
	2081-2090	201.9±18.5	205.8±18.5	6.6±5.4	5.3±4.6	3.5±3.4	2.8±2.9
	2091-2100	201.7±18.5	203.8±18.8	6.3±6.5	3.3±5.0	3.4±4.0	1.9±3.0
Greece	1961-1990	196.1±20.8	203.0±21.9				
	2071-2080	199.0±19.9	206.0±18.3	2.9±4.2	3.0±5.3	1.6±2.5	1.7±3.2
	2081-2090	201.0±19.6	207.2±18.5	4.9±4.9	4.2±4.8	2.6±3.1	2.3±3.0
	2091-2100	200.5±20.0	205.2±18.4	4.5±5.4	2.3±5.2	2.4±3.3	1.4±3.1

All observations made in the respective position of Table 1.7.1.a, b and c also apply here.

Table 1.7.2.b

Wind velocity (V, m/s) for time periods 1961-1990*, 2071-2080, 2081-2090 and 2091-2100, as well as changes in these values between the periods 2071-2080, 2081-2090, 2091-2100 and the reference period 1961-1990

Climate zones	Periods	V		ΔV		(%)	
		A2	B2	A2	B2	A2	B2
Western and Central Macedonia	1961-1990	2.53±0.88	2.71±1.00				
	2071-2080	2.42±0.79	2.66±0.91	-0.10±0.11	-0.04±0.13	-3.4±3.0	-0.9±4.2
	2081-2090	2.44±0.83	2.64±0.90	-0.08±0.09	-0.07±0.14	-3.1±2.8	-1.8±4.6
	2091-2100	2.45±0.83	2.65±0.94	-0.08±0.09	-0.05±0.11	-2.9±2.8	-1.6±4.2
Eastern Macedonia and Thrace	1961-1990	2.80±0.72	2.89±0.87				
	2071-2080	2.77±0.70	2.97±0.83	-0.03±0.05	0.08±0.15	-1.0±1.6	3.4±6.8
	2081-2090	2.82±0.75	2.95±0.83	0.02±0.06	0.07±0.16	0.6±2.1	3.0±7.2
	2091-2100	2.85±0.78	2.95±0.87	0.05±0.10	0.07±0.15	1.7±3.0	2.8±6.9
Northern Aegean	1961-1990	5.59±0.65	5.60±0.72				
	2071-2080	5.55±0.62	5.60±0.64	-0.04±0.12	0.01±0.22	-0.6±2.0	0.3±4.0
	2081-2090	5.62±0.65	5.56±0.67	0.03±0.10	-0.03±0.16	0.6±1.7	-0.5±3.1
	2091-2100	5.68±0.68	5.65±0.69	0.09±0.17	0.05±0.16	1.6±3.0	1.0±3.0
Cyclades	1961-1990	6.64±0.92	6.67±0.81				
	2071-2080	6.73±0.94	6.74±0.87	0.10±0.12	0.07±0.24	1.5±1.8	1.0±3.7
	2081-2090	6.83±1.00	6.75±0.82	0.20±0.12	0.08±0.20	2.8±1.7	1.2±3.1
	2091-2100	6.87±1.00	6.82±0.82	0.23±0.17	0.16±0.11	3.4±2.3	2.4±1.7
Eastern Aegean	1961-1990	5.56±0.80	5.64±0.93				
	2071-2080	5.62±0.71	5.74±0.82	0.07±0.11	0.10±0.14	1.4±1.9	2.1±2.4
	2081-2090	5.71±0.76	5.76±0.82	0.15±0.10	0.12±0.16	2.9±1.9	2.4±3.0
	2091-2100	5.75±0.75	5.82±0.81	0.19±0.12	0.19±0.18	3.7±2.3	3.6±3.5
Dodecanese	1961-1990	5.96±0.85	6.04±0.88				
	2071-2080	5.92±0.84	5.98±0.90	-0.04±0.07	-0.06±0.17	-0.7±1.1	-1.0±2.8
	2081-2090	5.91±0.86	5.99±0.87	-0.06±0.05	-0.05±0.14	-1.0±0.9	-0.9±2.3
	2091-2100	5.92±0.84	6.03±0.85	-0.05±0.12	-0.01±0.13	-0.8±1.9	-0.1±2.2
Crete	1961-1990	4.99±0.84	4.68±1.35				
	2071-2080	4.96±0.72	4.67±1.20	-0.02±0.16	-0.02±0.21	-0.2±2.5	0.3±3.6
	2081-2090	5.00±0.73	4.68±1.20	0.01±0.15	0.00±0.21	0.6±2.5	0.8±3.6
	2091-2100	5.03±0.75	4.71±1.17	0.04±0.17	0.02±0.22	1.1±3.0	1.5±4.4
Central and Eastern Greece	1961-1990	3.22±1.03	3.29±1.17				
	2071-2080	3.17±0.97	3.34±1.10	-0.05±0.08	0.05±0.14	-1.2±1.8	2.4±5.4
	2081-2090	3.22±1.01	3.31±1.07	0.00±0.06	0.01±0.16	0.1±1.7	1.5±6.2
	2091-2100	3.23±1.02	3.34±1.11	0.01±0.08	0.04±0.16	0.3±2.2	2.2±6.6
Attica	1961-1990	3.30±1.18	3.27±1.38				
	2071-2080	3.31±1.19	3.42±1.34	0.01±0.04	0.14±0.20	0.5±1.0	6.1±10.5
	2081-2090	3.38±1.23	3.39±1.31	0.08±0.07	0.12±0.22	2.4±1.5	5.6±11.5
	2091-2100	3.41±1.26	3.43±1.34	0.11±0.10	0.15±0.23	2.9±2.2	6.4±12.5
Eastern Peloponnese	1961-1990	3.42±1.31	3.44±1.55				
	2071-2080	3.35±1.21	3.42±1.39	-0.07±0.17	-0.02±0.21	-1.6±2.9	1.2±6.0
	2081-2090	3.39±1.25	3.40±1.37	-0.03±0.15	-0.04±0.25	-0.6±2.9	0.7±6.8
	2091-2100	3.41±1.27	3.43±1.42	-0.01±0.15	-0.01±0.20	-0.2±3.4	1.0±6.5
Western Greece	1961-1990	2.38±1.05	2.53±1.21				
	2071-2080	2.31±1.02	2.55±1.17	-0.07±0.09	0.02±0.14	-2.7±2.9	1.7±7.3
	2081-2090	2.32±1.04	2.52±1.16	-0.05±0.08	-0.01±0.14	-2.3±2.9	0.8±7.6
	2091-2100	2.32±1.05	2.54±1.18	-0.06±0.10	0.01±0.15	-2.7±3.5	1.2±8.2
Ionian	1961-1990	4.51±0.75	4.63±0.88				
	2071-2080	4.32±0.68	4.45±0.76	-0.20±0.28	-0.18±0.34	-4.2±5.5	-3.5±6.3
	2081-2090	4.29±0.67	4.42±0.80	-0.22±0.24	-0.21±0.31	-4.7±4.5	-4.3±5.6
	2091-2100	4.27±0.69	4.47±0.80	-0.24±0.24	-0.16±0.31	-5.2±4.9	-3.3±6.0
Western Peloponnese	1961-1990	3.62±0.76	3.88±0.74				
	2071-2080	3.52±0.70	3.87±0.67	-0.11±0.12	-0.01±0.20	-2.8±2.8	0.1±5.5
	2081-2090	3.51±0.73	3.84±0.65	-0.12±0.09	-0.03±0.22	-3.1±2.3	-0.4±5.9
	2091-2100	3.51±0.74	3.86±0.69	-0.11±0.11	-0.01±0.21	-3.1±2.8	-0.1±5.7
Greece	1961-1990	4.72±0.66	4.79±0.74				
	2071-2080	4.68±0.60	4.78±0.67	-0.04±0.09	-0.01±0.13	-0.8±1.6	0.1±2.7
	2081-2090	4.72±0.64	4.77±0.66	-0.01±0.07	-0.02±0.11	-0.1±1.2	-0.2±2.3
	2091-2100	4.74±0.65	4.81±0.68	0.01±0.11	0.02±0.11	0.3±2.2	0.7±2.5

All observations made in the respective position of Table 1.7.1.a, b and c also apply here.

Table 1.7.2.c

Cloud cover fraction (C, %) for time periods 1961-1990*, 2071-2080, 2081-2090 and 2091-2100, as well as changes in these values between the periods 2071-2080, 2081-2090, 2091-2100 and the reference period 1961-1990

Climate zones	Periods	C		ΔC		(%)	
		A2	B2	A2	B2	A2	B2
Western and Central Macedonia	1961-1990	41.0±7.7	41.6±5.2				
	2071-2080	37.2±7.4	38.4±6.0	-3.8±1.8	-3.2±1.6	-9.4±4.6	-8.1±4.5
	2081-2090	35.3±6.8	37.8±5.5	-5.7±2.0	-3.8±1.3	-13.9±4.3	-9.3±3.9
	2091-2100	34.5±6.7	38.5±6.3	-6.5±2.4	-3.1±2.0	-15.8±5.2	-7.9±5.5
Eastern Macedonia and Thrace	1961-1990	41.3±7.7	42.0±5.7				
	2071-2080	37.1±7.4	38.6±6.4	-4.2±1.9	-3.3±1.8	-10.1±4.6	-8.2±4.9
	2081-2090	35.3±6.7	37.8±5.8	-6.0±2.2	-4.2±1.3	-14.4±4.5	-10.1±3.6
	2091-2100	34.6±6.5	38.6±6.5	-6.7±2.6	-3.4±2.2	-16.1±5.5	-8.2±5.6
Northern Aegean	1961-1990	36.0±5.5	35.9±3.1				
	2071-2080	32.1±5.6	32.9±4.1	-3.9±1.7	-3.0±1.4	-11.0±4.9	-8.8±4.7
	2081-2090	30.8±5.1	32.3±3.8	-5.2±1.7	-3.6±1.2	-14.7±4.3	-10.3±4.0
	2091-2100	30.4±5.2	33.0±4.3	-5.6±2.0	-2.9±2	-15.6±5.4	-8.3±5.9
Cyclades	1961-1990	32.6±4.3	33.2±3.9				
	2071-2080	28.5±4.4	30.3±4.4	-4.1±1.5	-2.9±1.4	-12.9±4.9	-9.0±4.7
	2081-2090	27.4±4.5	29.5±4.0	-5.2±1.6	-3.6±1	-16.3±5.5	-11.1±3.2
	2091-2100	27.7±4.5	30.6±3.8	-4.9±1.6	-2.5±1.8	-15.3±5.3	-7.6±5.1
Eastern Aegean	1961-1990	33.3±4.3	34.0±2.1				
	2071-2080	29.0±3.9	30.8±3.1	-4.2±1.6	-3.2±1.5	-12.7±4.6	-9.5±4.8
	2081-2090	27.7±3.7	30.3±2.4	-5.6±1.6	-3.8±1.2	-16.9±4.2	-11.2±3.5
	2091-2100	27.5±3.6	31.2±2.9	-5.8±2.0	-2.9±2.1	-17.2±5.0	-8.4±6.1
Dodecanese	1961-1990	29.0±4.8	29.6±4.9				
	2071-2080	25.1±5.1	27.1±4.7	-3.8±1.4	-2.5±1.2	-13.6±5.2	-8.5±4.2
	2081-2090	23.9±5.1	26.4±5.1	-5.1±1.5	-3.3±1.0	-17.9±5.7	-11.3±4.2
	2091-2100	23.9±4.9	27.3±4.8	-5.1±1.5	-2.4±1.5	-18.1±5.7	-8.0±5.3
Crete	1961-1990	31.2±6.1	32.4±6.9				
	2071-2080	27.4±6.1	29.6±6.2	-3.9±1.4	-2.8±1.4	-12.8±4.8	-8.5±4.0
	2081-2090	26.0±6.2	28.9±6.2	-5.2±1.6	-3.5±1.1	-17.1±5.8	-10.7±2.4
	2091-2100	26.6±5.9	30.0±6.2	-4.7±1.3	-2.4±1.2	-15.3±4.6	-7.3±3.3
Central and Eastern Greece	1961-1990	37.2±5.7	37.5±3.6				
	2071-2080	33.1±5.2	34.4±4.4	-4.1±1.6	-3.1±1.4	-11.1±3.9	-8.5±4.2
	2081-2090	31.7±4.8	33.8±3.9	-5.5±1.9	-3.7±0.9	-14.8±4.0	-10.0±2.8
	2091-2100	31.5±4.9	34.7±4.4	-5.7±2.3	-2.9±1.6	-15.3±5.4	-7.8±4.7
Attica	1961-1990	34.2±5.5	34.3±3.8				
	2071-2080	29.8±4.8	31.3±4.4	-4.3±1.5	-3.0±1.4	-12.6±3.8	-9.0±4.3
	2081-2090	28.8±4.8	30.6±3.9	-5.3±1.9	-3.7±0.7	-15.6±4.5	-11.0±2.4
	2091-2100	28.9±5.1	31.6±4.4	-5.2±2.3	-2.7±1.6	-15.3±6.0	-8.0±5.0
Eastern Peloponnese	1961-1990	35.7±5.4	36.5±3.6				
	2071-2080	31.1±4.6	33.1±4.5	-4.6±1.6	-3.5±1.4	-12.8±3.8	-9.7±4.2
	2081-2090	29.7±4.5	32.4±3.6	-6.0±1.9	-4.1±0.7	-16.9±4.2	-11.4±2.3
	2091-2100	29.7±4.5	33.4±4.0	-6.1±2.3	-3.1±1.6	-16.8±5.3	-8.6±4.5
Western Greece	1961-1990	43.6±6.7	45.0±4.8				
	2071-2080	39.1±5.9	41.1±5.4	-4.4±2.1	-3.8±2.0	-10±4.1	-8.7±4.8
	2081-2090	36.9±5.5	40.3±4.5	-6.6±2.1	-4.6±1.4	-15.1±3.5	-10.3±3.0
	2091-2100	35.7±5.2	41.2±5.0	-7.9±2.8	-3.8±2.0	-17.8±4.9	-8.5±4.5
Ionian	1961-1990	38.6±6.0	39.8±4.1				
	2071-2080	34.9±6.4	36.2±4.5	-3.7±2.0	-3.6±1.4	-9.7±5.3	-9.1±4.0
	2081-2090	33.0±6.0	35.8±4.5	-5.6±1.7	-3.9±0.8	-14.7±4.6	-10.1±2.8
	2091-2100	32.1±6.3	36.6±4.8	-6.5±2.1	-3.2±1.6	-17.1±5.8	-8.3±4.5
Western Peloponnese	1961-1990	37.6±5.3	39.7±2.2				
	2071-2080	33.2±4.8	36.0±3.3	-4.4±2.0	-3.8±1.8	-11.6±4.7	-9.6±4.7
	2081-2090	31.3±4.7	35.4±2.5	-6.4±2.1	-4.4±1.2	-16.9±4.7	-11.0±3.0
	2091-2100	30.8±4.5	36.3±3.0	-6.8±2.5	-3.5±1.8	-17.8±5.6	-8.8±4.5
Greece	1961-1990	35.8±4.4	36.4±2.1				
	2071-2080	31.7±4.3	33.3±3.1	-4.0±1.6	-3.1±1.4	-11.3±4.3	-8.8±4.2
	2081-2090	30.2±4.2	32.7±2.6	-5.5±1.7	-3.8±1.0	-15.5±4.3	-10.4±2.9
	2091-2100	30.0±4.1	33.6±3.1	-5.7±1.8	-2.9±1.7	-16.1±4.8	-8.0±4.8

All observations made in the respective position of Table 1.7.1.a, b and c also apply here.

Table 1.8.a

Mean values and standard deviation of air temperature at 2 m above ground (T, ˚C) and rainfall (R, mm/year) from the 12 RCM simulations of the ENSEMBLES project for the thirty-year periods 1961-1990*, 2021-2050 and 2071-2100 (SRES A1B)

Climate zones	Periods	T	ΔT	(%)	R	ΔR	(%)
Western and Central Macedonia	1961-1990	12.33±1.52			658.9±143.7		
	2021-2050	13.94±1.56	1.61±0.44	13.3±4.2	605.8±126.3	-53.0±33.9	-7.8±4.1
	2071-2100	15.90±1.71	3.57±0.84	29.4±7.6	539±114.5	-119.8±47.8	-18±4.9
Eastern Macedonia and Thrace	1961-1990	12.91±1.35			709.8±184.7		
	2021-2050	14.51±1.36	1.60±0.44	12.6±4.0	651.2±169.4	-58.6±26.3	-8.2±2.9
	2071-2100	16.39±1.53	3.49±0.85	27.3±7.4	580.4±155.6	-129.4±49.2	-18.3±4.7
Northern Aegean	1961-1990	15.82±1.22			509.7±205.6		
	2021-2050	17.33±1.15	1.51±0.53	9.7±3.8	501.4±198.8	-8.3±30.3	-1.1±5.6
	2071-2100	19.04±1.25	3.23±1.00	20.7±7.1	450.8±189.1	-59.0±39.9	-11.9±7.0
Cyclades	1961-1990	17.58±0.81			449.5±169.2		
	2021-2050	18.91±0.94	1.33±0.30	7.6±1.6	426.9±158.4	-22.6±33.1	-4.4±6.7
	2071-2100	20.51±1.00	2.92±0.59	16.7±3.4	371.4±166.3	-78.2±26.8	-19±8.0
Eastern Aegean	1961-1990	16.83±0.91			585.3±230.6		
	2021-2050	18.27±1.04	1.44±0.38	8.5±2.2	558.1±219.6	-27.3±49.9	-4.2±7.7
	2071-2100	19.97±1.17	3.14±0.75	18.7±4.5	491.3±215.3	-94.1±32.9	-17.1±6.0
Dodecanese	1961-1990	18.26±0.70			479.4±216.8		
	2021-2050	19.58±0.81	1.32±0.32	7.2±1.7	445.0±197.8	-34.3±39.9	-6.4±7.9
	2071-2100	21.22±0.90	2.96±0.65	16.2±3.6	385.1±196.9	-94.3±29.1	-21.2±7.3
Crete	1961-1990	16.35±0.91			567.8±224.3		
	2021-2050	17.73±1.01	1.38±0.35	8.5±2.2	504.7±183.3	-63.1±50.7	-9.8±6.3
	2071-2100	19.47±1.21	3.12±0.67	19.1±4.1	407±164.4	-160.8±79.6	-28.1±8.0
Central and Eastern Greece	1961-1990	14.48±1.37			507.4±111.8		
	2021-2050	16.02±1.41	1.54±0.42	10.8±3.2	480.5±97.9	-26.9±29.6	-5.0±4.9
	2071-2100	17.88±1.58	3.41±0.80	23.7±5.9	421.8±102.4	-85.6±33.7	-17.2±6.5
Attica	1961-1990	15.32±1.19			379.2±108.3		
	2021-2050	16.86±1.24	1.54±0.42	10.1±3.0	353.6±97.9	-25.5±26.7	-6.6±6.3
	2071-2100	18.69±1.44	3.37±0.80	22.1±5.4	302.5±94.8	-76.7±28.4	-20.8±6.8
Eastern Peloponnese	1961-1990	15.72±1.13			479.6±81.1		
	2021-2050	17.19±1.21	1.46±0.36	9.3±2.4	442.1±79.4	-37.6±20.7	-7.9±4.6
	2071-2100	19.00±1.38	3.27±0.70	20.9±4.6	371.8±82.0	-107.9±27.0	-23.0±7.0
Western Greece	1961-1990	12.28±1.25			1185.4±302.9		
	2021-2050	13.8±1.40	1.52±0.43	12.4±3.5	1084.5±304.0	-100.9±41.1	-9.0±4.3
	2071-2100	15.76±1.63	3.48±0.78	28.4±6.3	932.4±264.7	-253.0±87.4	-21.8±5.8
Ionian	1961-1990	17.31±0.90			786.6±247.8		
	2021-2050	18.59±1.01	1.28±0.37	7.4±2.1	738.6±250.4	-48.0±35.9	-6.6±5.3
	2071-2100	20.28±1.08	2.97±0.63	17.2±3.8	652.0±246.2	-134.6±44.3	-18.2±6.8
Western Peloponnese	1961-1990	14.41±1.16			881.1±229.7		
	2021-2050	15.89±1.30	1.48±0.40	10.3±2.7	786.5±218.6	-94.7±48.1	-10.9±5.7
	2071-2100	17.79±1.51	3.39±0.74	23.6±5.1	655.2±202.6	-225.9±59.7	-26.2±6.0
Greece	1961-1990	15.97±0.94			585.2±165.0		
	2021-2050	17.39±1.03	1.42±0.38	8.9±2.4	546.9±154.2	-38.3±27.4	-6.4±4.2
	2071-2100	19.14±1.16	3.17±0.72	19.9±4.7	476.5±155.3	-108.7±26	-19.3±5.5

* The small differences in estimates of climate parameters in the reference period 1961-1990 for the different emission scenarios are due to the fact that climate parameters are estimated on the basis of different sets of climate simulations for the different scenarios.

Table 1.8.b

Mean values and standard deviation of relative humidity at 2 m above ground (RH, %) and total incident short-wave radiation (S, W/m²), from the 12 RCM simulations of the ENSEMBLES project for the thirty-year periods 1961-1990*, 2021-2050 and 2071-2100 (SRES A1B)

Climate zones	Periods	RH	ΔRH	(%)	S	ΔS	(%)
Western and Central Macedonia	1961-1990	67.01±7.21			180.7±17.3		
	2021-2050	65.27±7.06	-1.74±0.63	-2.6±1.0	182.5±16.8	1.8±1.5	1.0±0.8
	2071-2100	63.53±6.59	-3.48±1.51	-5.1±2.3	184.3±15.3	3.6±2.8	2.1±1.6
Eastern Macedonia and Thrace	1961-1990	68.57±6.25			178.6±16.9		
	2021-2050	66.93±6.24	-1.64±0.46	-2.4±0.7	180.3±16.4	1.8±1.4	1.0±0.8
	2071-2100	65.25±5.80	-3.32±1.21	-4.8±1.8	182.2±15.1	3.6±2.8	2.1±1.6
Northern Aegean	1961-1990	74.20±3.85			186.5±18.6		
	2021-2050	73.26±3.86	-0.94±0.61	-1.3±0.8	187.3±18.4	0.9±1.3	0.5±0.7
	2071-2100	72.52±3.88	-1.68±1.32	-2.3±1.8	188.2±18.5	1.8±2.2	1.0±1.1
Cyclades	1961-1990	73.93±3.08			196.0±20.8		
	2021-2050	73.64±2.96	-0.29±0.41	-0.4±0.6	197.0±20.9	1.0±1.0	0.5±0.5
	2071-2100	73.48±2.66	-0.45±0.6	-0.6±0.8	198.1±21.5	2.1±1.9	1.1±0.9
Eastern Aegean	1961-1990	71.75±3.82			194.3±19.2		
	2021-2050	71.01±3.91	-0.75±0.27	-1.0±0.4	195.3±19.3	1.1±1.1	0.6±0.6
	2071-2100	70.14±3.68	-1.62±0.81	-2.2±1.1	196.7±19.3	2.4±2.0	1.2±0.9
Dodecanese	1961-1990	72.75±2.79			201.0±22.0		
	2021-2050	72.50±2.75	-0.25±0.32	-0.3±0.4	202.1±22.0	1.1±0.8	0.5±0.4
	2071-2100	72.32±2.41	-0.42±0.76	-0.6±1.0	203.4±22.8	2.4±1.7	1.2±0.8
Crete	1961-1990	71.56±3.69			200.6±19.0		
	2021-2050	70.79±3.68	-0.77±0.38	-1.1±0.5	202.2±19.0	1.6±1.3	0.8±0.6
	2071-2100	69.95±3.85	-1.61±1.05	-2.3±1.5	203.9±19.1	3.3±2.5	1.7±1.2
Central and Eastern Greece	1961-1990	66.68±5.93			188.3±17.7		
	2021-2050	65.43±5.85	-1.25±0.58	-1.9±0.9	189.7±17.3	1.4±1.5	0.8±0.8
	2071-2100	64.06±5.54	-2.63±1.46	-3.9±2.3	191.2±16.0	2.9±2.6	1.6±1.4
Attica	1961-1990	66.51±4.32			192.4±17.3		
	2021-2050	65.28±4.26	-1.23±0.64	-1.9±1.0	193.7±17.0	1.3±1.6	0.7±0.8
	2071-2100	63.98±4.04	-2.53±1.59	-3.8±2.5	195.2±16.6	2.8±2.9	1.5±1.5
Eastern Peloponnese	1961-1990	67.50±5.48			195.3±18.5		
	2021-2050	66.50±5.59	-1.01±0.49	-1.5±0.8	196.7±18.3	1.5±1.3	0.8±0.7
	2071-2100	65.31±5.45	-2.20±1.23	-3.3±1.9	198.4±17.5	3.1±2.4	1.6±1.2
Western Greece	1961-1990	71.38±6.17			179.1±18.7		
	2021-2050	69.92±6.23	-1.46±0.46	-2.1±0.7	181.6±18.3	2.5±1.6	1.4±0.9
	2071-2100	67.96±6.18	-3.41±0.98	-4.8±1.4	184.1±16.8	5.0±2.5	2.9±1.4
Ionian	1961-1990	73.16±3.56			186.9±19.7		
	2021-2050	72.84±3.72	-0.32±0.44	-0.5±0.6	188.3±19.6	1.4±0.9	0.7±0.5
	2071-2100	72.47±3.72	-0.69±0.72	-1.0±1.0	189.6±19.5	2.7±2.0	1.5±1.0
Western Peloponnese	1961-1990	70.55±5.2			189.9±19.3		
	2021-2050	69.25±5.27	-1.29±0.35	-1.9±0.5	192.2±19.0	2.2±1.3	1.2±0.7
	2071-2100	67.45±5.26	-3.09±0.94	-4.4±1.4	194.5±18.0	4.5±2.2	2.5±1.2
Greece	1961-1990	71.40±3.71			191.1±18.8		
	2021-2050	70.61±3.70	-0.79±0.25	-1.1±0.4	192.4±18.8	1.3±1.0	0.7±0.5
	2071-2100	69.78±3.42	-1.62±0.73	-2.3±1.0	193.8±18.7	2.7±2.1	1.5±1.0

* The small differences in estimates of climate parameters in the reference period 1961-1990 for the different emission scenarios are due to the fact that climate parameters are estimated on the basis of different sets of climate simulations for the different scenarios.

Table 1.8.c Mean values and standard deviation of wind velocity (V, m/s) and cloud cover (CC, %) from the 12 RCM simulations of the ENSEMBLES project for the thirty-year periods 1961-1990*, 2021-2050 and 2071-2100 (SRES A1B)

Climate zones	Periods	V	ΔV	(%)	CC	ΔCC	(%)
Western and Central Macedonia	1961-1990	2.90±0.83			41.4±8.3		
	2021-2050	2.88±0.81	-0.01±0.04	-0.4±1.2	39.2±8.0	-2.2±0.6	-5.3±1.3
	2071-2100	2.82±0.77	-0.07±0.09	-2.1±2.7	36.7±7.8	-4.7±1.2	-11.4±3.0
Eastern Macedonia and Thrace	1961-1990	3.54±0.86			41.7±7.5		
	2021-2050	3.56±0.86	0.02±0.03	0.5±0.9	39.4±7.3	-2.2±0.5	-5.4±1.3
	2071-2100	3.57±0.82	0.02±0.08	0.9±2.0	36.9±7.1	-4.8±1.1	-11.6±3.0
Northern Aegean	1961-1990	6.21±0.96			39.2±5.9		
	2021-2050	6.26±0.95	0.05±0.08	0.8±1.4	37.0±5.7	-2.1±0.6	-5.5±1.7
	2071-2100	6.38±0.96	0.18±0.18	2.9±2.9	34.7±5.7	-4.5±1.1	-11.7±3.1
Cyclades	1961-1990	6.51±1.24			36.5±6.3		
	2021-2050	6.51±1.24	0.01±0.06	0.1±0.9	34.2±6.4	-2.3±0.6	-6.4±2.0
	2071-2100	6.64±1.28	0.13±0.12	2.0±1.8	31.8±6.4	-4.7±1.0	-13.2±3.8
Eastern Aegean	1961-1990	5.74±1.13			35.6±5.5		
	2021-2050	5.75±1.11	0.01±0.05	0.3±1.1	33.3±5.4	-2.3±0.5	-6.5±1.5
	2071-2100	5.87±1.13	0.13±0.12	2.4±2.0	30.8±5.3	-4.8±1.1	-13.7±3.7
Dodecanese	1961-1990	6.08±0.69			34.6±7.4		
	2021-2050	6.03±0.65	-0.05±0.11	-0.8±1.8	32.2±7.4	-2.4±0.5	-7.2±2.0
	2071-2100	6.01±0.62	-0.07±0.18	-1.1±2.9	29.7±7.5	-4.9±1.1	-14.7±5.0
Crete	1961-1990	4.61±1.25			36.6±5.9		
	2021-2050	4.59±1.24	-0.02±0.04	-0.3±0.9	34.1±5.5	-2.5±0.7	-6.8±1.6
	2071-2100	4.64±1.23	0.04±0.08	0.9±1.7	31.4±5.2	-5.2±1.4	-14.2±3.2
Central and Eastern Greece	1961-1990	3.47±1.08			37.9±7.5		
	2021-2050	3.47±1.07	0.00±0.03	0.1±0.8	35.8±7.1	-2.1±0.6	-5.6±1.5
	2071-2100	3.46±1.04	-0.01±0.06	0.2±1.8	33.5±6.8	-4.4±1.2	-11.6±3.1
Attica	1961-1990	3.73±1.15			36.9±7.0		
	2021-2050	3.75±1.14	0.02±0.03	0.5±0.8	34.7±6.6	-2.2±0.7	-6.0±1.8
	2071-2100	3.80±1.14	0.07±0.07	2.2±1.9	32.5±6.3	-4.4±1.3	-12.0±3.4
Eastern Peloponnese	1961-1990	4.16±1.27			35.3±6.7		
	2021-2050	4.15±1.27	0.00±0.04	-0.1±0.9	33.1±6.3	-2.2±0.7	-6.2±1.9
	2071-2100	4.18±1.27	0.02±0.11	0.6±2.2	30.9±6.1	-4.4±1.3	-12.6±3.7
Western Greece	1961-1990	3.09±1.11			44.9±7.9		
	2021-2050	3.06±1.10	-0.04±0.04	-1.1±1.3	42.4±7.6	-2.5±0.8	-5.7±1.6
	2071-2100	3.01±1.07	-0.09±0.07	-2.5±1.7	39.4±7.6	-5.5±1.1	-12.4±2.9
Ionian	1961-1990	4.95±0.86			40.6±6.0		
	2021-2050	4.88±0.84	-0.07±0.06	-1.3±1.1	38.3±6.0	-2.3±0.7	-5.8±1.8
	2071-2100	4.78±0.80	-0.17±0.09	-3.4±1.4	35.5±5.9	-5.1±1.0	-12.9±2.9
Western Peloponnese	1961-1990	3.60±1.09			40.8±7.0		
	2021-2050	3.57±1.08	-0.03±0.04	-0.8±1.1	38.3±6.7	-2.5±0.8	-6.2±1.9
	2071-2100	3.53±1.06	-0.07±0.07	-2.0±1.6	35.4±6.6	-5.5±1.1	-13.6±3.1
Greece	1961-1990	5.02±0.87			38.0±5.8		
	2021-2050	5.00±0.86	-0.01±0.04	-0.3±0.9	35.8±5.7	-2.3±0.5	-6±1.4
	2071-2100	5.01±0.84	0.00±0.07	0.1±1.4	33.3±5.6	-4.8±1.0	-12.7±3.1

* The small differences in estimates of climate parameters in the reference period 1961-1990 for the different emissions scenarios are due to the fact that climate parameters are estimated on the basis of different sets of climate simulations for the different scenarios.

ation in the six climate parameters for the 13 climate zones can be found on the website pages of the Bank of Greece dedicated to the Climate Change Impacts Study Committee (CCISC).[26]

Presented in Tables 1.7.1.a, b, c and 1.7.2.a, b, c are the annual mean values of the six climate parameters for the reference period 1961-1990 and for the decades 2071-2080, 2081-2090 and 2091-2100, as well as the variation in annual mean values in the case of Scenarios A2 and B2 between the periods 2071-2080, 2081-2090, 2091-2100 and the reference period 1961-1990 for each of the country's 13 climate zones. The respective estimates for the periods 1961-1990, 2021-2050 and 2071-2100 in the case of Scenario A1B are presented in Table 1.8.a, b, c. The results of the assessment are discussed separately for each of the six climate parameters immediately below.

Mean air temperature

The climate simulations under all four emission scenarios (Tables 1.7.1.a, b, c, 1.7.2.a, b, c and 1.8.a, b, c) point to an overall mean warming in Greece over the coming decades, relative to the reference period 1961-1990. This increase in temperature is projected to be most pronounced under Scenario A2 and smallest under Scenario B1. Warming is also projected to be greater in the continental regions than in the islands, and greater in summer and autumn than in winter and spring.

Under the more extreme Scenario A2, in the decade 2091-2100 the mean air temperature countrywide is projected to be 3.9ºC higher in winter and spring, 5.4ºC higher in summer, 4.7ºC higher in autumn and 4.5ºC higher year-round. The increase in winter temperature is projected to range between 4ºC and 4.5ºC in the continental regions, but will be less pronounced in the island regions where it will not exceed 3.5ºC, except in the Northern Aegean, where it will reach 4 ºC. Spring temperatures are expected to be 4.5ºC higher in the continental regions and 3.5ºC higher in the island regions. The temperature increase in summer is expected to be greater than in the other seasons, and is projected to range from 6ºC to 7ºC in the continental regions and from 4.5ºC to 5ºC on the islands. Lastly, the temperature increase in autumn is projected be more uniform across the different climate zones and should range between 4.3ºC and 5.2ºC.

As for the somewhat milder Scenario A1B, the projected variation in annual mean air temperature, relative to the reference period 1961-1990, can be seen in Figure 1.25 (for the period 2021-2050 on the left panel, and for the period 2071-2100 on the right panel). As can be seen on the left panel (a), all of Greece's regions should have 1.5ºC higher annual mean temperatures in 2021-2050. As mentioned earlier, the temperature increase will be greater in summer and smaller in winter. It should also be noted that the differences in estimated air temperature vari-

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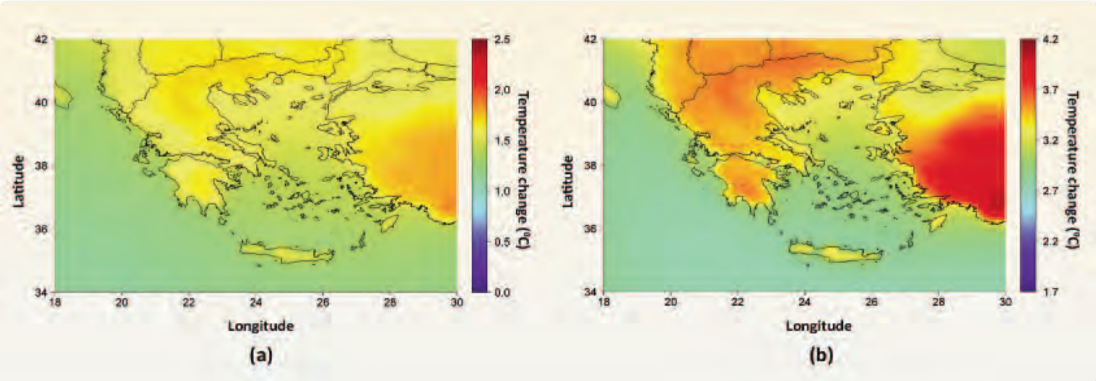
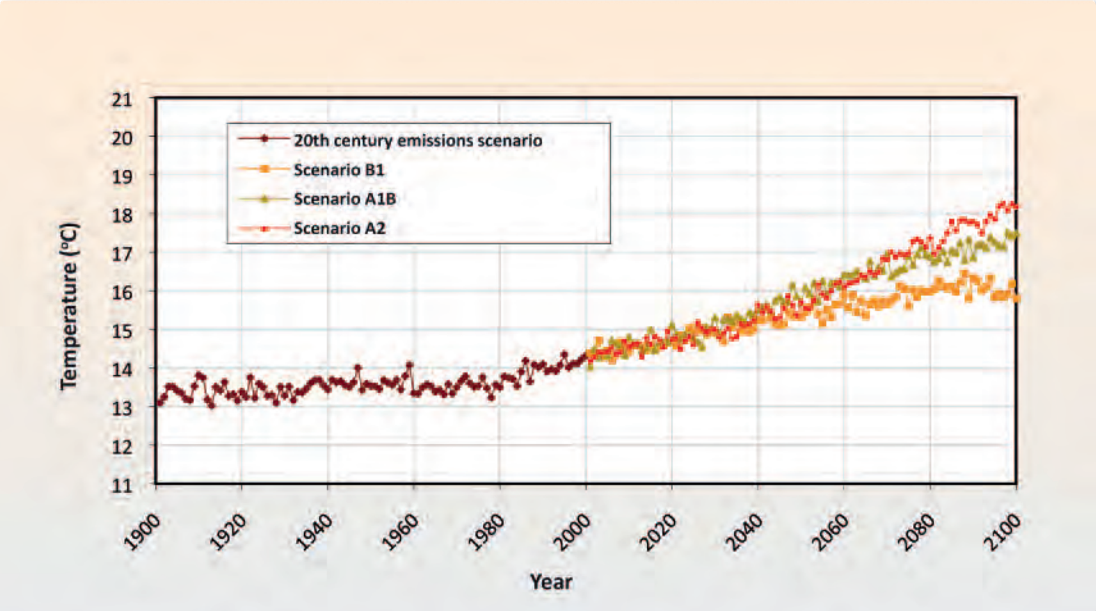
[26] http://www.bankofgreece.gr/Pages/en/klima/

Figure 1.25 Variation in mean air temperature in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990



Mean value of 12 RCMs from the ENSEMBLES project. Scenario A1B.

Figure 1.26 Variation across time in the average annual temperature in Greece in the course of the 2000-2100 period under Scenarios B1, A1B and A2



Average of 10 simulations with AOGCMs.

ation presented by the various emission scenarios are small for the near future (Figure 1.26, Kapsomenakis, 2009). During the decade 2091-2100, the mean temperature countrywide is projected to be higher than in the reference period by 3.2ºC in winter, 4.2ºC in summer and ~3.5ºC in spring and autumn, as well as on annual basis. The increase in winter temperature will range across the different climate zones between 3ºC and 3.5ºC, with higher values projected for Northern Greece and lower values projected for the islands. The increase in summer temperature is expected to approach 4.5-5ºC in the continental regions, but should not exceed 4ºC on the islands.

Under Scenario B2, the annual mean warming at the end of the 21st century is projected to be ~1.3ºC lower than under Scenario A2. The difference in projected warming between the two scenarios will be smallest in winter and spring (1ºC) and more pronounced in autumn (1.5ºC) and summer (1.7ºC).

Lastly, the warming projected under Scenario B1 will be less pronounced than under all of the other scenarios considered. In particular, the mean air temperature countrywide for the decade 2091-2100 will be higher, with respect to the reference period, by 2ºC in winter, 2.2ºC in spring, 3ºC in summer and 2.4ºC in autumn as well as on an annual basis. An analysis of the results found the differences in temperature variations across the different climate zones to be smaller under Scenario B1 than under the other scenarios considered.

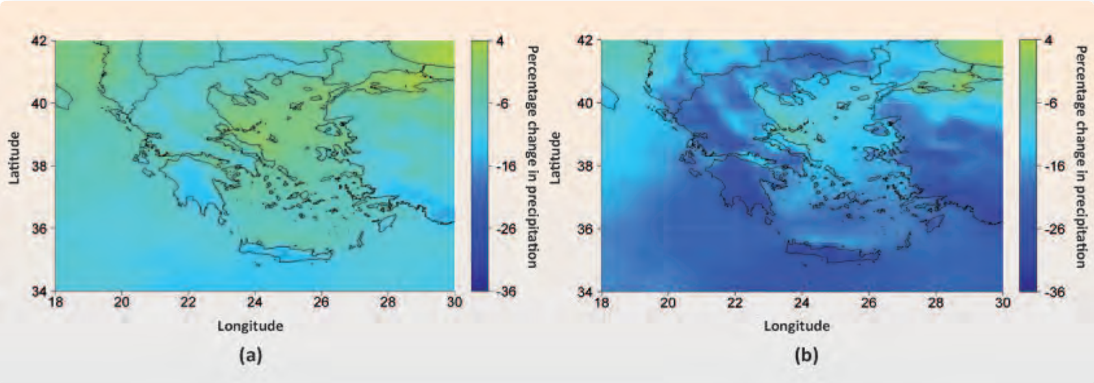
It should be noted that under all four scenarios the warming trend increases throughout the 21st century. During the period 2071-2100 in particular, this trend is stronger under Scenarios A2 (0.5ºC/decade) and A1B (0.4ºC/decade), milder under Scenario B2 (0.25ºC/decade) and milder yet under Scenario B1, the only scenario under which the warming trend slackens off toward the end of the century (0.1ºC/decade). The difference in projected warming between the four scenarios is therefore greatest at the close of the 21st century, as can be seen in Figure 1.26.

Precipitation

According to the results of the climate model simulations, annual precipitation levels countrywide are projected to decline under all three emission scenarios considered. The decrease is particularly important under Scenarios A2 and A1B and milder under Scenario B2.

In the case of Scenario A2, precipitation levels countrywide during the period 2071-2100 are expected to decrease, relative to the reference period, by 16% in winter, 19% in spring, 47% in summer, 10% in autumn and 17% on a annual basis. The percentage decrease in annual mean precipitation is projected to be greatest in the western continental areas and in the Eastern Peloponnese (over 20%), followed by the rest of Greece (15-20%), with the exception of the Northern Aegean where the decrease in annual precipitation should not exceed 10%. In winter, when Greece receives most of its precipitation, the percentage decrease is projected to be greatest in the eastern continental regions, the Western Peloponnese and the Southern Aegean (over 18%), smallest in the Northern Aegean (under 8%), while ranging between 9% and 12% in the rest of Greece. The greatest percentage decrease in precipitation is projected for summer, when it will exceed 40% in the larger part of Greece. In absolute terms, however, the decrease in summer precipitation will —with the exception of Northern Greece— be small, as even today summer precipitation ranges from limited to minimal. In spring, precipitation should decrease by more than 20% in the larger part of Greece, and in other regions by ~15%. Lastly, autumn precipita-

Figure 1.27 **Percentage changes in average annual total precipitation in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990**



Mean value of the 12 RCMs from the ENSEMBLES project. Scenario A1B.

tion is expected to decrease significantly by over 18% in Western Greece, the Western Peloponnese and Eastern Macedonia-Thrace.

Turning to Scenario A1B, the percentage changes in annual mean precipitation projected for the periods 2021-2050 and 2071-2100, relative to the reference period, are represented in Figure 1.27. In 2021-2050, precipitation levels countrywide will decrease relative to the reference period by about 5% (Table 1.8.a). In percentage terms, annual mean precipitation is projected to decrease most in Crete and the Peloponnese (close to 15%), followed by the rest of Greece (between 5% and 10%), but to increase slightly in the Northern Aegean (Figure 1.27, panel (a)). The decrease in precipitation countrywide is projected to be greatest toward the end of the century. More specifically, in 2071-2100, mean precipitation is projected to decrease by 16% in winter, 26.5% in spring, 37% in summer, 12.5% in autumn and 19% on an annual basis. The percentage decrease in annual mean precipitation will be greatest in Crete and the Peloponnese (close to 25%), while ranging around 20% in the rest of Greece and remaining below 15% in the Northern Aegean (See Figure 1.27, panel (b)). The percentage decrease in winter precipitation is expected to be largest in Greece's southern island areas and the Peloponnese (over 20%), followed by Western Greece, the Ionian and the Eastern Aegean islands (about 15%), and the rest of Greece (about 10%). The percentage decrease in summer precipitation should be around or even above 40% in most of Greece, while even in the Northern Aegean, i.e. the region with the smallest projected percentage decrease, it will exceed 20%. Spring precipitation should decrease in most of Greece by more than 20%. Lastly, in autumn, the percentage decrease is projected to be greatest in Crete and the Western Peloponnese (20%), whereas in Central and Eastern Greece and the Northern Aegean it will not exceed 7%.

Under Scenario B2, the decrease in precipitation projected for the period 2071-2100, relative to the reference period, will be smaller. A significant decrease in winter and spring precipitation (of

~10%) is projected only for Southern Greece. Autumn precipitation will decrease significantly only in Western Greece (by ~8%), and in contrast will increase by as much as 10% in the island regions. Lastly, summer precipitation is projected to decrease significantly countrywide. In absolute terms, however, the decrease in summer precipitation will be sizeable only in Northern Greece.

Relative humidity at 2 m above ground

Annual mean relative humidity is projected to decrease in Greece under all three Scenarios A2, A1B and B2, with the changes projected under Scenario B2 expected to be much more moderate than under Scenario A2, and the changes projected under Scenario A1B figuring somewhere in the middle. As also indicated by the simulations, the variation in relative humidity —under all three scenarios— will be much milder in the island regions than in the continental climate zones, and much milder in the near future than at the close of the 21st century.

In greater detail, under extreme Scenario A2, annual mean relative humidity is projected to decrease countrywide by 4.5% in 2091-2100, relative to the reference period 1961-1990. The percentage decrease in annual mean relative humidity is projected to be about 10% in the western and northern continental regions, between 6% and 8% in the remaining continental regions, but less than 4% in the islands. Winter relative humidity is estimated to decrease by 6% to 8% in the continental regions —with the exception of the Western Peloponnese (3.5%)— whereas an even smaller decrease is projected for the island regions. The largest percentage decrease in relative humidity is expected in summer, with relative humidity more than 20% lower in the western and northern continental regions, close to 15% lower in the remaining the continental regions, but only between 3% and 7% lower on the islands. In spring, similarly, the decrease in relative humidity should be more pronounced in Western and Northern Greece (close to 10%) and in the remaining continental regions (around 8%) than on the islands (below 5%). Lastly, in autumn, the changes in relative humidity are projected to be similar to those in winter.

Turning to Scenario A1B, the largest percentage decrease in relative humidity is, once again, projected for summer. More specifically, summer mean relative humidity in 2091-2100 is expected to be 12% lower in Greece's western and northern continental regions, 6% to 8% lower in the remaining continental regions, and 3% to 5% lower in the islands. The change in winter relative humidity, however, is not expected to be substantial on a countrywide basis. In spring, mean relative humidity is projected to be 6% lower in the continental regions, 4% lower in the islands of the Northern Aegean, the Eastern Aegean and Crete, and less than 2% lower in the remaining islands. Lastly, autumn relative humidity is expected to decrease slightly in the western and northern continental regions, but to remain essentially unchanged elsewhere.

In the case of Scenario B2, the changes in seasonal and annual relative humidity are projected to be small, with the exception of the summer, when the decrease in relative humidity is projected to reach as much as 10% in continental Greece.

The decrease in relative humidity is attributable in part to the rise in temperatures, which results in higher saturation specific humidity. Thus, when the water vapour content of the atmosphere can no longer increase, as in the case of Greece's continental regions particularly in summer, mean relative humidity drops.

Cloud cover

As shown by the results of the climate simulations for the three scenarios considered, cloud cover is projected to decrease countrywide in the coming decades, relative to the reference period 1961-1990. The decrease in cloud cover is projected to be more pronounced under Scenario A2 and least pronounced under Scenario B2.

Based on the projections, the percentage decrease in annual mean cloud cover countrywide in 2091-2100 relative to the reference period will reach 16% and 8% under Scenarios A2 and B2, respectively. It should be noted that the spatial distribution of the projected changes was found to be similar under both scenarios. Depending on the climate zone, the percentage decrease in winter cloud cover ranges between 10% and 14% under Scenario A2, and between 4% and 8% under Scenario B2. Similar results were obtained for spring. The largest percentage decreases in cloud cover are projected for summer, reaching 36% and 20%, respectively, under Scenarios A2 and B2 countrywide. In absolute terms, however, the change in summer cloud cover will be small, with the exception of the western and northern regions, given that low level of summer cloud cover even today. Lastly, autumn cloud cover is expected to fall to 14% and 7%, respectively, under Scenarios A2 and B2.

Future cloud cover is projected to decrease under Scenario A1B as well, with the percentage decreases in mean cloud cover in the different climate zones generally assuming intermediate values, between those obtained under Scenario A2 and under Scenario B2.

Incident short-wave radiation

According to the results of the studied simulations, incident short-wave radiation is —according to Scenarios A2, A1B and B2— expected to increase slightly in Greece. It should be noted that this increase is, to some extent, correlated with the anticipated decrease in cloud cover.

In greater detail, under Scenario A2, annual incident radiation is projected to increase countrywide by 4.5 W/m^2 in 2091-2100, relative to the reference period. The increase is expected to exceed 6 W/m^2 in Northern Greece, but at the other end, to be less than 3 W/m^2 in the southern island regions. In addition, the increase will in general be greater in Western than in Eastern Greece. In winter, the increase in incident radiation is expected to be greater in the southern regions, in some cases reaching 5 W/m^2, and smaller in the northern regions where it should not exceed 3 W/m^2. Summer incident radiation is projected to increase countrywide by 3.5 W/m^2, with the most significant increase projected for Western and Northern Greece (8-10 W/m^2), in contrast with the southern island regions, where incident radiation should remain broadly unchanged. The highest increase in incident radiation countrywide is projected to take place in spring, reaching 9 W/m^2, with the highest levels of increase anticipated for Western Greece (15 W/m^2), followed by other western and northern regions (above 10 W/m^2) and the rest of the country (between 6.5 W/m^2 and 9 W/m^2). Lastly, in autumn, the increase in incident short-wave radiation is projected to be relatively smaller (2 W/m^2 countrywide).

Turning to Scenario A1B, annual mean incident solar radiation is projected to increase countrywide by 2.4 W/m^2 in the period 2091-2100. The increase will range between 4.5 W/m^2 in Western Greece and 2 W/m^2 in the Cyclades, the Eastern Aegean and the Dodecanese. In winter, the increase in incident solar radiation in the larger part of Greece should range between 3 W/m^2 and 5 W/m^2, with the exception of Northern Greece, where it is not expected to exceed 2.5 W/m^2. In summer, incident solar radiation is not projected to change significantly countrywide. The highest increase in incident solar radiation countrywide is projected to occur in spring, when it would reach 10 W/m^2. The increase will be greatest in the western continental regions, where it is expected to exceed 13 W/m^2, but will also be substantial in the rest of Greece, where it will range between 8 W/m^2 and 11 W/m^2. Lastly, incident short-wave radiation in autumn is expected to decline. The decrease will be uniform countrywide and is expected to reach 3 W/m^2.

Lastly, under Scenario B2, the increase in incident solar radiation that is projected countrywide is smaller than under Scenario A2. More specifically, as indicated by the simulations, annual incident solar radiation countrywide will be 2.3 W/m^2 higher at the end of the 21st century, relative to the reference period. Season-wise, the greatest increase in incident solar radiation is projected to occur in spring and the smallest in autumn. In terms of spatial distribution, the highest increase in incident solar radiation is expected to occur in Western and Northern Greece, whereas the smallest increase is projected for the southern island regions.

Wind speed

No change is projected in the annual mean wind speed countrywide, according to all three Scenarios (A2, A1B and B2). However, certain specific regions are expected to experience significant changes in wind speed toward the end of the 21st century, on a seasonal and annual basis.

More specifically, under extreme Scenario A2, the annual mean wind speed is projected to increase in Eastern Greece (except in the Dodecanese, where it will remain unchanged), and to decline in the western regions. In winter, the mean wind speed will decrease countrywide, by as much as 7% in the western regions but by no more than 2% in the Cyclades and the Eastern Aegean islands. In summer, on the other hand, the mean wind speed countrywide will increase by about 5%. This increase is attributed to the strengthening of the Etesians in the Aegean, as projected by the models. In greater detail, the mean summer wind speed will increase by more than 10% in the Cyclades and the Eastern Aegean islands, and by close to 5% in the other eastern regions (except for the Dodecanese). In Western Greece and the Dodecanese, the wind speed will not change substantially. In the intermediate seasons, the mean wind speed countrywide is projected to remain essentially unchanged. However, in the Cyclades and the Eastern Aegean islands an increase in wind speed is projected both for spring and autumn, on account of the higher intensity and frequency of the Etesians early and late in the season. In other eastern regions, the wind speed should increase slightly in autumn, but is not expected to change substantially in spring. By contrast, wind intensity in Western Greece is expected to decline, particularly in spring.

Turning to the projections under the milder scenario (B2), the changes in seasonal and annual mean wind speed in different regions of Greece will have the same sign as under Scenario A2, but lower absolute values, with the exception of the summer wind speed in the Aegean, where the variation in intensity of the Etesians is projected to be roughly equal under both Scenarios.

Lastly, similar results were also obtained using the intermediate Scenario (A1B). On a seasonal basis, the mean wind speed countrywide will increase in summer by nearly 4%, on account of a strengthening of the Etesians in the Aegean. It should be noted that, whereas the PRUDENCE models (Scenarios A2 and B2) place the highest strengthening of the Etesians in the Central Aegean, the ENSEMBLES models (Scenario A1B) project the highest strengthening (above 10%) to take place in the Northern Aegean. The winter mean wind speed will, in contrast, decline countrywide, and will be more pronounced in the Ionian and in Western Greece (5%) than in eastern continental Greece and the Aegean islands (3%). During the intermediate seasons, the changes in wind speed will be similar to those estimated under Scenarios A2 and B2. It is worth noting the upward trend in the intensity of the Etesians over the period 2071-2100 under all three scenarios.

1.16 Assessment of extreme weather events and their regional impact in Greece

The severity of the climate change impact is more likely to be associated with changes in the frequency of extreme weather events than with a drawn-out 'average' climate evolution, given that, in the case of extreme events, a simple change in mean value above a critical threshold can bring about a disproportionate, non-linear impact.

The complexity of the natural and social systems' interactions with the climate system makes it difficult to assess and describe the impacts of climate change in a comprehensive and straight-forward manner. Instead, one has to use indicators gauging changes in observable and measurable characteristics of natural systems and human societies that are heavily dependent on climate change and can point to changes in the broader system. For instance, a longer or shorter growing season can serve as an indicator of a climate change impact on agriculture.

For the purpose of the present study, we used the datasets from the regional climate model RACMO2, developed by the Royal Meteorological Institute of the Netherlands (KNMI), with a horizontal resolution of 0.25° (~25 km). These datasets were compiled in the context of the EU-financed project ENSEMBLES,[27] in which the National Observatory of Athens took part. The objective of the ENSEMBLES project was the study of climate change in Europe and the quantification of uncertainty in climate projections. The specific model was selected because, during an assessment exercise of all the models forming the basis for the simulations under the ENSEMBLES project, RACMO2 was found to be more accurate in simulating temperature and rainfall extremes. The datasets cover a 30-year reference period, 1961-1990, for the current climate, and two future periods, 2021-2050 and 2071-2100, for the study of climate change using Scenario A1B of the IPCC. For each of Greece's 13 climate zones, we computed the change in the relevant climate indices between each future period (2021-2050 and 2071-2100) and the reference period (1961-1990). Scenario A1B is a mid-line scenario in terms of carbon dioxide emissions and economic growth (Alcamo et al., 2007). The first future period, 2021-2050, was chosen with the specific needs of policy-makers in mind, in order to assist them with nearer-term planning, whereas the second period, 2071-2100, serves to underscore the extent of the changes toward the end of the 21st century. Using the data from this model, it was possible to study the variation in climate parameters and indices between the reference period and each one of the two future periods, and to determine climate change for each of Greece's 13 climate zones.

Maximum summer and minimum winter temperatures

As can be seen from the projected changes in mean minimum winter temperature represented in Figure 1.28, minimum winter temperatures in all of Greece's regions will be ~1.5ºC higher in 2021-2050 and ~3.5ºC higher in 2071-2100, than in the reference period 1961-1990. These results concur with large-scale findings, which have recorded a significant upward trend in minimum temperatures over the past few decades. The warming trend will be more pronounced in the more mountainous areas, especially in the mountain ranges of Pindos and of Northern Greece, where it is projected to reach 2ºC in 2021-2050 and 4ºC in 2071-2100.

The increase in this parameter is likely to have an impact on forests, presently adapted to colder weather conditions. If the conditions become prohibitive, certain categories of forests (e.g. fir) would have to shift to higher altitudes.

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[27] www.ensembles-eu.org

Figure 1.28 Variation in the mean minimum winter temperature in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990 (in °C)

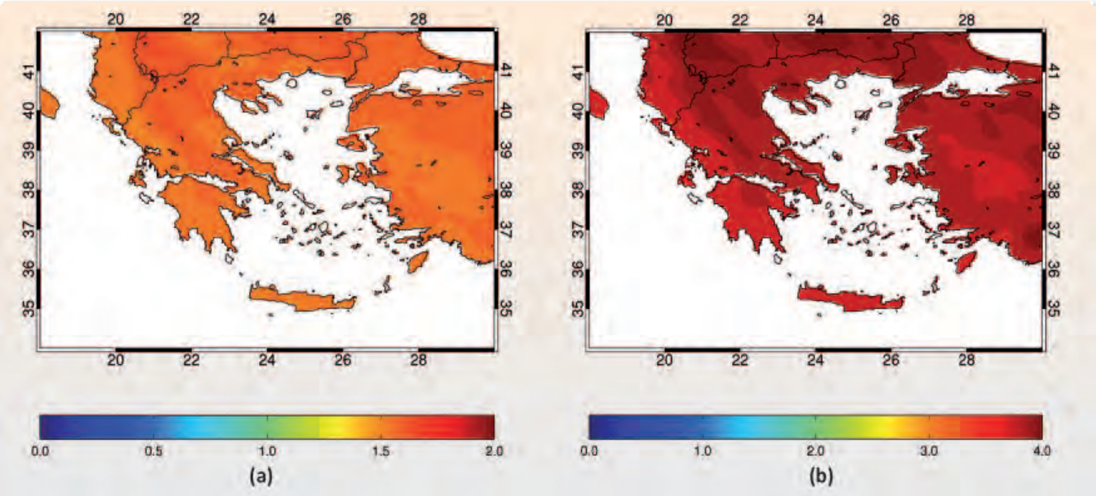
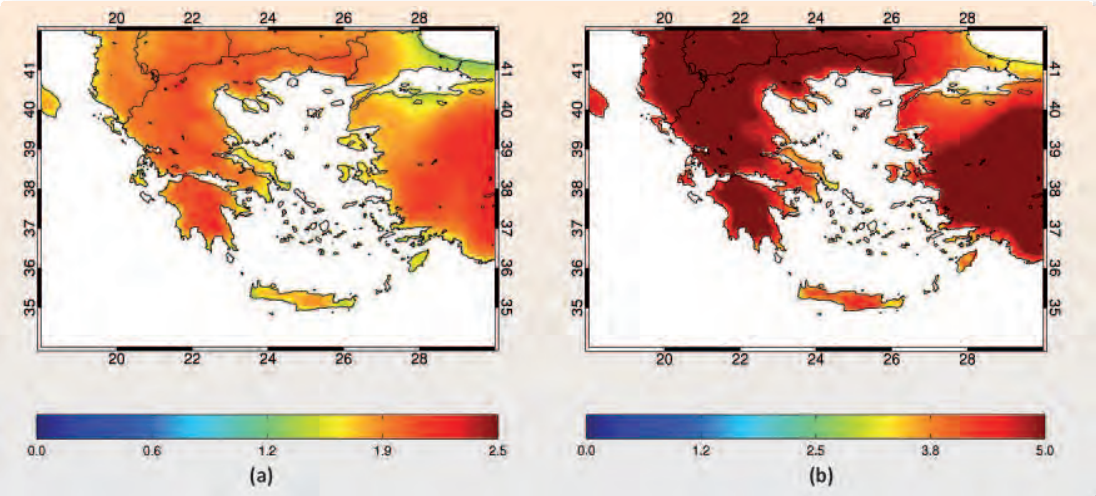


Figure 1.29 Variation in the mean maximum summer temperature in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990 (in °C)



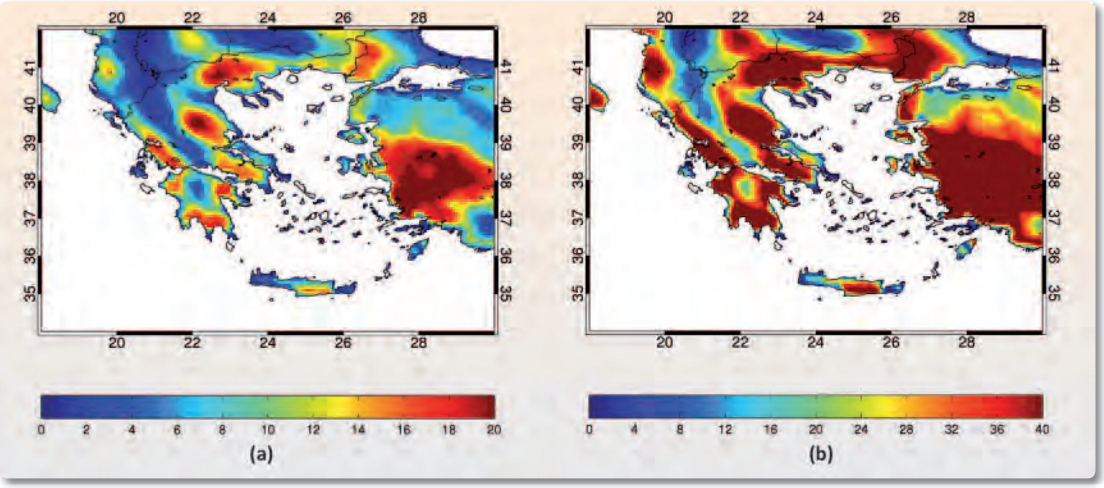
The projected changes in mean maximum summer temperatures are represented in Figure 1.29. The increase in mean maximum summer temperatures in the period 2021-2050 will be greater than that of the winter minimums and will exceed 1.5ºC and in some cases reach as much as 2.5ºC. In the period 2071-2100, the increase in mean maximum summer temperatures may be as much as 5ºC. Most affected will be the continental inland regions, situated far from the cooling effects of the sea, whereas regions with strong sea breezes (Crete, Aegean islands) will experience a significantly smaller variation in maximum summer temperatures.

Warm days and warm nights

The projected variation in the number of days with maximum temperatures above 35ºC, as represented in Figure 1.30, is expected to have a significant impact on human discomfort, especially in urban areas, as the number of hot days countrywide is clearly projected to increase. The most noticeable changes are projected for the low-lying inland regions of Central Greece, Thessaly, the Southern Peloponnese as well as Central Macedonia, where up to 20 additional very warm days are expected per year in 2021-2050 and up to 40 in 2071-2100, relative to the reference period 1961-1990. The change is expected to be somewhat milder in Crete and Attica, where the number of additional very warm days per year should not exceed 15 in 2021-2050 and 30 in 2071-2100, and milder yet in the Aegean and the Ionian islands, which will count 10 additional very warm days per year in 2021-2050 and 15 additional ones in 2071-2100, due to the proximity of the sea and the tempering effect of sea breezes.

Another temperature-related and significant parameter is the change in the annual number of warm nights. Nights are defined as warm (or tropical) when the minimum temperature does not fall below 20ºC. This parameter is closely associated with human health, as a tropical night following an extremely hot day can increase human discomfort. As can be seen from Figure 1.31, the annual number of tropical nights is projected to increase almost everywhere in Greece, but substantially more so in the coastal and island regions than in the continental mainland

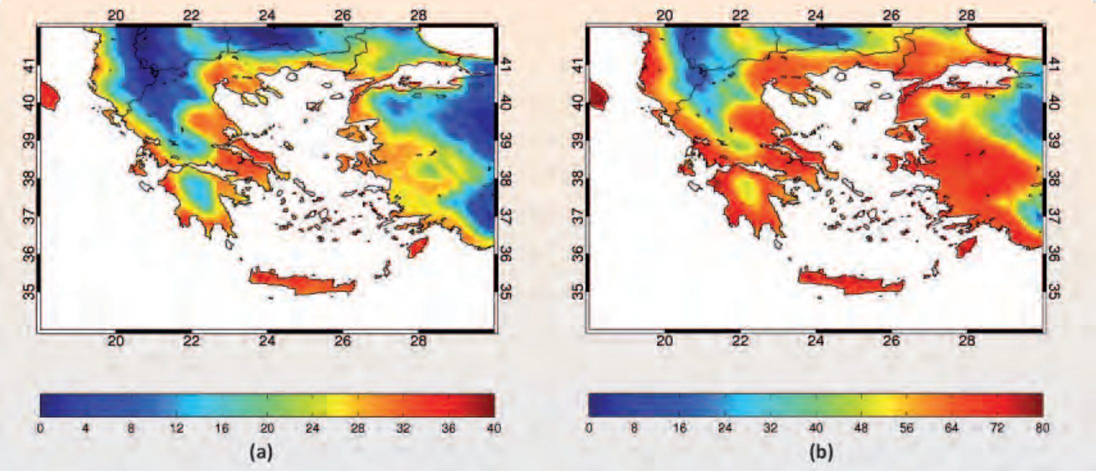
Figure 1.30 **Variation in the number of days with maximum temperature > 35°C in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990**



(a)

(b)

Figure 1.31 Variation in the number of days with minimum temperature > 20°C in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990

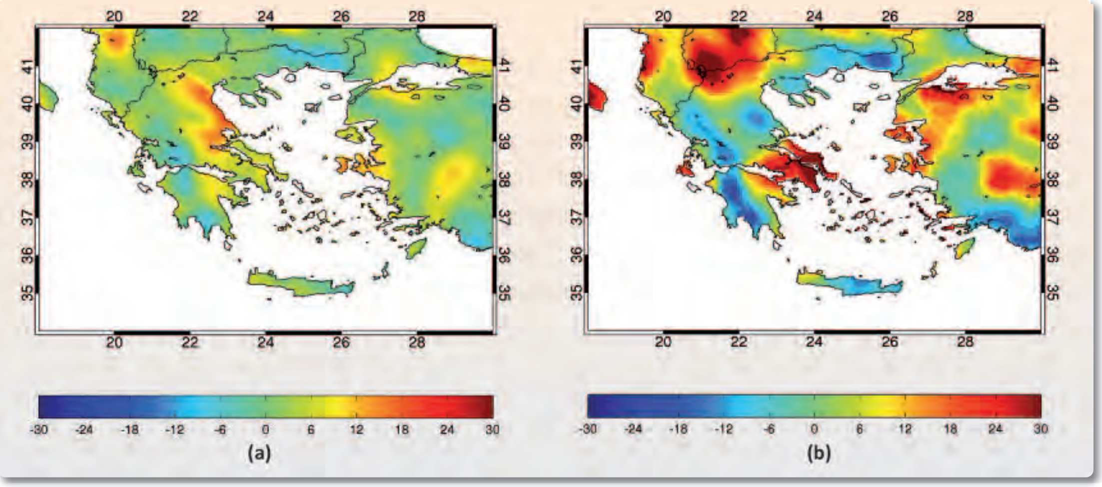


regions. Crete, the coastal regions of Eastern Greece and the Aegean islands are expected to have 40 additional warm nights per year in 2021-2050 and 80 additional warm nights per year in 2071-2100. In Western Greece and Eastern Macedonia-Thrace, however, the increase in the annual number of warm nights will be less than 30 in 2021-2050 and 70 in 2071-2100, with even smaller increases projected for Western Macedonia (15 or less additional warm nights per year in 2021-2050 and 30 or less in 2071-2100).

Days with precipitation and dry days

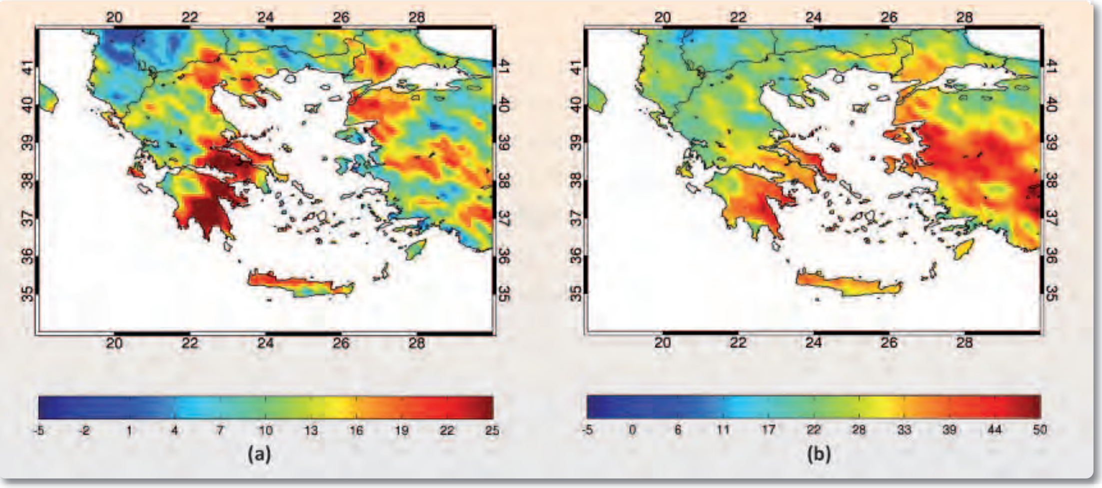
Apart from maximum temperature extremes and their association with human discomfort, another source of concern is flash flooding, especially if its frequency were to increase on account of climate change. As can be seen from Figure 1.32, the percentage variation in annual maximum consecutive 3-day precipitation is projected to increase. Together with the projected decrease in total annual rainfall, this means that extreme precipitation events will increase in intensity, thereby raising the flood risk. As can be seen from the left panel of Figure 1.32, maximum consecutive 3-day precipitation period during 2021-2050 will remain essentially unchanged, relative to the reference period 1961-1990, in regions like Western Greece, Eastern Macedonia-Thrace and Crete, but will increase significantly in others. In the eastern continental regions, in particular, maximum consecutive 3-day precipitation is projected to increase by 20%. These contrasts become even more pronounced toward the end of the 21st century, with the amount of extreme rainfall projected to decrease by 10-20% in regions of Western Greece and Thrace, but to increase by 30% in the Eastern Central Greece and the NW Macedonia. Small variations are projected for the rest of the country.

Figure 1.32 Percentage change in annual maximum consecutive 3-day precipitation in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990



(a) (b)

Figure 1.33 Variation in maximum length of dry spell (in consecutive dry days) in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990



(a) (b)

Projections were also made regarding the variation in the maximum duration of dry spells, i.e. consecutive dry days, defined as days with no or less than 1 mm precipitation. As can be seen from Figure 1.33, the length of dry spells will clearly increase. The smallest variations in dry spell length are projected for Greece's western regions in 2021-2050 (less than 10 more consecutive dry days) and for Western and Northern Greece in 2071-2100 (less than 20 more consecutive dry days). The largest increases in dry spell length are projected for the eastern continental regions (Eastern Central Greece, the Eastern Peloponnese and Euboia) and Northern

Crete, which will have more than 20 additional consecutive dry days in 2021-2050 and as many as 40 more consecutive dry days in 2071-2100.

Frost days and growing season

The projected changes in the number of frost days per year are represented in Figure 1.34. This is an important parameter for agricultural regions, especially those where frost-sensitive crops, like citrus fruit, are grown. The number of frost days per year is projected to decrease in

Figure 1.34

Variation in number of night frosts in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990

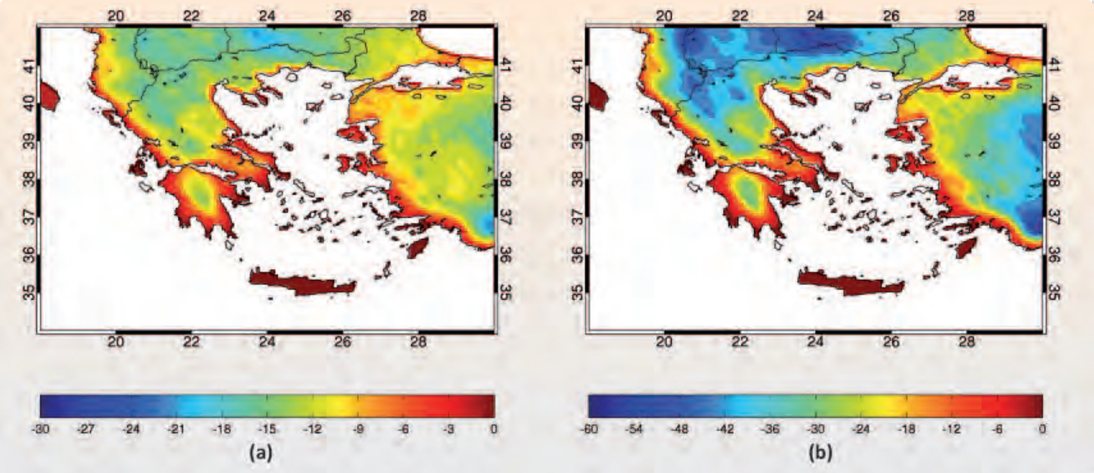
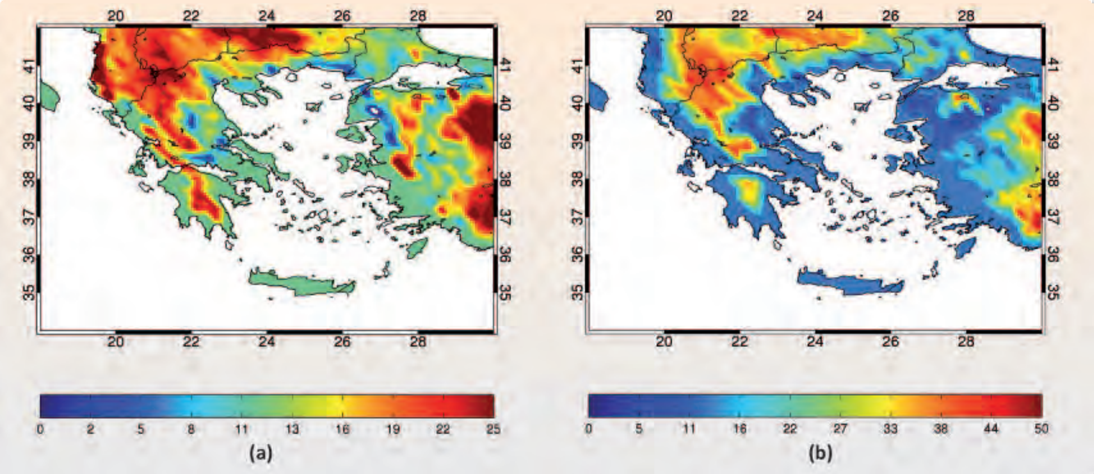


Figure 1.35

Variation in growing season length (in days) in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990



Macedonia and Thrace by 15 in 2021-2050 and by 40 in 2071-2100, and in the continental regions of Thessaly and the Peloponnese by 10 to 15 in 2021-2050 and by 25 in 2071-2100. Smaller decreases are projected for the rest of Greece, mainly because of the small number of frost days that these regions have even today.

In addition to the number of frost days, we also examined the length of the growing season, defined as the period favourable to plant and crop growth between the last spring frost and the first autumn frost. The projected changes in the length of the growing season are represented in Figure 1.35. The observable lengthening can be attributed to the earlier occurrence of the last spring frost and to the later occurrence of the first autumn frost. The largest increases in growth season length (in the order of 25 days for 2021-2050 and 45 days for 2071-2100) are projected for the country's continental mountain regions. Length increases of 10-15 days for 2021-2050 and 15-25 days for 2071-2100 are projected for the rest of the country.

Energy demand for heating and cooling

In order to estimate future energy demand, we used the degree-days method, which consists in calculating the daily difference (in ºC) between a mean temperature and a base temperature. The base temperature can be given a value such that heating or cooling consumption would be at a minimum. Since the choice of such a base temperature would result in the degree-day index taking on positive values in the warm season and negative values in the cold season, we chose to use two separate indices: (a) Heating Degree Days (HDD) and (b) Cooling Degree Days (CDD), using the following mathematical formulas:

$$HDD = \max(T^* - T, 0)$$

$$CDD = \max(T - T^{**}, 0)$$

where T^* and T^{**} are the respective base temperatures for HDD and CDD that can be either the same or different, and T is the daily mean temperature, as obtained from the daily temperatures of the regional climate models for the reference period and the future periods. The HDD (CDD) index is usually summed up for a specific period (annual or seasonal), and therefore provides a measure of the severity of winter (summer) conditions in terms of outdoor dry-bulb temperature. This, in turn, is a measure of the likely aggregate energy demand for reasonable heating (cooling) during that period in a particular location. In the present study, we adopted a base temperature of 15ºC for our HDD calculations and 25ºC for our CDD calculations, in line with the recent study by Giannakopoulos et al. (2009a; 2009b).

One major impact of global warming is that the electricity demand for cooling will increase in summer. This could lead to more frequent network overloads and power disruptions, calling into question the ability to meet demand. The projected changes in the number of days per year with significant cooling needs (defined as days with a temperature 5ºC or more above the CDD base temperature) are represented in Figure 1.36. As can be seen, the low-lying continental

Figure 1.36 Variation in number of days with strong cooling demand in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990

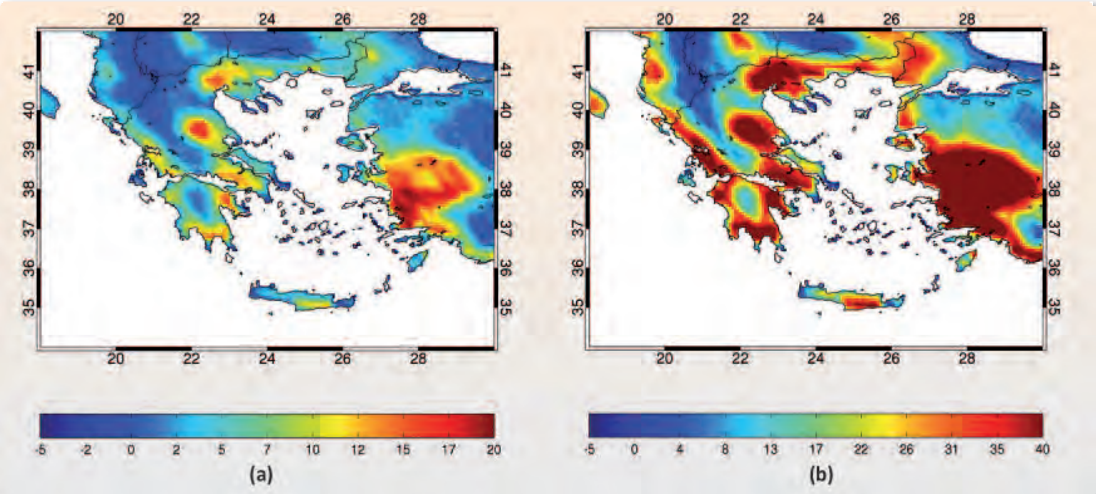
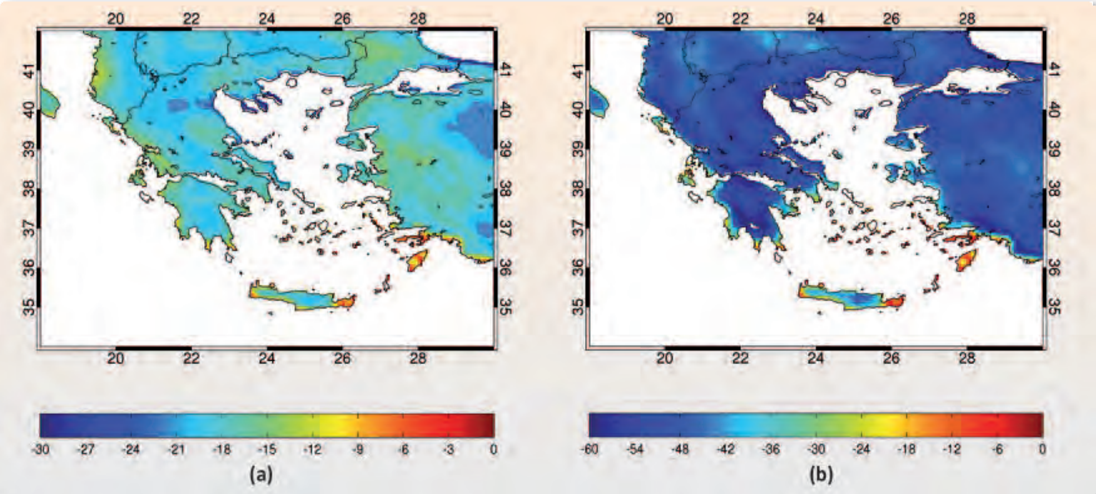


Figure 1.37 Variation in number of days with strong heating needs in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990



regions are projected to have an additional 10-20 days per year with a significant demand for cooling in the period 2021-2050 and 30-40 additional days per year in the period 2071-2100, relative to the reference period 1961-1990. In the island and mountain regions, the respective increases will be smaller.

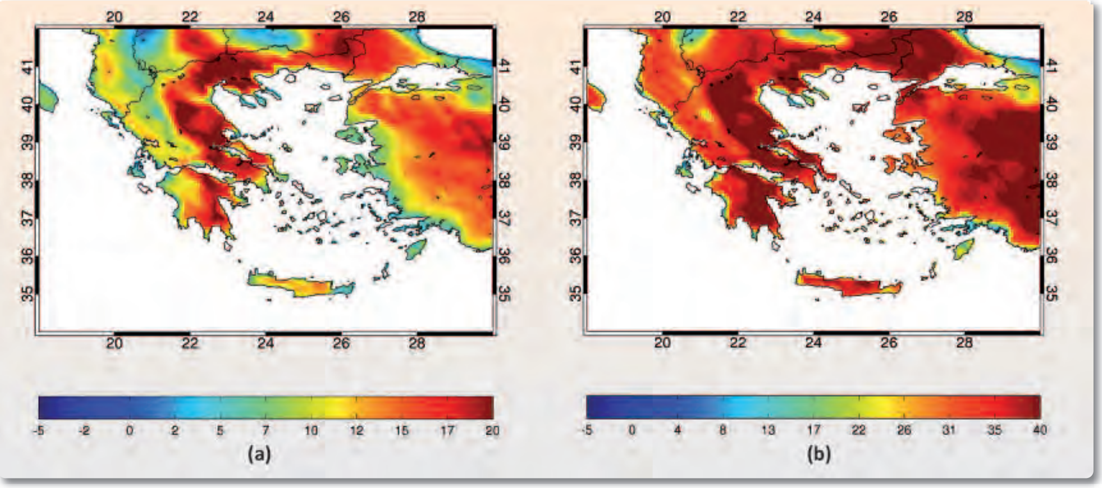
One positive aspect of climate change is that energy needs for heating in winter are expected to decline. As shown by the projected changes in the number of days requiring heavy heating, represented in Figure 1.37, the electricity demand for heating in winter will clearly decline in almost all parts of Greece, by roughly 20 days per year in 2021-2050 and by 45 days per year in 2071-2100.

Forest fires

Forest fires, like all other ecosystem processes, are highly sensitive to climate change, as fire behaviour responds immediately to fuel moisture, which in turn is affected by precipitation, relative humidity, air temperature and wind speed. The projected rise in temperature as a result of climate change should therefore increase fuel dryness and reduce relative humidity, more markedly in those regions where rainfall will decrease. The increased frequency of extreme climate events is expected to have a significant impact on the fire vulnerability of forests.

The Forest Fire Weather Index (FWI) is a daily meteorological-based index, designed in Canada and used worldwide to estimate the wildland fire potential for a standard fuel type. It is computed from six standard components, each measuring a different aspect of fire danger. The first three components refer to forest fuel moisture codes that simulate daily changes in the moisture contents of three classes of forest fuel with different drying rates. The other three components are fire behaviour indices representing the rate of fire spread, the total amount of fuel available for combustion and the frontal fire intensity. The FWI is a numerical rating of a fire's intensity and is used to estimate the difficulty of fire control. The system depends solely on weather readings taken each day at noon: temperature, relative humidity, wind speed and rainfall. In the present study, RCM daily outputs of maximum temperature (Tmax), relative humidity (RH), wind speed at 10 m above ground and total rainfall were used as input variables to the

Figure 1.38 Variation in number of days with extremely high risk of fire in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990



FWI system. The FWI system was developed for Canadian forests, but has found a wide application in other countries and environments, such as Mexico, SE Asia, Florida, Argentina. For the Mediterranean basin, several studies have shown that the FWI system and its components were well suited to the estimation of fire risk in the region (Moriondo et al., 2006). FWI values over 15 were found to be indicative of an elevated fire risk, while FWI values over 30 indicate extreme fire risk (Good et al., 2008).

The projected changes in the number of extreme fire danger days are presented in Figure 1.38. Apart from forest regions, this parameter is equally important to agricultural and tourist areas. In all of Eastern Greece, from Thrace down to the Peloponnese, extreme fire danger days are likely to increase by 20 in 2021-2050 and 40 in 2071-2100. Smaller increases are projected for Western Greece, mostly on account of the higher humidity conditions.

Days with increased thermal discomfort

Heat effects on human comfort (or discomfort) are assessed by computing the humidex (Masterton and Richardson, 1979). This index, used generally during warmer periods to describe how hot or humid the weather feels to the average individual, is derived by combining temperature and humidity values into one number to reflect the perceived temperature. Humidex (equivalent to dry temperature inºC) is computed with the following formula:

$T (h) = Tmax + 5/9 * (e - 10)$

where e is the vapour pressure (given by $6.112 * 10^{(7.5 * Tmax / (237.7 + Tmax))} * h/100$), Tmax is the maximum air temperature (ºC) at 2 m above ground and h is the relative humidity (%).

Figure 1.39 **Variation in number of days with high thermal discomfort (humidex > 38°C) in (a) 2021-2050 and (b) 2071-2100, relative to 1961-1990**

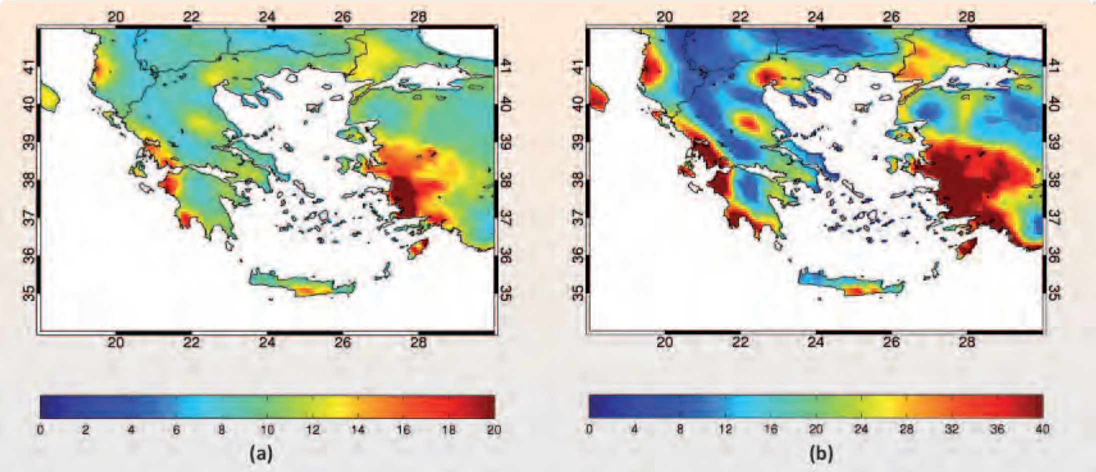


Table 1.9 **Variation in examined climate indicators for each of Greece's 13 climate zones**

	WG	CEG	ATT	WCM	EMT	WP	EP	C	D	CY	EA	NA	I
Minimum winter temperature (°C)	2 4	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5
Maximum summer temperature (°C)	2 4	2 4.5	1.7 4	2 4	2 4	2 4	2.5 4.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5	1.5 3.5
Tmax>35 °C (days)	20 40	20 40	15 35	20 40	15 40	20 40	20 40	15 35	10 15	10 15	10 15	10 15	10 15
Tmin>20 °C (days)	20 50	35 65	40 70	15 20	20 50	25 60	25 60	40 70	40 70	30 60	30 60	25 50	25 50
Maximum 3-day rainfall (%)	0 -10	20 0	10 25	10 20	0 0	0 -15	15 10	0 0	0 0	0 0	15 15	0 10	0 20
Length of dry spell (days)	10 20	15 25	20 35	10 20	10 25	15 30	20 45	20 40	10 30	10 30	10 40	10 30	15 30
Number of frosts (days)	0 0	-10 -25	-5 -5	-15 -40	-15 -30	-5 0	-10 -15	0 0	0 0	0 0	0 0	0 0	0 0
Growing season length (days)	20 35	10 20	10 15	15 35	10 20	10 15	10 15	10 15	10 15	10 15	10 15	10 15	10 15
Days with strong cooling demand	10 35	15 40	10 35	0 10	10 30	10 35	10 35	10 30	5 25	5 20	5 25	5 20	5 20
Days with strong heating demand	-10 -35	-15 -40	-15 -35	-15 -35	-15 -40	-10 -30	-15 -40	-10 -25	-5 -20	-5 -20	-10 -25	-15 -30	-10 -25
Extreme fire risk (days)	10 30	20 40	15 35	20 40	20 40	15 30	20 40	15 35	10 25	10 25	10 30	10 30	10 25
High thermal discomfort (days)	20 40	15 30	15 25	5 10	10 20	20 40	10 25	15 30	20 40	10 20	10 25	10 20	20 40

Climate zones: Western Greece (WG). Central and Eastern Greece (CEG), Attica (ATT), Western and Central Macedonia (WCM), Eastern Macedonia-Thrace (EMT), Western Peloponnese (WP), Eastern Peloponnese (EP), Crete (C), Dodecanese (D), Cyclades (CY), Eastern Aegean (EA), Northern Aegean (NA) and Ionian (I).
Changes with a negative sign indicate a decrease, while those without any sign indicate an increase. The first value in each cell corresponds to the 2021-2050 period and the second one to the 2071-2100 period.

Six humidex categories have been established to inform the general public of discomfort conditions:[28]

- <29°C: no discomfort
- 30-34°C: some discomfort
- 35-39°C: discomfort; avoid intense exertion
- 40-45°C: great discomfort; avoid exertion

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[28] http://www.eurometeo.com/english/read/doc_heat

- 46-53ºC: significant danger; avoid any activity
- >54ºC: imminent danger; heatstroke

The projected changes in the number of consecutive days during summer with a humidex value above 38ºC are represented in Figure 1.39. Interestingly, the coastal and island regions were found to be most affected, contrary to our findings for heat wave occurrences which showed the continental regions to be most vulnerable. In particular, in the coastal regions of the Ionian and the Dodecanese islands, the period with humidex>38ºC is projected to be 20 days longer in 2021-2050 and 40 days longer in 2071-2100, with obvious repercussions on human discomfort and, ultimately, health. In the low-lying continental regions and in Crete, the period with humidex>38ºC is projected to be some 15 days longer in 2021-2050 and 25 days longer in 2071-2100, whereas the mountainous regions will not experience significant changes and will retain their cool summer climate.

Table 1.9 summarises the findings of our analysis, presented per respective climate indicator, for each of Greece's 13 climate zones.

Statistical distributions for five large cities in Greece

This section further analyses the projections of the KNMI/RACMO2 model,[29] focusing on the statistical distribution of maximum temperatures as well as on extreme summer events for Greece's five largest urban centres. The kernel density estimations of maximum temperature (a non-parametric way to estimate the probability density function) for each of these large cities are represented in Figure 1.40. For all five cities, the temperature distribution curve for the reference period 1961-1990 (blue line) has two maxima corresponding, respectively, to the onset of the cold season (left maximum) and the warm season (right maximum). The distribution curves for the two future periods (2021-2050 in orange and 2071-2100 in violet) shift progressively to the right, reflecting a mean climate warming. As can be seen from the tails of the distribution curves, the temperature during extremely hot weather events (right tail of the curves) is projected to be 1-2ºC higher.

Turning to the occurrence of abnormally hot summers, Figure 1.41 illustrates the frequency of deviations of the summer mean maximum temperature (June-August mean values) from the climatological summer mean (1961-1990), for each of the 30 years of the period 1961-1990 (blue histogram) and 2071-2100 (coral histogram). In most cases, the histograms for the two periods overlap only slightly (violet histogram), suggesting that the 'cooler' summers at the end of the century are likely to be as warm as the hottest summers of the recent past. Of particular interest is the case of Athens: the summer of 1987, which —with its major heat wave that cost

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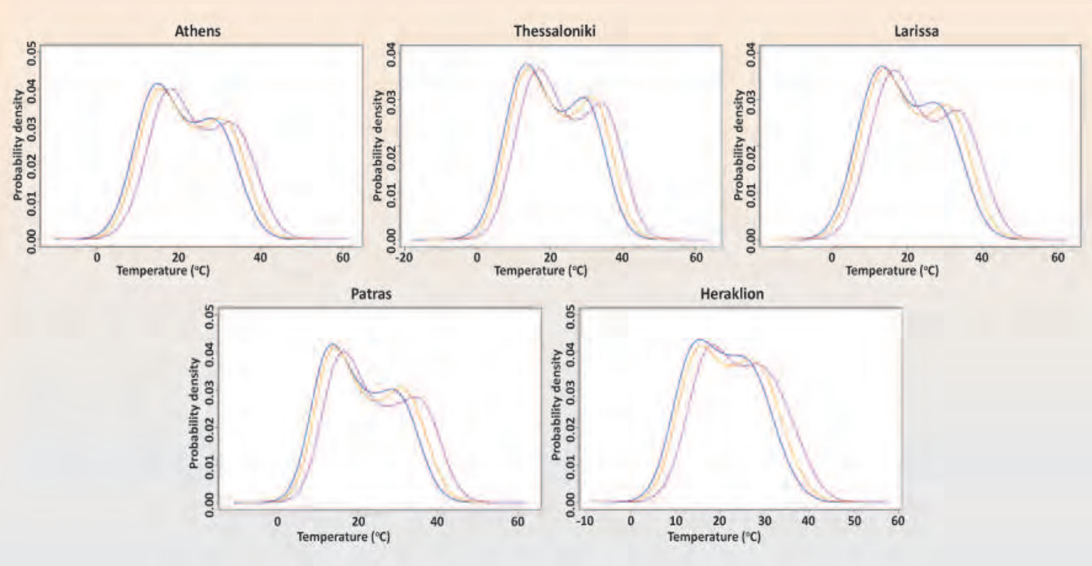
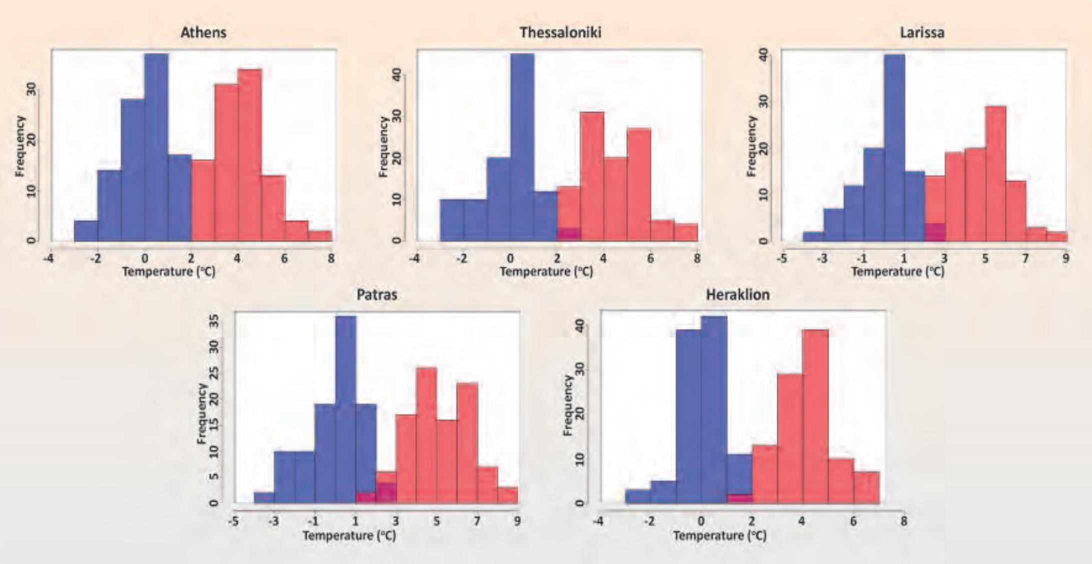
[29] The model used is known as 'RACMO2', i.e. the second version of the regional atmospheric climate model of the Royal Netherlands Meteorological Institute (KNMI).

Figure 1.40 **Kernel density estimates of maximum temperature for five major Greek cities**



Kernel densities: non-parametric estimates of the probability density function.
Blue line: 1961-1990, orange line: 2021-2050, violet line: 2071-2100.

Figure 1.41 **Frequency of deviation of mean summer maximum temperature (June to August) from the 1961-1990 average for five major Greek cities**



Periods 1961-1990 in blue; 2071-2100 in pink; overlap in purple.

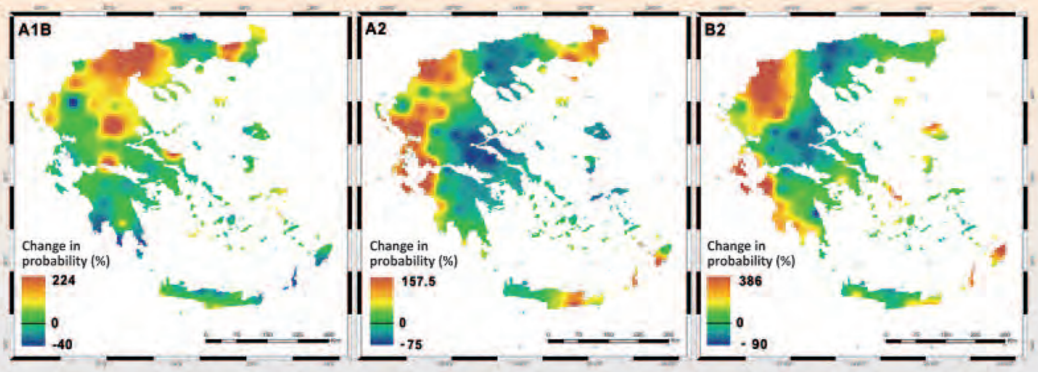
hundreds of lives in July— was the hottest summer of the reference period 1961-1990 (1.7ºC warmer than the climatological mean 1961-1990), would be considered quite cool (and even outside the probable distribution range) at the end of the century.

1.17 Changes in the intensity and distribution of landslides and floods in Greece

In the present section, we examine the variability of climate parameters and their likely regime, and the impact that such variability is likely to have on flood and landslide hazards. The datasets used for the purpose of the analysis were taken from an ECHAM5 model run for Scenario A1B and from a HadCM3 model run for Scenarios A2 and B2.

With regard to landslides, we examined the effect of rainfall intensity variability, a factor crucial to landslide occurrence (Caine, 1980; Koukis and Ziourkas, 1989). This meant that we first had to study the probability of rainfall exceeding certain thresholds beyond which landslides become highly probable (Caine, 1980), as well as possible changes in this probability. This probability change served as a means of assessing changes in landslide probability and,

Figure 1.42 Percentage change in probability of exceedance of rainfall intensity threshold for landslides

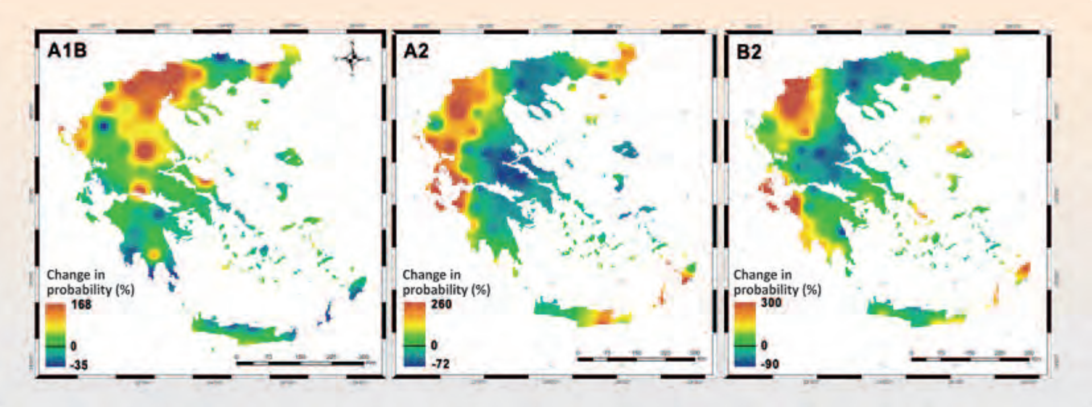


Between the reference period (1960-1990) and the 2070-2100 period for Scenarios A2 and B2, and the 2090-2099 period for Scenario A1B.

Table 1.10 Variation in probability of exceedance of rainfall threshold for landslides, based on the HadCM3 model for Scenarios A2 and B2 and the ECHAM5 model for Scenario A1B

	Probability of exceedance	Percentage change in probability		
Period	**1960-1990**	**2070-2100**		**2090-2099**
Scenario		**A2**	**B2**	**A1B**
Global threshold	0.011	+38.4	+10.6	+ 29.3
Local threshold	0.007	+44.6	+11.9	+ 33.7

Figure 1.43 **Percentage change in probability of exceedance of rainfall intensity threshold above which flood risk becomes high**



Between the reference period (1960-1990) and the 2070-2100 period for Scenarios A2 and B2, and the 2090-2099 period for Scenario A1B.

Table 1.11 **Average percentage change in probability of exceedance of rainfall intensity threshold above which flood risk becomes high**

Scenario	Period	Average percentage change in probability of exceedance
A1B	2090-2099	+ 30.15
A2	2070-2100	+ 24.7
B2	2070-2100	+ 6.45

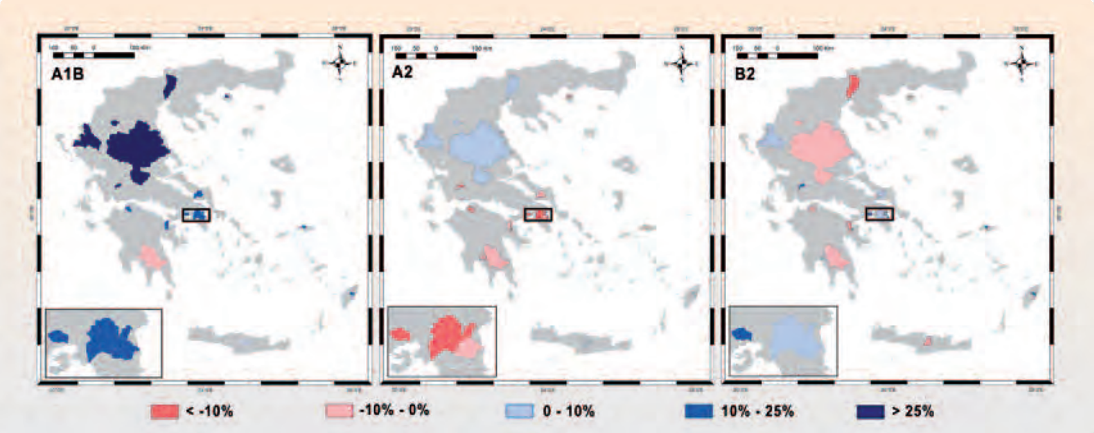
The reference period is 1961-1990.

thus, in landslide hazard. For the purpose of our calculations, we used the global threshold proposed by Caine (1980) and the regional threshold proposed by Calcaterra et al. (2000) for the Mediterranean.

The final results were obtained by calculating the percentage change in probability of rainfall exceeding the thresholds between the reference period (1960-1990) and the periods 2071-2100 (for Scenarios A2 and B2) and 2090-2099 (for Scenario A1B). The results present similar spatial distributions with regard to both thresholds, and point to significant increases, but also decreases, in landslide probability depending on the region (Figure 1.42). More specifically, the landslide probability increases 1.5 times (Scenario A2) and 3 times (Scenario B2) in Western Macedonia, Western Greece and the Western Peloponnese, while smaller increases of 1.4 times (Scenario A2) and 2 times (Scenario B2) are projected for Eastern Crete, the Dodecanese and Evros (Eastern Thrace). In contrast, the landslide probability is projected to be 50% lower (Scenario A2) and 90% lower (Scenario B2) in Central Greece, Central Macedonia and the Peloponnese. Under Scenario A1B, the landslide probability is projected to increase by up to 2 times in the largest part of Greece, with the greatest increases observed in Central Macedonia and Thessaly (100-224%), whereas decreases are projected for the Southern Peloponnese and some parts of the Dodecanese. In terms of average changes, significant differences (in the order of 10-45%) are observed in the results of the three scenarios (Table 1.10), with Scenario B2 presenting the smallest changes and Scenario A2 the largest.

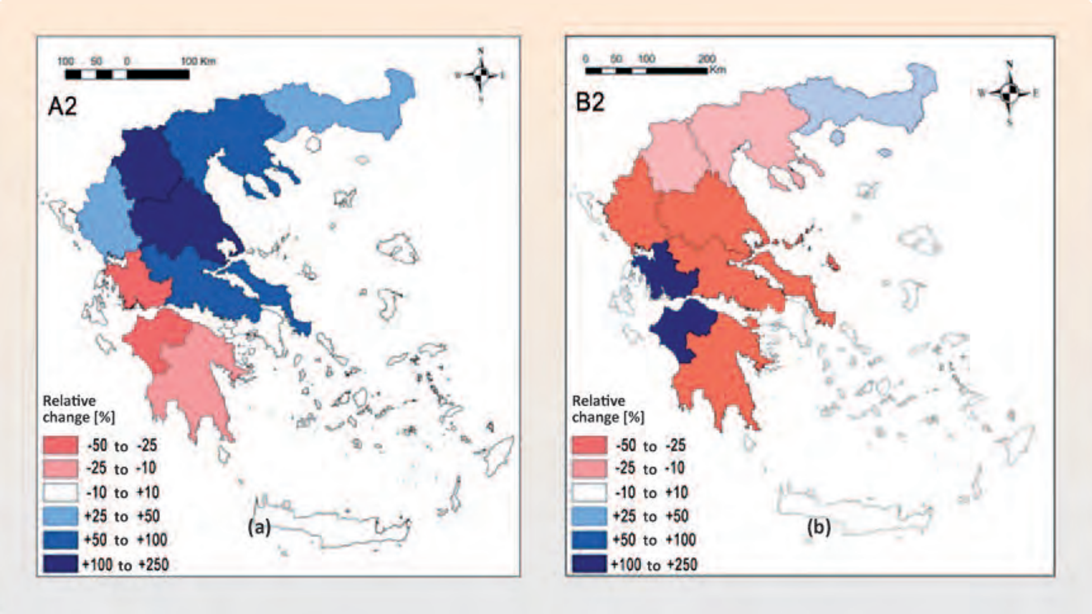
Turning to floods, we examined the future variability of heavy rainfall, as well as the effect of such variability on the flood occurrence regime. This indicator was chosen because of its established association with flood phenomena (Loukas et al., 2002; Lehner et al., 2006; Georgakakos, 2006; Norbiato et al., 2008). In order to achieve this, we analysed the projected changes in the probability of rainfall intensity exceeding the thresholds beyond which flooding becomes highly probable (Cannon et al., 2008; Diakakis, 2011). The results point to significant variation in flooding probability across the different regions depending on the climate scenario (Figure 1.43) and to increases in average values under all the scenarios for the periods 2071-2100 and 2090-2099 (Table 1.11). Specifically, the probability of flooding was projected to be 2.6 times higher (Scenario A2) and 3 times higher (Scenario B2) in the Western Peloponnese, Epirus and Western Macedonia, but 50% lower (Scenario A2) and 90% lower (Scenario B2) in Central Greece and Central Macedonia. Under Scenario A1B, the probability increases by as much as 168% almost everywhere in the country, with the highest increases recorded for Central Macedonia and Thessaly, but decreases by as much as 35% in the Southern Peloponnese, Northern Crete and the Dodecanese.

Figure 1.44 Percentage change in peak discharge rate with a 5-year return period in the 19 catchment areas studied



Calculated using Sutcliffe's (1978) method. Changes under Scenarios A2 and B2 were calculated using the results of HadCM3 model simulations for the time periods 1961-1990 and 2071-2100. Changes under Scenario A1B were calculated using the results of ECHAM5 model for the time periods 1990-1999 and 2090-2099.

Figure 1.45 **Relative percentage change in the estimated annual cost of direct damage from floods**



Under Scenarios A2 and B2 (HadCM3) between the periods 1960-1990 and 2070-2100 (Ciscar et al., 2009, modified).

In order to assess the future variation of flood hazards, we examined the projected changes in discharge of 19 selected hydrological basins of different sizes and geomorphology, selected in such a manner as to ensure that the geographical range was representative of the country as a whole. The projected changes were assigned a sign and magnitude. Using the method proposed by Sutcliffe (1978), we calculated the change in peak flows with a 5-year return period for these basins (Figure 1.44). The change in flood damage was calculated on the basis of models developed to assess the country-specific consequences of flooding (Ciscar et al., 2009), as well as the estimated change in flow of major waterways (Figure 1.45).

In summary, based on the results of our climate modelling and subsequent analysis, the future variation of flood and landslide risk regimes presents, on average, an increasing trend. However, in certain regions, the probability of such disaster event occurrence will decline. The values of change obtained are similar to the ones reached by other researchers, for instance Frei et al. (2006). The range of values obtained both in the present study and in other studies with results of a similar scope (Huntingford et al., 2003; Barnett et al., 2006; Frei et al., 2006) highlights the degree of uncertainty surrounding the projection of extreme values. The results should be interpreted with caution, as flood and landslide risks both depend on additional factors such as change in vegetation, land-use and anthropogenic impact (Alcamo et al., 2007), which are not assessable in full, but are expected to play a significant role in the occurrence of such disasters.

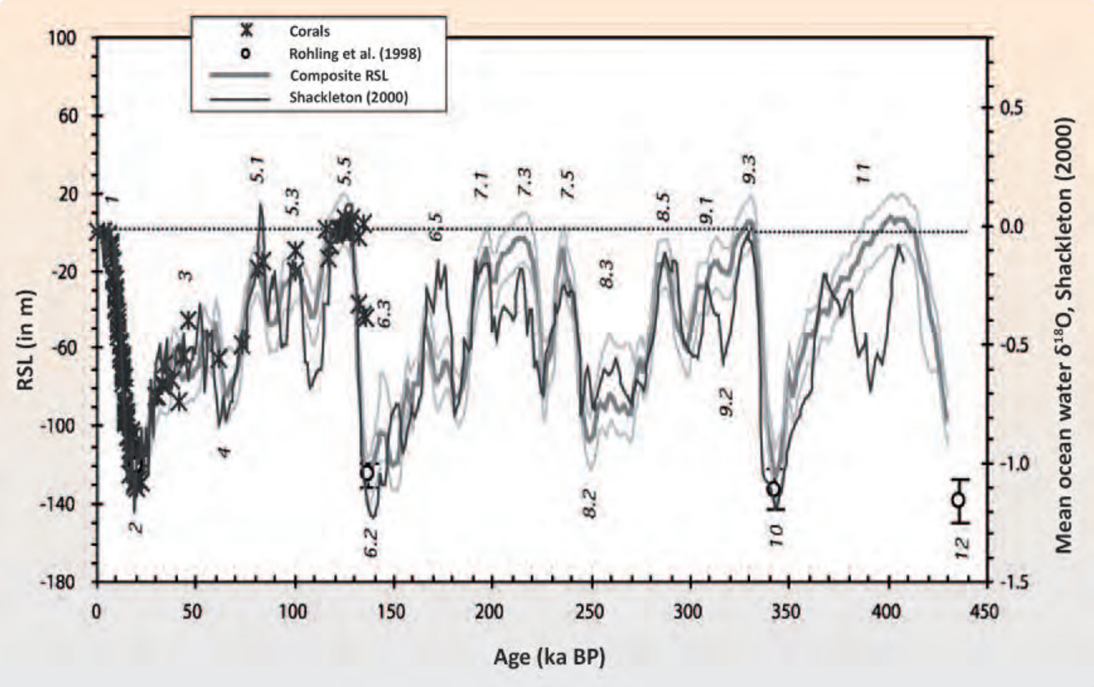
1.18 Change in mean sea level and its impact on Greece's shorelines

1.18.1 Global sea level changes in the geological past

Based on the records of global sea level change over the last 500,000 years (ka), for which available paleoclimatic data are more accurate, it has been estimated that the sea level during interglacial Marine Isotope Stage (MIS) 11 (400 ka BP, e.g. Bowen, 2009; Rohling et al., 2010), MIS 9c (320 ka BP), MIS 7e and MIS 7a (respectively, 237 ka BP and 197 ka BP, e.g. Siddall et al., 2003; Rabineau et al., 2006) may well have been close to current levels (Figure 1.46). During the more recent interglacial MIS 5 (120-125 ka BP), the sea level is estimated to have been 4-9 m higher than present (e.g. Stirling et al., 1998; McCulloch and Esat, 2000; Kopp et al., 2009), with a peak rate of increase of 10-16 mm/year (Rohling et al., 2008). This rate is similar to the rise of 10-20 mm/year estimated for the exceptionally long MIS 11 interglacial period (400 ka BP), as well as for the four 'warm' episodes within MIS 3 (60-25 ka BP; Siddall et al., 2008). The latest increase in sea level (20-6 ka BP) was in the order of 10 mm/year (Rohling et al., 2010).

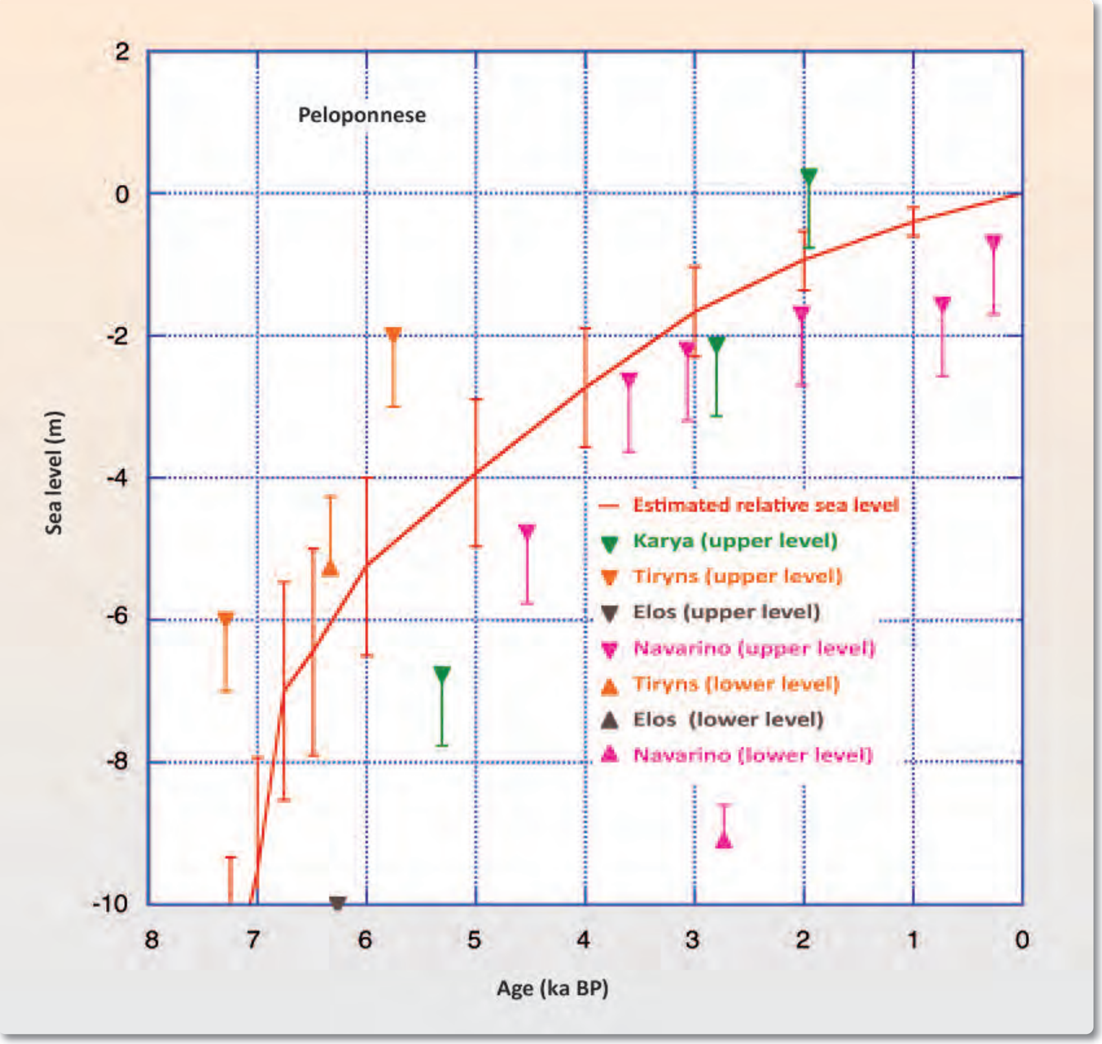
The global mean sea level is estimated to have risen 120-130 m since the last glacial maximum (about 21 ka) (e.g. Shackleton, 2000; Waelbroeck et al., 2002; Siddall et al., 2003; Peltier

Figure 1.46 **Composite relative sea level (RSL) over the past 450 ka**



Crosses: coral reef RSL data. Empty circles: RSL low stands estimated by Rohling et al. (1998). Right axis: variations in mean ocean water δ^{18}O derived by Shackleton (2000) from atmospheric δ^{18}O (black line). The numbers above sea-level curves represent marine isotope stages (MIS). Chart from Waelbroeck et al. (2002).

Figure 1.47 **Estimated variation curve in paleo-sea level of the Peloponnese**



Comparison with observed sea levels in selected areas. The above chart shows upper and lower levels of estimated sea level. Field data from Kraft and Rapp (1975) and Kraft et al. (1977, 1980), and summarised by Lambeck (1995b).

and Fairbanks, 2006). During the current interglacial, the rate of sea level increase is estimated to have been close to 11 mm/year from 14 to 7 ka BP (Bard et al., 1996), and to have dropped to 1 mm/year over the last 6 ka (Lambeck, 1995; Lambeck and Purcell, 2005; Figure 1.46). Recent studies have shown that the sea level is still on the rise today (IPCC, 2007; Poulos et al., 2009a; Woodworth et al., 2009).

Focusing more specifically on the area of Greece, the sea level during 21-18 ka BP (end of the last glacial period) was 105-120 m lower than it is today (e.g. Pirazzoli and Pluet, 1991; Lambeck and Bard, 2000), but according to Lambeck (1995; 1996) and Lambeck and Purcell (2005), it rose rapidly between 11.5 ka and 6 ka, due to glacio-eustatic fluctuations, to 2 m below current sea level (Northern Aegean) and to 6 m below current sea level (Southern

Table 1.12 **Past sea level (SL) and rate of sea level rise for various time intervals, along with the geographical origin of indicated data**

Time period	Past sea-level (SL)	Rate of SL rise	Geographical origin of data	References
From 21 to 18 ka BP	Between -120 m and -105 m			
From 8 to 6 ka BP		8.5 mm/year	Euboia	Kambouroglou et al. (1988)
From 10 to 5 ka BP		4 mm/year	Thessaloniki	Vouvalidis et al. (2005)
8.3 ka BP	-28 m		Thessaloniki	Chronis (1986)
From 8 to 7 ka BP		12.3 mm/year	Akarnania	Vött (2007)
From 7.6 to 6.2 ka BP	-11 m		Plain of Argolis	Jacobsen and Farrand (1987), van Andel (1987)
From 7 to 6.5 ka BP		6.0 mm/year	Peloponnese	Lambeck and Purcell (2005)
Last 6 ka BP	-2 m		Northern Aegean	Lambeck (1995), Lambeck and Purcell (2005)
Last 6 ka BP	-6 m		Southern Aegean	Lambeck (1995), Lambeck and Purcell (2005)
From 6 ka BP to 0 BC		2.5 mm/year	Cyprus	Gifford 1980
Last 6 ka BP		1 m/1000 years	Peloponnese	Lambeck and Purcell (2005)
From 6 to 2.5 ka BP		0.2–1.4 mm/year	Akarnania	Vött (2007)
Last 4 ka BP		1.0 mm/year	Thessaloniki	Vouvalidis et al. (2005)
From 5.5 to 1.3 ka BP		1.68 mm/year	Marathon	Pavlopoulos et al. (2006)

Aegean). Indicatively, the rate of sea level rise during 8-6 ka BP was about ~8.5 mm/year in Southern Euboia (Kambourolgou et al., 1988), 12.3 mm/year in SW Akarnania (Vött, 2007) and 6 mm/year in the Peloponnese (Lambeck and Purcell, 2005; Figure 1.47). During the last 5,000-6,000 years, the sea level continued to rise at a rate of <1 mm/year, without ever exceeding the current levels and without excluding small variations in the rate of increase (Lambeck and Purcell, 2005; Pavlopoulos et al., 2007; Vött, 2007; Poulos et al., 2008a). Table 1.12 summarises typical rates of sea level rise over time for various Greek coastal regions.

1.18.2 Current and future mean sea levels

As shown by instrumental measurements (tide gauges, satellite altimetry), mean sea level has been rising at a rate of 1.8 mm/year since the late-19th century, while based on satellite measurements for the last 15 years, this rate has accelerated to 3 mm/year (Bindoff et al., 2007). As reported in IPCC (2007), by 2100 the air temperature is projected to rise by 1.1-2.9ºC under the most conservative scenario (B1) and by as much as 2.4-6.4ºC under the worst-case scenario

(A1FI). Meanwhile, sea level rise for the period 2090-2099, relative to the period 1980-1999, is projected to range between 0.18 m and 0.38 m under Scenario B1, and between 0.26-0.59 m under Scenario A1FI. However, subsequent studies anticipate an even greater sea level rise by 2100. According to the semi-empirical model advanced by Rahmstorf (2007) relating the rates of change in global surface temperature to sea level, a rise in temperature of 1ºC corresponds to a sea level rise of 10-30 cm. Applying this ratio to the rise in temperature of 1.4-5.8ºC projected by the SRES scenarios (IPCC, 2007), we obtain sea level rise figures of 0.5-1.4 m. The most adverse projections are reported in Pfeffer et al. (2008), with sea level rise likely to reach 0.8 m to 2 m. According to this study, the IPCC (2007) has not successfully modelled the dynamic development (decline) of the Greenland and Antarctic glaciers, a view recently also supported by other researchers (e.g. Rohling et al., 2009; Grinsted et al., 2010).

1.18.3 A comparison of sea level projections with paleoclimatic data

The current rates of sea level rise are markedly lower than those of past interglacials (e.g. 120 ka BP), some interstadial phases of the last glacial period (40-41 ka BP) and the beginning of the current interglacial (14-8 ka BP).

Looking at the course of sea level changes during the Holocene, it would seem that the sea level is currently nearing its upper limits, given on one hand the highstand recorded since the beginning of the ‘warm’ period (similar to other previous warm periods) and the slowdown in the rate of sea level rise in the past 5,000-6,000 years. Still, the course of sea level changes remains uncertain, as signalled by the significant acceleration in the rate of increase (3 mm/year) in the last 15 years. This development, likely associated with greenhouse gas-induced global warming, in turn a cause of ‘glacier waning’, leads us to the conclusion that today’s higher rate of sea level rise is likely to pick up further, to values not unheard of in the geological past. One would also have to factor in the impact of orbital forcing on the course of the current climate cycle, as orbital forcing would be directly linked to the onset of the next glacial period.

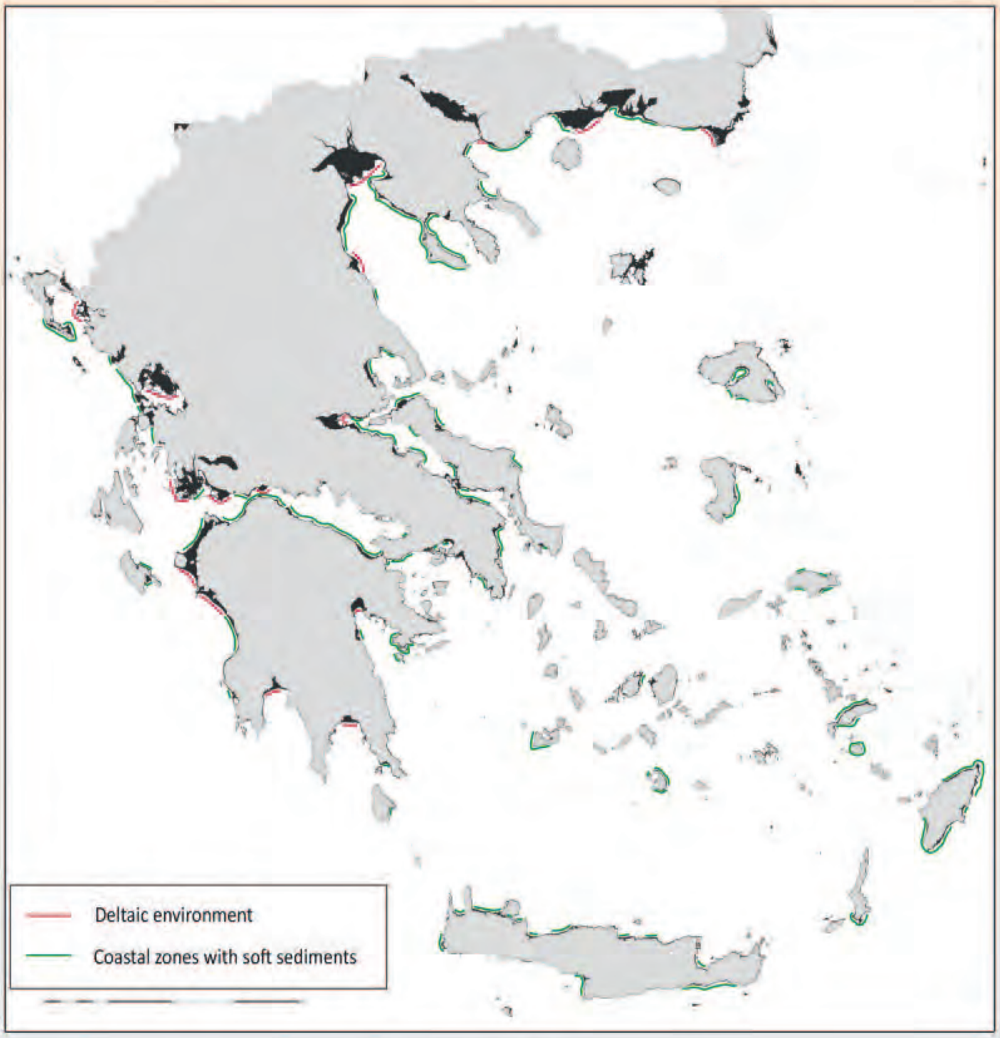
1.18.4 Coastline classification into geomorphologic-geodynamic categories and map representation

Given that the sea level rise by 2100 is, depending on the scenario, projected to be between 0.2 m and 2 m, we chose to examine which parts of Greece’s coastline would find themselves ‘endangered’ if the sea level were to rise by 1 m.

However, the vulnerability of a coastal region cannot be safely estimated on the basis of the rate and scale of sea level rise alone. Other local factors, such as tectonics, sediment transport (from inland) and coastal geomorphology/lithology, also need to be taken into account.

Tectonics obviously play a highly important role in tectonically active areas, as a rise in sea level can be offset (amplified) by tectonic uplift (subsidence). Typical examples in Greece are

Figure 1.48 **Classification map of Greece's coastal zones**



Greece's coastal areas can be classified into: a) coastal areas of medium vulnerability to sea level rise (in green), usually of low altitude and consisting of soft sediments of the Neogene and Quaternary age; b) coastal areas of high vulnerability to sea level rise (in red), low-lying and formed of deltaic deposits; and c) rocky coastal areas of low vulnerability to sea level rise (black sections) of high altitude.

the coastal zone of the Northern Peloponnese, with an uplift rate of 0.3 to 1.5 mm/year, Crete with 0.7 to 4 mm/year and Rhodes with 1.2 to 1.9 mm/year. Thus, a supposed average value of sea level rise of 4.3 mm/year would be reduced to 3.5 mm/year due to the counteraction of a mean tectonic uplift of 0.8 mm/year.

A change (i.e. increase) in sediment discharge and deposition in large river delta-front estuaries can cause the delta front to advance and locally offset the sea level rise. Conversely, a decrease in river sediment discharge could reinforce the incursion of the sea following a sea level rise.

Lastly, another important determinant of coastal vulnerability to sea level rise is the coast's morphology and, specifically, the slope and lithological composition, factors directly associated with erosion rates. An erosion rate can range from very high (several metres per year) in the case of coastlines with a low-lying geomorphology and an 'erodible' lithology, to low (mms per year) in the case of hard coastal limestone formations (e.g. cliffs).

Taking all of the above factors into consideration and using a map scale of 1:50,000, Greece's coastal areas can be subdivided into the following three main zones (Figure 1.48):

1) Deltaic coastal areas. Represented in red in Figure 1.48, these low-lying coastal areas are formed of loose, unconsolidated sediment deposits and are highly vulnerable to sea level rise.

2) Coastal areas consisting of non-consolidated sediments of Neogene and Quaternary age. Represented in green, these coastal areas, usually of low altitude, are prone to recessional erosion and present a medium vulnerability to sea level rise.

3) Rocky coastal areas. These coastal areas (without any specific colouring/marking in Fig. 1.48) consist mostly of hard rock of low vulnerability to erosion and sea level rise, form the bulk of Greece's coastline.

The estimation of the length of these three types of coastal areas, as illustrated in Figure 1.48, shows that out of the total ~16,300 kms of coastline, 960 km (6%) correspond to deltaic areas of high vulnerability (red colour); 2,400 km (15%) correspond to non-consolidated sediments of medium vulnerability (green colour), and the remaining 12,810 km (79%) correspond to rocky coastal regions of low vulnerability. Thus, the total coastline length presenting medium to high vulnerability to sea level rise amounts to 3,360 km or 21% of Greece's total shoreline.

1.18.5 Estimates of shoreline retreat due to the rise in mean sea level

Table 1.13 presents indicative approximate values of flooded coastal areas and shoreline retreat (without any correction for tectonic and geodynamic effects) in response to possible sea level rises, respectively, of 0.5 m and 1 m in high-risk deltaic areas, such as the Axios river delta, the Aliakmon river delta and the Alfeios river delta (Poulos et al., 2008b). The shoreline retreat was estimated to range between 30 m and 2,750 m in response to a possible sea level rise of 0.5 m, and between 400 and 6,500 m in response to a rise of 1 m.

Assessing the severity of a possible sea level rise impact on coastal regions involves a degree of uncertainty, concerning:

(a) The intensity of the sea level rise, with projections ranging between 0.2 m and 2 m. The sea level rise will be determined by the interaction between several factors, both natural (e.g. astronomical forcing) and anthropogenic (e.g. greenhouse gases). The severity of each factor will determine the overall evolution of the current climate cycle, which should soon be crossing the finish line of the current 'warm' interglacial period.

Table 1.13 **Estimated coastline retreat (in m) and coastal inundation from a potential sea-level rise of 0.5 m and 1 m, for various deltaic areas of Thermaikos Gulf and Kyparissiakos Gulf (Poulos et al., 2008b)**

Coastal area	Sea-level rise (m)	Coastline retreat, Bruun's model (m)	Coastline retreat due to sea-level rise (m)	Coastline retreat due to coast erosion (m)	Total coastline retreat (m)	Inundated area (km²)
Alfeios Delta (northern part)	0.5	51.1	175	15	190	224
	1.0	102.2	810	-110	700	683
Alfeios Delta (southern part)	0.5	54.5	15-30	0-15	30	35
	1.0	109.0	10-100	400	400-450	344
Axios Delta	0.5	52.7	250-2,000	0	250-2,000	10,825
	1.0	213.6	2.000-2,500	0	2,000-2,500	28,482
Aliakmon Delta	0.5	63.6	50-1,750	0	50-1,750	4,875
	1.0	195.4	250-2,500	0	250-2,500	8,950
Deltaic plain of Loudias-Aliakmonas	0.5		500-2,750	0	500-2,750	8,900
	1.0		5,000-6,500	0	5,000-6,500	25,575

(b) The relationship between tectonic uplift and the eustatic sea level rise. In several areas of Greece, the high tectonic uplift may locally offset and sometimes even exceed the eustatic sea level rise.

(c) The sedimentation of clastic materials in coastal areas, which is determined by geological and climatic conditions, as well as by anthropogenic intervention (e.g. dams, river sand mining). In the case of river delta areas for instance, these factors could alter their vulnerability to sea level rise.

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Chapter 2

The risks and impacts of climate change by sector*

2.1 Climatic changes and impacts on Greece's water systems**

2.1.1 Introduction

The concept of water resources derives from the relationship between the water required for various human activities (water needs) and the availability or search for water flows and reserves (water resources) in the natural environment that would be fairly easy to exploit to meet these needs.

From another perspective, water resources can be seen as the environment's capacity for water supply. The above relationship can concern different spatiotemporal and economic spheres. Supply (water resources) and demand (water needs) are both characterised by:

(a) location;

(b) quantitative variability over time (e.g. variation in quantity of water in a flow or reserve; and

(c) quality.

With regard to quality, distinctions are made between:

(a) the quality *supplied*, determined by the physical and chemical properties of the water in its natural environment, generally affected by the importance of the flow and depending on its characterisation according to use (criterion of needs from the natural environment); and

(b) the quality *required*, expressed in terms of the specifications that apply to each water use. Specifications tend to evolve with the increase in awareness in the fields of toxicology, medicine (water supply), biotechnology (irrigation), technology (industrial use) and ecology.

In economic terms, water resources are characterised by adequacy, overabundance and shortage, while with a view to ensuring the best possible allocation of water resources for each use an additional distinction is made between:

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* The bibliographies for all sub-chapters can be found at the end of Chapter 2.

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Table 2.1 **Anthropogenic impact on water balance**

Type of impact	Impact	
	Impact on inflows (deposits)	Impact on outflows (runoff)
Increase	Input of water (transfer). Capture of surface or underground water by an adjacent environment.	Decrease of real evapotranspiration, drainage. Output of water (partial phenomenon).
Decrease	Enhancement of real evapotranspiration. Decrease of active precipitation.	Consumption.

– the cost of *supply*, adjusted to each specific case of supply and demand in function of the above parameters (location, regime, and quality); and

– the cost of *needs*, expressed with different measures of 'water value' (value added, use value, etc.).

A system of water resources provides an ideal setting for the formulation and presentation of a water balance, quantified with respect to a specific time frame. The effects of anthropogenic activities on the components of this balance are summarised in Table 2.1.

2.1.2 State of play of Greece's water reserves

The state of Greece's water reserves and water management is of specific interest, with certain particularities indicative of the level of actual development and organisation. With regard to these particularities, Greece presents a wide variety and complexity of situations, the most predominant of which are:

– the uneven temporal distribution of precipitation, with over 85% of total precipitation falling during the winter (wet season) and the rest occurring in the summer (dry season);

– the highly uneven spatial distribution of precipitation, with higher rates of precipitation reported in Western Greece (west of the Pindos mountain range) and lower rates reported in Eastern Greece;

– the fact that the northern part of Greece is (quantitatively and qualitatively) affected by transboundary waters, with four major rivers originating in neighbouring countries, i.e. three in Bulgaria (the rivers Evros, Nestos, Strymon) and one in FYROM (the river Axios);

– an important period of water demand imbalance, with peak abstraction for irrigation and tourism typically occurring in the summer months when water availability is generally at a minimum (almost no rainfall).

– the highly uneven spatial distribution of demand, as a result of overconsumption associated with the excessive concentration of people in urban centres, the coastal zone and other areas;

– the country's complex configuration, both in geological terms (aquifer and surface flow) and geomorphological terms (surface flow generation);

– the tremendous length of Greece's coastline (approximately 16,300 km), relative to the country's total area, which, combined with the over-pumping of coastal aquifers, favours inland seawater intrusion; and

– the conditions specific to most of the Aegean Sea's many islands (low levels of rainfall, small overall surface, rough topographic relief with high surface runoff and low soil infiltration).

In terms of water reserves, Greece rightly qualifies as a 'rich' country, in comparison, of course, with the rest of the broader Mediterranean region, and this for a number of reasons associated with, and responsible for, the atmospheric precipitation regime. Quite remarkably for a country situated in the Mediterranean basin, Greece's mean annual precipitation is in the order of 800 mm, both on account of more general factors shaping the country's climate and weather patterns and on account of the country's complex topographic relief. A key factor in this respect is the Pindos mountain range, which receives moist winds from the west. Thus, precipitation west of the Pindos ridge is far heavier than in the regions to the east.

Greece's varied topographic relief offers favourable ground for the emergence of a dense surface drainage network, with particularly dense hydrographic networks and final recipients a number of large rivers (for a country the size of Greece) that drain surface and part of underground waters, to the extent that spring water discharges enhance surface flow. The rivers of Northern Greece represent a special case, as their upper courses, as previously mentioned, are in neighbouring countries (the rivers Evros, Nestos, Strymon originate in Bulgaria, and the river Axios in FYROM). The only river flowing in the opposite direction is the river Aoos, which originates in Greece and discharges in Albania. Greece's underground aquifers are also considerable, given that much of the country consists of permeable rock allowing primary or secondary infiltration. Such are the cases of the large inland and deltaic alluvial basins, and the carbonate rocks of karstic aquifers (limestone, dolomite, marble, gypsum, etc.).

Although none of the country's 13 water districts faces imminent water shortage, there are indications —as shown in Chapter 1— that the country's water potential is decreasing. According to the results of the ENSEMBLES research project,[1] Central and Northern Greece have seen their precipitation levels decrease over the last five decades, with the decrease per decade starting at 30 mm and regionally reaching 150 mm. At the same time, a comparison of river flows between 1971-1998 and 1900-1970 shows water flow to have decreased by 5-10% countrywide, save for the Epirus region where the decrease was found to be 2-5% (Milly et al., 2005).

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[1] http://www.ensembleseu.org

2.1.3 Conflict and mismatch between water requirements and water resources

The conflict between water requirements and water supply can be conceptualised by comparing (in qualitative and quantitative terms) the actual water requirements for specific uses, on one hand, with the water resource system (the properties of given water resources). The purpose of this exercise is mainly to determine resource adequacy and to identify possible water shortage risks.

The spatial examination of water sufficiency on a regional or national scale is where the concept of available water reserves comes into play. These reserves represent resources minus water abstraction on a local scale, and resources minus consumption on a national (or drainage basin) scale. One fundamental reason for this distinction is that water abstracted (for instance, at a local scale) may re-enter the system, thus becoming available for re-use, meaning that the available water resources need to be 'recalculated' to take any water re-entrances into account. In any event, management programmes need to distinguish between "water transfer" (from one basin or sub-basin to another, which alters the regional distribution of natural and exploitable natural resources) and "water addition" (transfer of water from a site of withdrawal to another area for use).

From a temporal perspective, the average amounts of water withdrawal are compared to the exploitable water resources, a method that makes it difficult to identify the impacts of variability over time on both sides of the equation. Such changes are determined by temporary inadequacies and all relevant problematic conditions (annual or seasonal), due to inadequate supply (drought) or excessive requirements. It is therefore necessary to determine the minimum values of the exploitable resources for a given acceptable time period and to establish, at a readjustment level, the local exploitation index (total water abstraction as a percentage share of natural resources), the regional exploitation index (total consumptions as a percentage share of natural resources), as well as other parameters, essential for elaborating a suitable and viable water management programme.

When examining water as a natural resource in adequacy terms, a clear distinction needs to be made between two very different concepts, sometimes confused even by specialists and policy makers. The first concept, *drought* or *aridity*, refers to a deficiency in the water supply to the environment – either direct (rainfall) or indirect (surface and underground), relative to the measurements of past time series. The second concept, *water scarcity*, refers to a decrease in available water potential, in comparison with present or anticipated use. Water scarcity can be a result of a drought (in which case the two concepts may quantitatively coincide), but can also occur at a time of normal or above-average water supply, as a result either of water mismanagement or of incorrect water use planning.

When discussing water availability issues, another major consideration is the breakdown of consumption by sector. At the global level, agriculture is the prime consumer of water: water consumption driven by agricultural needs has not only risen exponentially, it is projected to exceed 3,000 million m^3 by 2025, i.e. six times the consumption of the early 20th century. The industrial sector, second in terms of quantities consumed, also accounts for a steady rise in water consumption. By 2025, the water consumed by the global industrial sector is projected to be in the order of 1,000 million m^3. Water consumption by households, i.e. the sector that has always had the smallest consumption, is also projected to increase significantly.

Typical cases of water scarcity are presented by the Greek islands, especially the smaller ones, but also by the Attica region. Several islands (for instance the Cyclades) used to have sufficient water resources, despite low precipitation levels, small total surface area (hence limited potential for water accumulation) and high temperature and sunshine levels (thus high evaporation).[2] However, the shift in land use away from traditional agriculture, stockbreeding, etc. to tourism activities, the sharp influx of tourists during the summer, improved living standards (more frequent showering and laundering, etc.) and changes in lifestyle (swimming pools, car washing, gardening, etc.) generate a higher demand for water, which the existing water potential cannot meet. The problem is further exacerbated by the uneven distribution of rainfall, both temporal and spatial. Similar in nature is the problem faced by the Attica region, which includes the wider urban area of Athens and Piraeus and the surrounding municipalities. As a result of intense rural migration and residential, economic and administrative centralisation, the Attica basin at the end of the 1990s accounted for over 40% of the total national population[3] and close to 70% of total national economic activity.

At the European level, it is estimated that one third of the EU territory and at least 100 million residents of the EU have been affected by water scarcity to date. As recently underlined by the European Environment Agency in its 2009 annual report on water resources (EEA, 2009), overconsumption for certain uses in several regions has put the needs of other uses at risk. The EEA report also notes that the cases of saline intrusion into coastal aquifers throughout Europe are increasing, thus reducing the water reserves available for consumption.

2.1.4 General observations on freshwater availability in Greece

The estimation of water reserves refers to a specific area and time span or, on average, to a specific period of the hydrological year. The reserves are distinguished into (a) surface waters (surface flow, hydrographic network, etc., lakes, glaciers, snow cover), (b) subsurface (i.e. groundwater, unsaturated zone moisture) or (c) underground water (aquifer reserves). The fact

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[2] Quite tellingly, it was not uncommon for some of the islands to carry the name ‘Hydroussa’, literally meaning “abundant in water”.

[3] Apart from the permanent residents, the wider Athens area attracts millions of foreign visitors each year (drawn by its world famous archaeological sites), millions of domestic visitors (for financial, work-related, administrative, health-related reasons), as well as tens of thousands of businessmen. In addition to surface waters, EYDAP, the Athens Water Supply and Sewerage Company, keeps back-up underground water supplies (water well drillings) in surrounding areas (e.g. Kalamos).

that all water reserves, especially underground water, vary over time, must be taken into direct consideration at the water resource management level (exploitation, qualitative protection and quantitative replenishment). This variability stems from changes in the water budget (inflows and outflows, or water entering the system and consumptions). The variability of reserves can be expressed as a percentage of variable reserves relative to constant reserves. These are often referred to as "regulatory and permanent reserves" – a rather inaccurate wording from a hydrogeological perspective, which has, in the past, led to water resource misuse.

The relationship between the reserve of a given —surface or underground— water reservoir and the average flow running through it determines the reserve's replenishment rate. The importance of a water reservoir should not be rated on the basis of the resource's replenishment (static water reservoirs with very low rates of replenishment are nonetheless water reserves). The level or rate of replenishment of a water resource must be co-assessed with the

Table 2.2 **General annual water balance, by water district**

Water district	Area (km^2)	Precipitation volume[1] (million m^3)	Evaporation[1] (million m^3)	Water potential (million m^3)	Supply[2] (million m^3)	Demand[2] (million m^3)	Remarks[2]
01 Western Peloponnese	7,301	8,031	3,614	4,417	73	55	In surplus
02 Northern Peloponnese	7,310	6,404	2,824	3,580	122	104	In surplus
03 Eastern Peloponnese	8,477	6,563	3,290	3,273	56	67	In deficit
04 Western Central Greece	10,199	13,973	5,310	8,663	415	82	In surplus
05 Epirus	10,026	17,046	6,818	10,228	193	33	In surplus
06 Attica	3,207	1,642	1,150	492	56	54	Marginally in surplus[3]
07 Eastern Central Greece	12,341	9,516	5,257	4,259	128	187	In deficit[4]
08 Thessaly	13,377	10,434	6,260	4,174	210	335	In deficit
09 Western Macedonia	13,440	10,470	5,654	4,816	159	136	In surplus
10 Central Macedonia	10,389	6,068	3,034	3,034	137	130	Marginally in surplus[3]
11 Eastern Macedonia	7,280	4,917	2,722	2,195	354	132	In surplus
12 Thrace	11,177	8,574	5,325	3,249	424	253	In surplus
13 Crete	8,335	7,500	4,874	2,626	130	133	Marginally in surplus[5]
14 Aegean Islands	9,103	5,192	3,104	2,088	7	25	In deficit
Total Greece	131,962	116,330	59,236	57,094	2,464	1,726	

Source: Operational Programme "Environment and Sustainable Development" (2007).
1 Values are relatively overestimated.
2 Values and their characteristics refer to the month of July.
3 Water resources are basically transferred from adjacent districts.
4 Irrigated areas according to NSSG seem to be overestimated and for this reason this district appears to be in high deficit, although it currently has marginally sufficient resources.
5 Current demand is insufficiently met by wells and drillings.

level or rate of its utilisation, with the dual objective of meeting the water requirements of various uses and preserving the water component of the environment (the role of water in the ecosystem). It should be noted that the latest principles of water management call for the specification of minimum river flows, lake levels and aquifer levels, characterised and treated as water uses needed to ensure the systems' ecological requirements and the 'ecological services' that these systems provide.

Despite the long-standing efforts of public authorities and organisations, all of the data needed for a comprehensive and reliable estimate of the country's total water potential have yet to be collected. An estimate of the country's general hydrological balance on an average annual basis is presented in Table 2.2. This estimate was calculated using fairly reliable data from the analysis of the country's water districts. These data were collected from other individual studies, and from measurements of hydrological balance components and, as mentioned above, are only of relative reliability. Reliability decreases when the figures are aggregated to the national level (by adding the quantities of each district).

2.1.5 Physical impacts of climate change on Greece's water sector

The hydrological cycle begins with evaporation and atmospheric precipitation (rainfall, snowfall, hail, etc.). Upon reaching the earth's surface, precipitation waters are separated at a primary stage into evaporation/transpiration (through vegetation), drainage (through the hydrographic networks), and infiltration. At a secondary stage, the picture becomes more complex, as drained water may, further down the line, either evaporate or partly infiltrate and, conversely, infiltrated water may flow out to the surface through spring discharges, only to undergo surface drainage and partial evaporation. These processes can occur several times. Moreover, before recharging the underground aquifer, infiltration water first satisfies the water needs of the ground and underground zones and of the root system (detained, adsorbed, capillary water), where plant and animal organisms grow. Therefore, any change in the atmospheric precipitation regime inevitably entails significant changes in the entire hydrological cycle, as well as in hydrological (surface) and hydrogeological (underground) water balances.

Greece has a total area of roughly 130,000 km^2, one fifth (20%) of which corresponds to its approximately 3,000 islands. Two thirds of this area is mountainous and the country's complex topographic relief also features the longest coastline of any country in Europe (~16,300 km in length), 5% of which corresponds to regions of unique ecological value.

The primary factor that determines the distribution of total annual precipitation in Greece, which averages 800 mm, is the presence of the Pindos mountain range, to the West of which precipitation levels are considerably more important than in Eastern Greece. The water deficit is normal, with the distribution of surface drainage broadly matching rainfall distribution (see Figure 2.1).

Figure 2.1

Rainfall and surface runoff time series in the water district of Thessaly (From a mix of software programmes and measurements, Ministry of Development, 2003)

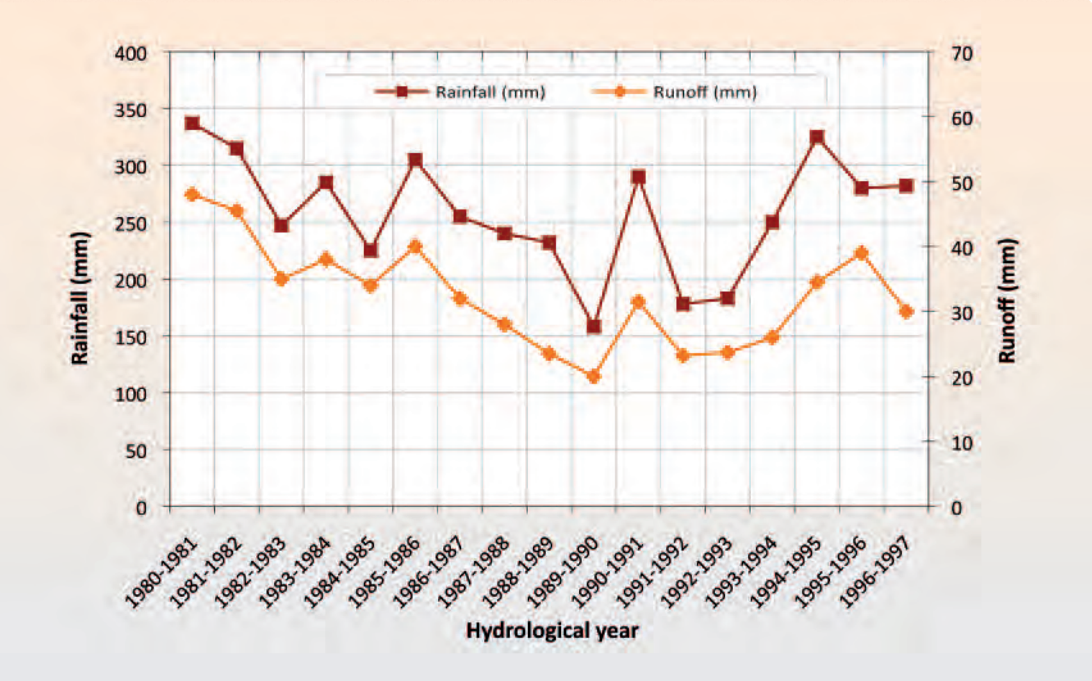


Figure 2.1 concerning the Thessaly water district and covering an extensive time period, including the critical hydrological years 1989-1990 and 1990-1991 during which substantially lower rainfall levels (-40%) were recorded countrywide, allows us to make the following interesting observations: the increase in rainfall from 130 mm in 1989-1990 to 170 mm in 1990-1991 (increase of about 30%) resulted in an increase in drainage from 26 mm to 50 mm (increase of about 90%). The decrease in rainfall from 170 mm to 140 mm (decrease of about 17%) brought about a decrease in drainage, from 50 mm to 33 mm (decrease of about 70%). This seems to indicate that an increase in rainfall is associated with a three-fold increase in drainage, whereas a decrease in rainfall is associated with a roughly similar decrease in drainage.

Three factors —geographical location (winward/leeward), morphology and geology— determine water accumulation, both in surface water bodies (lakes) and underground (extensive karstic fields). The vulnerability of karstic formations to pollution means, however, that there can be degradation in water system quality. Climate change is expected to result in increased evaporation and transpiration, increased needs for irrigation and, perhaps, tourism, and increased pollution concentrations, due to decreased dilution (increased load in smaller water volumes) (Stournaras, 2007).

Evapotranspiration represents an important hydrological loss, occurring both on the surface and in upper soil layers. Evapotranspiration rates in Greece are high, particularly in the drier eastern regions. A indicator widely used when characterising regional climates is UNESCO's indicator of dryness, defined as the ratio of the mean annual precipitation to the corresponding potential evapotranspiration. The distribution of this indicator in Greece underlines the severity of the drought situation in the SE regions and the Aegean islands (see Chapter 1).

Distinguishing between surface and underground renewable water resources is only of theoretical value, since both components of total flow are interconnected (secondary infiltration and runoff). When considering the water entering a regional system in the form of precipitation, account is taken of surface flow and infiltration into the aquifer. When considering the water leaving the system, account is taken of surface and underground flow. At the local or supralocal level, any separate estimate of surface and underground resources would risk overlooking secondary phenomena (infiltration, runoff) and incorrectly estimating the water entering or exiting the regional system. In fact, natural water resources, as determined by surface (measured or estimated) flow, and the respective water resources, as determined based on water entering the aquifer, should not be added, except in marginal cases. Generally speaking, they are only partly addable, depending on the scale of study and on the natural, climate and (secondarily) geological conditions affecting the relationship between a region's aquifers and surface flow.

The impacts of climatic change on water systems (mainly underground water systems) can be summarised as follows:

1. An overall decrease in aquifer infiltration and recharge, as a result of decreased rainfall and higher evapotranspiration.
2. Increased salinity of coastal and subsea aquifers, particularly karstic ones, as a result of the advance of the sea-water intrusion farther inland due to the decline of groundwater levels caused by lower inflow and overpumping.
3. Higher pollutant load concentrations in coastal water bodies and the sea, due to decreased dilution.
4. Faster degradation of deltaic regions, in cases where degradation has already begun as a result of transversal dam construction upstream (reduced drainage and sediment discharge) and parallel levee construction in the flat zone of the deltas (debris channelled to a single outlet).
5. Contamination or drainage of coastal wetlands.
6. Amplification of the desertification phenomenon as a result of water deficits and soil changes (compaction, sealing, etc.).

2.1.5.1 Observations and assumptions for estimating water availability variations in Greece as a result of climate change

In order to estimate the possible variations in Greece's water potential by 2100, we estimated the hydrological balance for 2021-2050 and 2071-2100 under Scenarios A1B, A2 and B2

Table 2.3

Processing of climate change data (Scenario A1B, 2021-2050, mainland part of water districts)

WD	CZ	A (km^2)	P (m)	P (mm)	V (million m^3)	Etr (m)	Etr (mm)	Etr (million m^3)	R (million m^3)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m^3)	I+R (million m^3)
1	**WP**	7,301	0.82	816.14	5,958.6	0.51	512.50	3741.8	1,231.04	2,331 km^2	1,300 km^2	1,230 km^2	2,440		
										3%	3%	10%	40%		
										57.1	31.8	100.4	796.6	985.8	2,216.9
3	**EP**	8,477	0.50	503.80	4,270.7	0.37	373.13	3,163.0	-121.06	1,634 km^2	838 km^2	1,012 km^2	4,993		
										3%	5%	10%	45%		
										24.7	21.1	51.0	1,132.0	1,228.8	1,107.7
4.5	**WG**	20,211	1.11	1,108.39	22,401.7	0.57	565.93	11,438.0	5,717.53	8,034 km^2	1,138 km^2	1,456 km^2	9,583		
										3%	3%	10%	45%		
										267.1	37.8	161.4	4,779.8	5,246.1	10,963.7
6.7.8	**CEG**	29,063	0.47	470.96	13,687.5	0.37	366.06	10,638.8	1,200.78	10,310 km^2	3,500 km^2	6,904 km^2	8,349		
										2%	3%	10%	35%		
										97.1	49.5	325.2	1376.2	1,847.9	3,048.7
9.10	**WCM**	23,832	0.58	575.50	13,715.3	0.40	400.13	9,535.9	2,673.47	8,139 km^2	5,298 km^2	7,343	3,052		
										3%	5%	10%	45%		
										140.5	152.4	422.6	790.4	1,506.0	4,179.4
11.12	**EMT**	18,457	0.66	659.17	12,166.3	0.46	460.48	8,499.1	2,523.84	10,377 km^2		5,567	2,513		
										4%		7%	37%		
										273.6		256.9	612.9	1,143.4	3,667.2
Total					72,200			47,017	13,226					11,958	25,184

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.4

Processing of climate change data (Scenario A1B,2071-2100, mainland part of water districts)

WD	CZ	A (km^2)	P (m)	P (mm)	V (million m^3)	Etr (m)	Etr (mm)	Etr (million m^3)	R (million m^3)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m^3)	I+R (million m^3)
1	WP	7,301	0.67	672.10	4,907.0	0.45	453.84	3,313.5	781.67	2,331 km^2	1,300 km^2	1,230 km^2	2,440 km^2		
										3%	3%	10%	40%		
										47.0	26.2	82.7	656.0	811.8	1,593.5
3	EP	8,477	0.42	418.13	3,544.5	0.33	330.51	2,801.7	-277.05	1,634 km^2	838 km^2	1,012 km^2	4,993 km^2		
										3%	5%	10%	45%		
										20.5	17.5	42.3	939.5	1,019.8	742.8
4.5	WG	20,211	0.95	946.76	19,135.0	0.53	533.09	10,774.3	3,879.57	8,034 km^2	1,138 km^2	1,456 km^2	9,583 km^2		
										3%	3%	10%	45%		
										228.2	32.3	137.8	4082.8	4,481.1	8,360.7
6.7.8	CEG	29,063	0.41	413.39	12,014.4	0.34	339.06	9,854.1	538.21	10,310 km^2	3,500 km^2	6,904 km^2	8,349 km^2		
										2%	3%	10%	35%		
										85.2	43.4	285.4	1,208.0	1,622.0	2,160.3
9.10	WCM	23,832	0.51	510.63	12,169.3	0.37	369.08	8,795.9	2,037.22	8,139 km^2	5,298 km^2	7,343 km^2	3,052 km^2		
										3%	5%	10%	45%		
										124.7	135.3	375.0	701.3	1,336.2	3,373.4
11.12	EMT	18,457	0.58	584.39	10,786.1	0.43	426.41	7,870.2	1,902.17	10,377 km^2		5,567 km^2	2,513 km^2		
										4%		7%	37%		
										242.6		227.7	543.4	1,013.7	2,915.8
Total					62,556			43,410	8,862					10,285	19,147

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.5

Processing of climate change data (Scenario A2, 2021-2050, mainland part of water districts)

WD	CZ	A (km^2)	P (m)	P (mm)	V (million m^3)	Etr (m)	Etr (mm)	Etr (million m^3)	R (million m^3)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m^3)	I+R (million m^3)
1	WP	7,301	0.59	589.49	4,303.9	0.49	494.94	3,613.6	-21.75	2,331 km^2	1,300 km^2	1,230 km^2	2,440 km^2		
										3%	3%	10%	40%		
										41.2	23.0	72.5	575.3	712.1	690.3
3	EP	8,477	0.41	411.29	3,486.5	0.35	351.73	2,981.6	-498.23	1,634 km^2	838 km^2	1,012 km^2	4,993 km^2		
										3%	5%	10%	45%		
										20.2	17.2	41.6	924.1	1,003.1	504.9
4.5	WG	20,211	0.78	779.64	15,757.3	0.51	513.63	10,381.0	1,686.21	8,034 km^2	1,138 km^2	1,456 km^2	9,583 km2		
										3%	3%	10%	45%		
										187.9	26.6	113.5	3,362.1	3,690.1	5,376.3
6.7.8	CEG	29,063	0.43	433.62	12,602.3	0.39	392.30	11,401.4	-500.53	10,310 km^2	3,500 km^2	6,904 km^2	8,349 km2		
										2%	3%	10%	35%		
										89.4	45.5	299.4	1,267.1	1,701.4	1,200.9
9.10	WCM	23,832	0.50	496.39	11,830.0	0.40	404.52	9,640.5	890.51	8,139 km^2	5,298 km^2	7,343	3,052		
										3%	5%	10%	45%		
										121.2	131.5	364.5	681.7	1,298.9	2,189.4
11.12	EMT	18,457	0.54	538.85	9,945.6	0.45	452.24	8,347.0	663.88	10,377		5,567	2,513		
										4%		7%	37%		
										223.7		210.0	501.0	934.7	1,598.6
Total					57,925.5			46,365.1	2,220.08					9,340	11,560

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.6

Processing of climate change data (Scenario A2, 2071-2100, mainland part of water districts)

WD	CZ	A (km^2)	P (m)	P (mm)	V (million m^3)	Etr (m)	Etr (mm)	Etr (million m^3)	R (million m^3)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m^3)	I+R (million m^3)
1	WP	7,301	0.50	504.37	3,682.4	0.47	465.63	3,399.6	-326.40	2,331 km^2	1,300 km^2	1,230 km^2	2,440 km^2		
										3%	3%	10%	40%		
										35.3	19.7	62.0	492.3	609.2	282.8
3	EP	8,477	0.35	349.46	2,962.4	0.33	326.86	2,770.8	-660.74	1,634 km^2	838 km^2	1,012 km^2	4,993 km^2		
										3%	5%	10%	45%		
										17.1	14.6	35.4	785.2	852.3	191.6
4.5	WG	20,211	0.68	682.58	13,795.6	0.49	490.99	9,923.4	641.50	8,034 km^2	1,138 km^2	1,456 km^2	9,583 km^2		
										3%	3%	10%	45%		
										164.5	23.3	99.4	2,943.5	3,230.7	3,872.2
6.7.8	CEG	29,063	0.39	392.09	11,395.3	0.39	390.28	11,342.7	-1,485.86	10,310 km^2	3,500 km^2	6,904 km^2	8,349 km^2		
										2%	3%	10%	35%		
										80.8	41.2	270.7	1,145.7	1,538.5	52.6
9.10	WCM	23,832	0.44	442.92	10,555.7	0.38	382.37	9,112.6	284.01	8,139 km^2	5,298 km^2	7,343 km^2	3,052 km^2		
										3%	5%	10%	45%		
										108.1	117.3	325.2	608.3	1,159.0	1,443.0
11.12	EMT	18,457	0.47	470.28	8,680.0	0.42	421.60	7,781.5	82.75	10,377 km^2		5,567 km^2	2,513 km^2		
										4%		7%	37%		
										195.2		183.3	437.3	815.7	898.5
Total					51,071			44,331	-1,465					8,206	6,741

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.7

**Processing of climate change data
(Scenario B2, 2021-2050, mainland part of water districts)**

WD	CZ	A (km²)	P (m)	P (mm)	V (million m³)	Etr (m)	Etr (mm)	Etr (million m³)	R (million m³)	Imperme-able formations	Semi-permeable formations	Alluvial formations	Karstic formations	I (million m³)	I+R (million m³)
1	**WP**	7,301	0.61	614.97	4,489.9	0.54	543.20	3,965.9	-218.85	2,331 km²	1,300 km²	1,230 km²	2,440 km²		
										3%	3%	10%	40%		
										43.0	24.0	75.6	600.2	742.8	524.0
3	**EP**	8,477	0.47	471.15	3,993.9	0.41	405.50	3,437.4	-592.61	1,634 km²	838 km²	1,012 km²	4,993 km²		
										3%	5%	10%	45%		
										23.1	19.7	47.7	1,058.6	1,149.1	556.5
4.5	**WG**	20,211	0.88	876.55	17,716.0	0.51	513.37	10,375.7	3,191.42	8,034 km²	1,138 km²	1,456 km²	9,583 km²		
										3%	3%	10%	45%		
										211.3	29.9	127.6	3,780.0	4,148.8	7,340.2
6.7.8	**CEG**	29,063	0.47	467.55	13,588.4	0.40	396.47	11,522.6	231.25	10,310 km²	3,500 km²	6,904 km²	8,349 km²		
										2%	3%	10%	35%		
										96.4	49.1	322.8	1,366.3	1,834.5	2,065.8
9.10	**WCM**	23,832	0.55	550.10	13,110.0	0.43	430.02	10,248.2	1422.26	8,139 km²	5,298 km²	7,343 km²	3,052 km²		
										3%	5%	10%	45%		
										134.3	145.7	403.9	755.5	1,439.5	2,861.7
11.12	**EMT**	18,457	0.62	618.31	11,412.1	0.49	485.82	8,966.8	1,372.86	10,377 km²		5,567 km²	2,513 km²		
										4%		7%	37%		
										256.6		240.9	574.9	1,072.5	2,445.4
Total					64,310			48,517	5,406					10,387	15,794

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.8

Processing of climate change data (Scenario B2, 2071-2100, mainland part of water districts)

WD	CZ	A (km²)	P (m)	P (mm)	V (million m³)	Etr (m)	Etr (mm)	Etr (million m³)	R (million m³)	Impermeable formations	Semipermeable formations	Alluvial formations	Karstic formations	I (million m³)	I+R (million m³)
1	WP	7,301	0.58	584.03	4,264.0	0.55	547.14	3,994.7	-436.13	2,331 km²	1,300 km²	1,230 km²	2,440 km²		
										3%	3%	10%	40%		
										40.8	22.8	71.8	570.0	705.5	269.3
3	EP	8,477	0.44	440.76	3,736.3	0.40	401.68	3,405.0	-743.72	1,634 km²	838 km²	1,012 km²	4,993 km²		
										3%	5%	10%	45%		
										21.6	18.5	44.6	990.3	1,075.0	331.3
4.5	WG	20,211	0.85	849.10	17,161.2	0.52	521.96	10,549.3	2,592.94	8,034 km²	1,138 km²	1,456 km²	9,583 km²		
										3%	3%	10%	45%		
										204.7	29.0	123.6	3,661.6	4,018.9	6,611.8
6.7.8	CEG	29,063	0.45	447.23	12,997.8	0.40	402.40	11,695.0	-451.92	10,310 km²	3,500 km²	6,904 km²	8,349 km²		
										2%	3%	10%	35%		
										92.2	47.0	308.8	1,306.9	1,754.8	1,302.9
9.10	WCM	23,832	0.53	531.73	12,672.2	0.43	430.79	10,266.6	1,014.19	8,139 km²	5,298 km²	7,343 km²	3,052 km²		
										3%	5%	10%	45%		
										129.8	140.9	390.4	730.3	1,391.4	2,405.6
11.12	EMT	18,457	0.59	593.21	10,948.9	0.49	487.41	8,996.1	923.78	10,377 km²		5,567 km²	2,513 km²		
										4%		7%	37%		
										246.2		231.2	551.6	1,029.0	1,952.8
Total					61,780			48,907	2,899					9,975	12,874

WD: water district, CZ: climate zone, A: area, P: precipitation, V: water volume, Etr: real evapotranspiration, R: surface runoff, I: infiltration, I+R: water potential.
WP: Western Peloponnese, I: Ionian, EP: Eastern Peloponnese, WG: Western Greece, CEG: Central and Eastern Greece, WCM: Western and Central Macedonia, EMT: Eastern Macedonia and Thrace.
Water district and lithological formation areas, as well as infiltration ratios, were taken from Management Studies of the Ministry of Development.

Table 2.9 **Estimated percentage change in parameters V (precipitation volume) and I+R (water potential) of the general water balance by climate scenario and time period (In percentages)**

	A1B		A2		B2	
2021-2050	V	I+R	V	I+R	V	I+R
	-8	-14	-8	-22	-3	-14
2071-2100	V	I+R	V	I+R	V	I+R
	-20	-37	-19	-54	-7	-30

(Scenario B1 was omitted). The processing of the results led to the formulation of two estimates for the following hydrological balance parameters: P (precipitation), Etr (evapotranspiration), I (infiltration) and R (runoff). In the first case, we were not able to obtain acceptable results for evapotranspiration and runoff, due to excessive evapotranspiration in littoral regions). In the second case, however, we were able to calculate all of the hydrological balance parameters in question. It must be noted that in the first case the geographical delineation of regions was such as to include *part mainland, part island* (except in the case of Water District 14, consisting entirely of the Aegean Islands), whereas in the second case, the delineation was such as to include *only mainland.* This distinction was made to evaluate result representativeness.

In processing the hydrological balance parameters, use was made of the infiltration coefficients for the respective lithological formations encountered in Greece, based on the data from the Management Studies (Master Plan) of the Ministry of Development (2003).

The results of our analysis for the mainland part are presented in Tables 2.3 to 2.8. A comparison of the results of each hydrological balance parameter under each envisaged scenario led to the results presented in Table 2.9.

As shown in Table 2.9, in the period 2021-2050, precipitation volume (V) is expected to decrease countrywide by between 3% (Scenario B2) and 8% (Scenario A2) and water potential (Infiltration + Runoff) by between 14% (Scenario B2) and 22% (Scenario A2). In the period 2071-2100, precipitation volume is expected to decrease by between 7% (Scenario B2) and 20% (Scenario A1B) and water potential by between 30% (Scenario B2) and 54% (Scenario A2).

In light of the fact that the demand for irrigation water corresponds to roughly 75-80% of the country's total water potential, it becomes apparent from these results that climate change would, together with changes in agricultural practices, have direct implications on crop type and area.

2.1.5.2 Correlation between rainfall, infiltration and surface runoff

Figures 2.2, 2.3 and 2.4, based on the processing of results obtained for the hydrological balance parameters for the periods 2021-2050 and 2071-2100, illustrate the relationship between

Figure 2.2 Change in precipitation volume (V) and water potential (I+R), 1961-2100, Scenario A1B

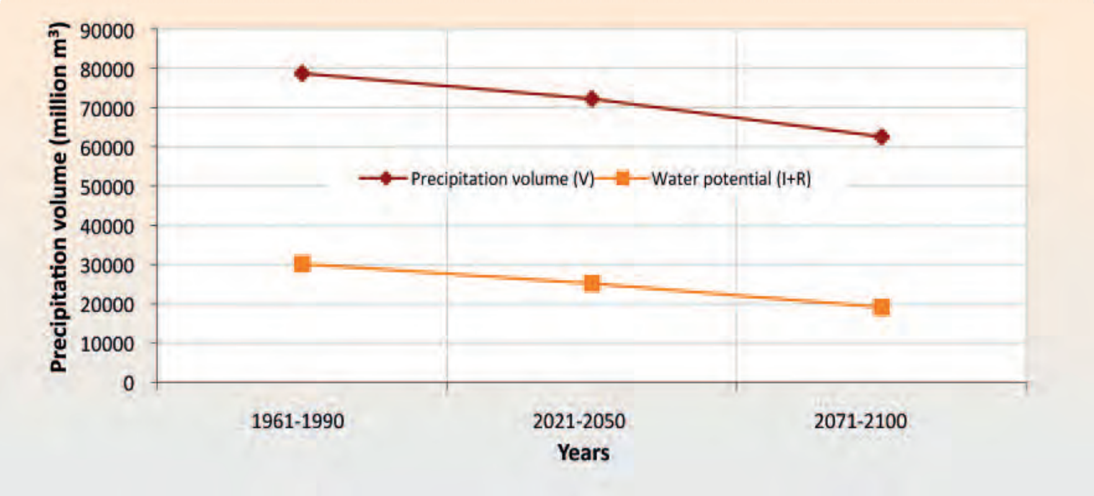
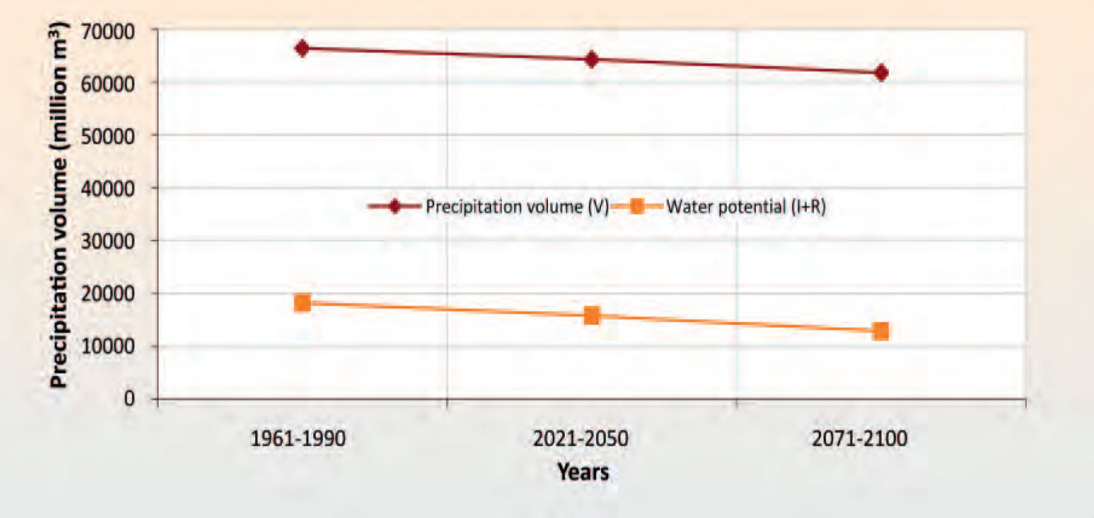


Figure 2.3 Change in precipitation volume (V) and water potential (I+R), 1961-2100, Scenario B2

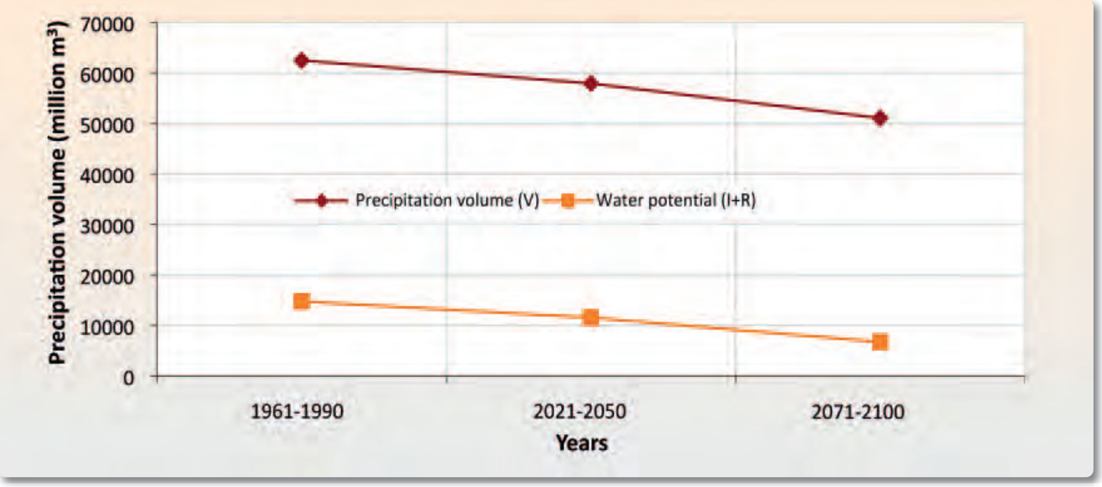


rainfall (V, in million m^3), infiltration (I, in million m^3) and surface runoff (R, in million m^3) under the respective scenarios (Scenarios A1B, B2 and A2).

2.1.6 Economic impacts of climate change on Greece's water reserves

Having estimated the physical impacts of Scenarios A1B, A2 and B2 on Greece's hydrological cycle and water reserves, we proceeded to an economic valuation of the impacts from cli-

Figure 2.4 **Change in precipitation volume (V) and water potential (I+R), 1961-2100, Scenario A2**



mate change. Due to time and data availability constraints, we narrowed our focus to the impacts on the public water supply, which includes many tourism and industrial uses, but excludes irrigation[4] and 'ecological purposes'.[5]

2.1.6.1 A typology of the economic impacts of water use

Water resources provide goods and services, the management of which has an economic and a socio-political dimension, and concerns several sectors of the economy. The possible economic impacts of climate change on freshwater availability are, thus, likely to affect a wide range of activities highly important to society, with additional repercussions further down the line. The major economic impacts expected include:

1. Lower productivity on account of the shortage (and, as a result, the poorer quality) of water resources in sectors where water is a major input in the production process (agriculture, hydroelectric power plants, industry, forestry, pisciculture, etc.).
2. Increased cost of pollution and wastewater treatment.
3. Increased risks (flooding, fires, etc.).
4. Decrease in benefits from recreation activities.
5. Loss of benefits due to damage to water ecosystems.
6. Higher cost of extracting underground waters.

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[4] The use of water for irrigation is indirectly estimated in Sub-chapter 2.4 which deals with the impact of climate change on agriculture.

[5] 'Water for ecological purposes', defined as the minimum quantity and quality of water reserves required in situ for ecosystems and species *not* to be endangered, represents a major use for water reserves in the light of climate change.

7. Increased risk of further seawater intrusion into underground aquifers.
8. Impacts on human health.
9. Negative impact on welfare, as a result of possible restrictions on water use.

The intensity of these economic impacts is, of course, expected to vary in function of the severity of the respective climate changes.

2.1.6.2 General framework for estimating the cost of climate change

Estimating the cost implications of climate change on water resources is a process of successive stages, which form the basis of economic valuation. The first stage consists in identifying the major stresses on water bodies likely to be induced by climate change. In a second stage, the repercussions of these stresses on water resources are assessed in volumetric, chemical and ecological terms. In a third stage, the damage sustained by the water systems and water users are identified and, where feasible, quantified, with ‘damage’ defined as the difference between the reference state (status quo) and the state expected to arise in the wake of climate change, taking in account both the impact on the supply and quality of water services *and* the increased risk. The risk increase rate is determined by a number of parameters, such as the probability of occurrence of severe flooding, aquifer salinisation (as a result of saline intrusion), health-related incidents (as a result of the poorer quality of water resources) and the smaller availability of water for fire-fighting use. The final stage involves the monetary valuation of the anticipated damage, drawing on methods for valuating both market and non-market goods and focusing in particular on the loss of welfare induced by changes in supply and in the quality of goods and services.

There are several ways to assess environmental impacts and climate impacts in particular (Papandreou and Skourtos, 2000). The economic assessment of non-market goods and services involves the monetary valuation of goods and services not traded in markets. Depending on the welfare measure used (price, cost or willingness-to-pay), the available methodologies can be classified into three categories: *pricing, costing (cost accounting)* and *valuing*. The first group consists of market methods, in which market prices serve as value proxies. Such methods are only suitable for measuring direct use value. The estimated prices represent a lower bound of the goods’ ‘true’ values (maximum willingness-to-pay). The second group, i.e. costing methods, are based on the existence of a relationship (‘weak complementarity’) between environmental quality and private market goods. The third group, i.e. valuing or valuation approaches, are based on consumer preferences, and are further distinguished today into two sub-categories: (a) indirect or ‘revealed’ preferences for goods and services provided by the environment and (b) direct or ‘stated’ preferences for such goods and services.

On account of budget and time constraints, decision makers are rarely in favour of primary studies for the economic assessment of environmental goods and tend to prefer the ‘benefit transfer' assessment method, which consists in 'transferring' the results of previously conducted economic assessments from the 'study site' to a new, but similar case, called 'policy site' (Navrud and Ready, 2007). This overcomes the need for primary field research. The use of the benefit transfer method for the economic assessment of environmental impacts has become quite widespread in recent years, due among other factors to the accessibility of large databases of valuation studies.

2.1.6.3 Water reserves, climate change and the economic cost of non-action in Greece

Published research on the economic assessment of water resources in Greece covers a wide range of goods and services. Unfortunately, the heterogeneity of the units used to measure the impacts makes the use of the relevant results for 'benefit transfer' problematic. Furthermore, the monetary valuations available from Greek studies do not seem to serve even 'conservative' estimates. Therefore, the economic valuation, performed in the present study, of the impacts of climate change on water services will be based on a costing method. Of all water uses, only domestic water use (including tourist use) was examined.

The economic valuation of climate-induced damage to water reserves was carried out using the following approach: First, the future demand for water resources was identified per year and water district. Second, assuming that the price of water is already an underestimate of its full value, we estimated in value terms the cost or benefit that would arise from the variation in water demand in 2041-2051 and 2091-2100. Third, we estimated what the future annual cost or benefit would be to the sector from the impact of climate change on the supplied quantities of water resources. After estimating the changes in demand and supply of water reserves, we were able to calculate the net result, which consists in subtracting the value of the variation in supply due to climate conditions from the value of the variation in demand. Finally, the process was completed with the calculation in monetary terms of the Net Present Value (NPV) of the loss.

As already mentioned, three scenarios (A1B, A2 and B2) were considered, using the market price of domestic water supply as a 'lower bound' of the resource's value to society. In Greece, the needs of the Attica and greater Thessaloniki areas are met, respectively, by the Athens Water Supply and Sewerage Company (EYDAP) and the Thessaloniki Water Supply and Sewerage Company (EYATH). In all other regions, the domestic water supply is managed either by a Municipal Water Supply and Sewerage Company (DEYA) or, otherwise, by a similar municipal service. These companies are usually able to recover their operating and administrative costs, plus part of the capital costs of the water supply and sewerage networks and of municipal well drillings, if needed (Ministry for the Environment, Physical Planning and Public Works, 2008). In brief, from the perspective of the Greek consumer, there is a wide disparity in what water bills actually cover and which body they are payable to, while from the perspective of the water companies only part of their total costs are recovered. In order to estimate the impacts at a Water District level, we used reference values corresponding to the average prices charged by the DEYAs for 1 m^3 of water (Hellenic Union of Municipal Enterprises for Water Supply and Sewerage, 2007) as follows:

- €1.54 in the Western Peloponnese, the Northern Peloponnese and the Eastern Peloponnese;
- €1.26 in Western Central Greece and Eastern Central Greece;
- €1.90 in Epirus;
- €1.08 in Thessaly;
- €0.73 in Attica;
- €1.67 in Western Macedonia;
- €1.20 in Central Macedonia;
- €1.09 in Eastern Macedonia and Thrace;
- €1.77 in the Aegean Islands; and
- €1.29 in Crete.

These prices concern 2007 and were obtained from data published by the DEYAs. The estimates produced for this study are prone to a number of uncertainties that arose at different stages of the estimation exercise, i.e. uncertainty regarding the estimation of a) climate data, b) the future distribution of water reserves, and c) Greece's future population. Meanwhile, in order to estimate the costs from climate change the following research assumptions were adopted: a) to estimate future demand, average expected water consumption was set at 200 litres daily per person for permanent residents and at 300 litres per person and overnight stay for tourists; b) the number of overnight stays in future was considered to remain stable, i.e. the same as today's; c) the price of water was also considered to remain stable. The cost estimates are given both undiscounted and discounted using discount rates of 1% and 3%.

The estimated cumulative cost of climate change in the water supply sector is presented in Table 2.10 for two different decades (2041-2050 and 2091-2100) and under the three considered scenarios. During the decade 2041-2050, the impact of climate change on the water supply sector alone would cost from 0.89% of GDP (Scenario A1B) to 1.32% of GDP (Scenario

Table 2.10 **Cost of climate change in the water supply sector**

	Cumulative cost of climate change			
	2041-2050		2091-2100	
Scenario	€ (prices 2007)	% GDP	€ (prices 2007)	% GDP
A1B	2,077,099,481	0.89	1,189,116,259	0.51
A2	3,069,725,843	1.32	4,284,065,911	1.84
B2	2,191,388,771	0.94	1,383,394,988	0.59

Source: Estimates of the authors.

Table 2.11 Net Present Value (V) of total damage to water reserves, by scenario and discount rate

	i=0%		i=1%		i=3%	
Scenario	**€ (prices 2010)**	**% GDP**	**€ (prices 2010)**	**% GDP**	**€ (prices 2010)**	**% GDP**
A1B	3,266,215,740	1.40	1,937,702,529	0.83	786,655,612	0.34
A2	7,353,791,754	3.16	3,926,853,946	1.69	1,355,659,735	0.58
B2	3,574,783,759	1.53	2,098,537,132	0.90	839,785,746	0.36

i=discount rate
Source: Estimates of the authors.

A2). During the decade 2091-2100, the decline in GDP would start at 0.51% in the best case (Scenario A1B) and climb as high as 1.84% of GDP (Scenario A2).

The final stage of the economic valuation process consisted in estimating the cost of the climate change impact in Net Present Value (NPV) terms. As can be seen from Table 2.11, the NPVs were estimated both undiscounted and discounted (using discount rates of 1% and 3%). When discounting was used, the total cost for the Greek economy was found to be greatest at 1.69% of GDP under Scenario A2 at a discount rate of 1%, and lowest at 0.34% of GDP under Scenario A1B at a discount rate of 3%. The climatic zones most vulnerable from an economic point of view were shown to be Central Macedonia and Central, Eastern and Western Greece.

2.1.7 Potential for adaptation and for addressing the impacts of climate change

Adaptation can prove to be a decisive option in light of the inevitable impacts of climate change, already being felt worldwide. Considering, first and foremost, that climate change mitigation policies call for concerted global action, and, secondly, that the Greek economy is not large enough to ‘make a difference at the global level’ in terms of greenhouse gas (GHG) emissions, the implementation of targeted adaptation actions presents itself as the only way for Greece to reduce the damage and costs it will sustain from climate change.

Adaptation is expected to play a major role in developing countries, likely to be affected both more severely and sooner by climate change. In the absence of adaptation measures, Greece would be faced with a situation similar to the one of developing countries, given its lack of an even basic integrated water management plan. The problem generated by this shortcoming would, aside from the general impacts of climate change (reduced rainfall, and increases in temperature, evaporation and water consumption needs), be further compounded by the irrational use of water for irrigation in the summer months (e.g. water irrigation canons and flood irrigation), water loss due to obsolete systems in urban water supply networks, the rising demand for water associated with population increases (influx of tourists, permanent population) and improving living standards (increased number of second/summer homes, parks, better everyday life conditions, etc.). To this overall situation, one would also have to add the acute impacts from increased evapotranspiration, increased irrigation and rising water consumption brought about by land use changes, notably the conversion of former farmland into resort areas.

The need for vigilance and to address the issue promptly and comprehensively is imperative. In the field of water systems, what is needed is the elaboration of a comprehensive integrated water management plan and corrective interventions to reduce the considerable loss of water (e.g. in public distribution and supply networks or via evaporation). Particular attention should also be drawn to specific small-scale instances (i.e. certain islands or a sector such as tourism) that could seriously undermine the overall water management effort (unregulated operation of private, licensed or unlicensed water well drillings).

Uncoordinated and unplanned adaptation poses a major risk to water systems in countries like Greece, where water management is one of many sectors suffering from deficient legislation (lack of water abstraction protection zones, incomplete restrictions on private water well drilling, etc.) and where violation and abuse of legislation are commonplace. Due to the inability of the State to meet water supply and irrigation needs in an efficient and well-regulated manner, what has come to prevail, with regard to water, is a kind of ‘each man for himself’, as illustrated by the number of unlicensed water well drillings, illegal connections and the frequent cases of overpumping, contamination and unregulated water trading. Policy-led adaptation, in order to be reliable and effective and to entail minimal side-effects, must be based on a comprehensive integrated water management plan and corrective interventions to reduce water loss.

Such a management plan should include:

- an elaborate national land-use plan, with a delineation and description of the uses of all surface and underground water bodies and lands;
- the implementation of a national water management plan, adjusted to prevailing conditions, with a permanent monitoring of implementation;
- a modernisation of irrigation systems;
- a modernisation of urban water supply systems;
- the establishment and protection of minimum, ecologically sound, freshwater reserves;
- the regulation of water abstractions, with restrictions applicable to each case;
- the reuse of water (e.g. for park irrigation);
- the artificial recharge of groundwaters (aquifers); and
- the establishment of water abstraction protection zones, at least for abstractions intended to public water supply needs, either directly (networks) or indirectly (bottling).

There is a wide and complex range of adaptation options available, belonging to two main categories depending on whether their purpose is (a) to satisfy demand, or (b) to manage, i.e. curb, demand. Policies geared towards satisfying total demand rely on large hydraulic infrastructure as their main tool, opting for such projects as dam construction, water transfer projects[6] (within a basin or between basins), aquifer recharge works and —when technically feasible— desalination. Policies geared toward managing, i.e. curbing, water demand, on the other hand, almost entirely rely on water pricing. The principle underlying this approach is that the rational pricing of water, in accordance with Directive 2000/60/EC on Water Resources, will provide an incentive for efficient water use. At the same time, an adequate pricing policy can ensure revenue much needed to ensure the maintenance of water supply infrastructure and the solvency of water companies. The complexity of the whole endeavour lies in the need to strike a balance between the two policy orientations.

The economic effectiveness of adaptation policy hinges upon a planning ability taking into account the technical and economic adaptation potential, and the specificities of each case. Cost/benefit analysis has been shown to be the most appropriate tool for choosing and applying the optimal mix of adaptation actions. However, alternative forms of adaptation policy can be assessed as to their cost and effectiveness only if the necessary specialised data for water resource management is available.

To give a particularly telling example, a study of data on water loss from network leakages, collected from a large sample of Municipal Water Supply and Sewerage Companies ("DEYAs") covering one fifth of the population of Greece, showed that the quantity of water lost corresponds to more than 60% of demand. Assuming that the water loss rate is similar in other water supply systems and that it could be reduced to an acceptable 10% (through network renewal and preventive maintenance), the average benefit from this adaptation action would, depending on the scenario, amount to some €240 million per year. One definite obstacle to the adoption of such a policy is the cost of implementation.[7]

Another good example to consider is the future cost effectiveness of water abstractions, under climate change conditions, from existing and potential water sources. Assuming that water abstraction costs remain unchanged for the municipal water companies (DEYAs) and that annual investments of roughly €68.4 million (± €7.8 million) are made, the estimated average annual benefit per climate scenario would come to €380 million (± €47 million). Once again, however, the cost of implementation would be a major obstacle.[8] A study of the cost effectiveness of adaptation could lead to the selection of alternative optimal policy mixes for each time period.

Listed immediately below are some of the more advisable adaptation actions (in terms of the benefits they would yield), the implementation costs of which have yet to be established:

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[6] Water transfers are associated with such environmental impacts as reduced river flow and decreased estuary sedimentation. The EU has formulated a series of considerations (COM (2007) 414 final) to be taken into account for inter-basin water transfers. In accordance with these considerations, particular attention is focused on water demand —both present and future— at the 'donor basin' level, in light of water scarcity likely to be induced by climate change. Moreover, the EU recommends studying the social and environmental impacts, at both the 'donor basin' and the 'receiving basin' level. The actual cost of the water transfer infrastructure is, of course, not to be overlooked.

[7] The assessment of the cost effectiveness of the specific action exceeds the scope of the present study.

[8] Once again, the assessment of the cost effectiveness of the specific action exceeds the scope of the present study.

- the preservation (non-use) of underground water reserves, suitable for future use in public water supply, in priority those situated near present-day consumptions;
- the water conservation potential on the users side, e.g. from the use of water saving appliances; and
- various institutional actions, such as pricing, incentives to reduce consumption, information/education/awareness campaigns, and the gradual banning of particularly water-consuming urban uses.

2.1.8 Conclusions

Climate change is expected to have the following negative impacts on the water resource sector in all of Greece's water districts and under all the scenarios considered:

- An overall decrease in aquifer infiltration and recharge, as a result of decreased rainfall and higher evapotranspiration;
- Increased salinity of coastal and subsea aquifers, particularly karstic ones, as a result of the advance of the sea-water intrusion farther inland due to the decline of groundwater levels caused by lower inflow and overpumping;
- Higher pollutant load concentrations in coastal water bodies and the sea, due to decreased dilution;
- A faster degradation of deltaic regions, in cases where degradation has already begun as a result of transversal dam construction upstream (reduced drainage and sediment discharge) and parallel levee construction in the flat zone of the deltas (debris channelled to a single outlet);
- Contamination or drainage of coastal wetlands; and
- Amplification of the desertification phenomenon as a result of water deficits and soil changes (compaction, sealing, etc.).

As shown earlier in Table 2.9, the period 2021-2050 is projected to see precipitation levels decrease countrywide by between 3% (Scenario B2) and 8% (Scenario A2) and total water potential by between 14% (Scenario B2) and 22% (Scenario A2). The period 2071-2100 is projected to see precipitation decrease by between 7% (Scenario B2) and 20% (Scenario A1B) and total water potential by between 30% (Scenario B2) and 54% (Scenario A2).

Considering that the demand for irrigation water corresponds to roughly 75-80% of the country's total water potential, it becomes apparent from these results that climate change would, together with changes in agricultural practices, have direct implications on crop type and area.

From a financial perspective, the highest, discounted damage for the Greek economy incurred in Scenario A2 reaching 1.69% of GDP at a discount rate of 1%. The lowest damage incurred in Scenario A1B reaching 0.36% of GDP at a discount rate of 3%. In annual terms, the damages range between €81.1 million (Scenario A2) and €69.3 million (Scenario A1B).

The most vulnerable climate zones for which the heaviest cost estimates was recorded were found to be Central, Eastern and Western Greece and, in the northern part of the country, Central Macedonia. However, there appears to be considerable leeway for adaptation measures.

The estimates produced for this study are clouded by a number of uncertainties that arose at different stages of the estimation exercise, i.e. uncertainty regarding the estimation of climate data, the future distribution of water reserves, and Greece's future population. It must furthermore be stressed that the use of water prices as reference values in economic valuation largely underestimates the real cost of climate change impacts. In fact, as shown by the implementation in Greece of Directive 2000/60/EC, the recovery rate of the full cost of water uses is so low that the prices charged for water cannot cover the financial costs or, a fortiori, the full costs of water use. It is broadly estimated that if the full cost of Greece's water resources had been estimated and used as a reference value in the present study, the cost of climate change would have been found to be three times higher.

2.2 Climate change risks and impacts from sea level rise*

2.2.1 Introduction

Throughout the course of modern history, coasts have been a substantial means of human development and an ever-growing number of people still continue to colonise the coasts worldwide. The rate at which human activities have been moving to the coastal zone has rightfully been described as "one of the greatest human migrations of modern times" (Tibbetts, 2002). Coasts make up dynamic and complex socio-ecological systems, encompassing a variety of biotic and abiotic elements. Their dynamic nature is responsible for their high productivity, leading to both periodic changes and gradual mutation.

The importance of coastal resources for the prosperity and wellbeing of coastal areas lies precisely in the ecosystem services and goods that they provide and that support human life (Daily 1997; Turner et al., 2001). A classification of coastal services and goods is presented in Table 2.12.

However, the anthropogenic activities ensuing from industrialisation and economic growth have brought coastal areas under intense pressure. Climatic change further exacerbates these pressures and has made mean sea level rise (SLR) one of the most predictable and alarming impacts globally (Church et al., 2001; Nicholls, 2007). To make things worse, SLR has, for roughly two decades now, been known to be rather inelastic to reductions in greenhouse gas

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* Sub-chapter 2.2 was co-authored by: Areti Kontogianni, Christos Tourkolias, Michalis Skourtos, Dimitrios Papanikolaou, Maria Papanikolaou, and Serafim Poulos.

emissions (OECD, 2006), a phenomenon known as “commitment to SLR”: even if drastic global mitigation policies succeed in stabilising the climate, SLR and the accompanying phenomena of coastal erosion and storm surges will continue to occur for centuries (Meehl et al., 2005; Wigley, 2005).

The present sub-chapter examines the impacts of SLR on Greece’s coastal zone and assesses their economic dimension. Researchers engaged in studies like this are confronted with two important issues. The first is the quantification of the economic impacts (damages) caused by coastal land loss due to SLR. The second is the ex ante estimation of welfare gains from reducing SLR risks, since this estimation constitutes an important input for decision-making regarding policy and engineering measures (mitigation and adaptation measures). Cost-benefit analysis is used as a tool for prioritising different policy goals. Therefore, methodologically, it must succeed in associating economic estimates with measurable physical indicators, so that researchers are well aware of exactly what is being appraised (Kontogianni et al., 2010a; Sonderquist et al., 2008). Changes in physical indicators mostly refer to non-tradeable environmental goods (e.g. human health, biodiversity conservation, quality of ecosystems etc.). Due to the difficulty in appraising their economic value, they are usually not taken into consideration in decision-making, therefore they constitute an external cost.

Climate change is a source of vulnerability for natural systems (climate, coasts, oceans, forests, soil productivity, etc.). A multidisciplinary approach, in order to be integrated and successful, must deal with the co-evolutionary aspects of natural and socio-economic systems, known together as ‘socio-ecological’ systems (Folke et al., 2002).

2.2.2 State of play of Greece’s coastal zone[9]

With a total shoreline of roughly 16,300 km, Greece has the most extensive coastal zone of any country in Europe. Almost half of this coastal zone is located in continental Greece, with the remaining half dispersed among Greece’s 3,000 islands (or 9,800, if islets are included). The four main categories of coastal goods and services provided in abundance by Greece’s coastal area are listed in Table 2.12.

About 33% of the Greek population resides in coastal areas within 1-2 km of the coast. If we define ‘coastal population’ as the population residing within 50 km of the coast, Greece’s coastal population represents 85% of the total.

Twelve of Greece’s total 13 administrative regions (prefectures) qualify as coastal (only one administrative region is landlocked). Located in the coastal zone are: (a) the country’s largest urban centres (Athens, Thessaloniki, Patras, Heraklion, Kavala, Volos), (b) 80% of national industrial activity, (c) 90% of tourism and recreation activities, (d) 35% of the country’s farm-

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[9] The information in this section is from the Ministry of the Environment, Physical Planning and Public Works (2006).

Table 2.12 **Categorisation of ecosystem services and goods provided by the coastal/marine environment**

Supportive services	1 Biogeochemical cycling 2 Primary production 3 Food web dynamics 4 Diversity 5 Habitat 6 Resilience	**Regulating services**	1 Atmospheric regulation 2 Local climate regulation 3 Sediment retention 4 Biological regulation 5 Pollution control 6 Eutrophication mitigation
Provisioning services	1 Food 2 Inedible resources 3 Genetic resources 4 Chemical resources 5 Ornamental resources 6 Energy resources 7 Waterways	**Cultural services**	1 Recreation 2 Aesthetic values 3 Science and education 4 Cultural heritage 5 Inspiration

Source: Adapted from Garpe (2008) and MEA (2005).

land (usually highly productive), (e) the country's fisheries and aquaculture, and (f) an important part of the country's infrastructure (ports, airports, roads, power and telecommunication networks, etc.). The value added generated in the coastal zone includes:

- the operation of 20 ports, handling an annual total of over 1 million tonnes of cargo;
- a total fishery production of 96,000 tonnes;
- a total fishing fleet of 19,000 vessels (representing 20% of the EU-25 total);
- a total aquaculture production worth €258,000 (or 10% of the EU-25 total); and
- the majority of hotel beds in the tourism sector. During the tourist season (summer), it is not unusual for the population of some Greek islands to increase 2- to 10-fold, due to the influx of domestic and foreign tourists.

The fishery and aquaculture sectors are important due to their contribution to Greek GDP, but mostly due to their role in fostering and preserving the social and economic cohesion of the coastal areas. The fishery sector in 1999 employed 40,000 and had a total output of 231,000 tonnes, while aquaculture employed 4,800 directly and more than 7,500 indirectly.

The coastal zone encompasses important habitats, which contribute to the conservation of biogenetic reserves. Indicatively, over 6,000 different species of flora, 670 species of vertebrates, and 436 species of avifauna are found in the coastal zone.

Marine ecosystems, by sequestrating carbon, play a major role in regulating the climate, while phytoplankton through the process of photosynthesis releases oxygen into the atmosphere.

Coastal areas help generate and preserve microclimates. The presence of coastal forests and wetlands ensures the minimisation of floods, erosion and other natural disasters, and offers valuable regulating and supporting ecosystem services.

The last 20 years have seen a boom in the construction of summer houses in Greece's coastal areas. The total urbanised area in the coastal zone is estimated at 1,315 km^2, or 1.31% of the total area of Greece.

All of the aforementioned coastal resources contribute to the production of cultural services, such as leisure, aesthetic values, the potential for scientific and educational activities, the conservation of cultural heritage and cultural capital, while also providing sources of artistic/philosophical inspiration. The coastal ecosystem services therefore support and supply, in both natural and cultural terms, the transfer of social capital from one generation to the next on a scale that surpasses the local level and historically extends to the European and global level.

From all the above, it becomes evident that the coastal zone, as an important natural resource, merits our respect and protection.

The threats to the Greek coastal and marine environment can be natural (e.g. erosion), but mostly stem from anthropogenic driving forces (e.g. overexploitation of natural resources, urbanisation, pollution, eutrophication, invasive species).

One major problem of the Greek coastal zone is the high rate of coastline erosion: over 20% of the total coastline is currently under threat (EUROSION, 2004), making Greece the 4th most vulnerable country of the 22 coastal EU Member States. The main reasons for the increased erosion are the particularly strong winds and storm surges in the Aegean Sea, anthropogenic interventions —e.g. dams that reduce sediment discharge (Llasat et al., 2010)— and the geomorphology of the coastline substrate: 2,400 km (15% of the total shoreline) correspond to non-consolidated sediment deposits, while 960 km (6% of the total shoreline) correspond to coastal deltaic areas.

Erosion is expected to increase in the immediate future (Velegrakis, 2010), due to (a) the anticipated rise in mean sea level; (b) the intensification of extreme wave phenomena; and (c) the further reduction of river sediment discharge as a result of variations in rainfall and the construction of river management works.

2.2.3 Changes in sea level and geomorphology/geodynamics

A reliable assessment of the potential risk associated with SLR should not limit itself to the trends and rates of SLR, but also consider such local factors as tectonics, sediment supply (from inland), and coastal geomorphology/lithology. The **role of tectonics** is especially important in tectonically active zones (Vött, 2007), as it can counterbalance the relative SLR when there is a tectonic uplift, or conversely, amplify the SLR when there is tectonic subsidence. Typical examples include the coastal zone of the Northern Peloponnese (with an uplift rate of 0.3 to 1.5

mm/year), Crete (with 0.7 to 4 mm/year) and Rhodes (with 1.2 to 1.9 mm/year). Thus, a supposed average SLR rate of 4.3 mm/year would be reduced to 3.5 mm/year due to the counteraction of a mean tectonic uplift of 0.8 mm/year. **Changes, i.e. increases in fluvial sediment discharge and deposition** in deltaic plains can result in the advance of the shoreline and locally offset the sea level rise (Poulos et al., 2002). Conversely, reduced fluvial sediment discharge can reinforce the incursion of the sea following a sea level rise.

An important factor in the vulnerability of coastal areas to SLR is coastal morphology (i.e. slope and lithological composition), directly related to the rate of erosion. The latter can range from very high (several m/year) in the case of low-lying land to low (a few mm/year) in the case of hard coastal limestone formations (e.g. cliffs).

Using maps of a scale of 1:50,000 and basing ourselves on the SLR recorded in past decades, it was possible to indicatively map Greece's coastal areas according to their vulnerability to a potential SLR of 0.2 to 2 m by 2100. As can be seen from Image 2.1, three main categories were identified:

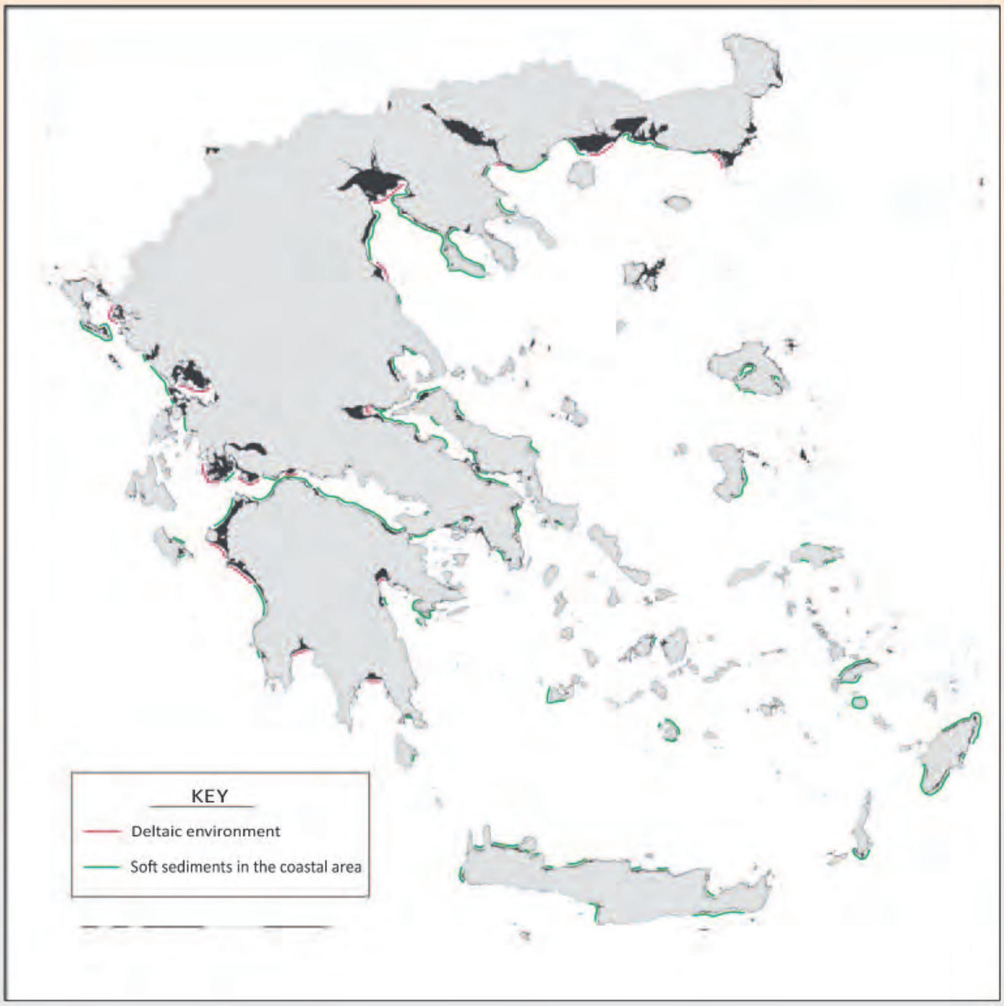
1) **Deltaic coastal areas.** Represented in red, these low-lying coastal areas are formed of loose, unconsolidated sediment deposits and are highly vulnerable to sea level rise.
2) **Coastal areas consisting of non-consolidated sediments of Neogene and Quaternary age.** Represented in green, these coastal areas, usually of low altitude, are prone to recessional erosion and present medium vulnerability to sea level rise.
3) **Rocky coastal areas** (without any specific colouring/marking in Image 2.1). These coastal areas, sometimes of high altitude, consist mostly of hard rock of low vulnerability to erosion and SLR, and form the bulk of Greece's coastline.

Based on the above categorisation, the 'high risk' coastal areas of Greece include the deltaic areas of the following rivers: Evinos (Messolonghi); Kalamas (Igoumenitsa); Acheloos; Mornos (Nafpaktos); Pineios; Alfeios (Ilia); Aliakmon and Axios (in the Thermaikos gulf); Pineios (NW Aegean, near Platamon); Strymon (near Amfipolis); Nestos (towards Abdera); Evros; as well as the deltaic regions in the Malliakos, Amvrakikos, Lakonikos, Messiniakos and Argolikos gulfs. All of the other coastal areas are characterised as being of 'low vulnerability' and usually consist of rocky and high altitude coastal formations. The areas father inland and marked heavily in black in Figure 2.1 represent areas lower than 20 m in altitude, with typically loose sedimentary depositions.

Assessing the severity of SLR impacts on coastal areas involves uncertainties with regard to:

(a) The intensity of the sea level rise, ranging between 0.2 m and 2 m. SLR is determined by the interaction of several parameters, natural (e.g. astronomical) and anthropogenic (e.g. greenhouse gas forcing). The severity of each factor will affect the overall development of the climate cycle we are currently in, which seems to be at the peak of the current 'warm' interglacial period.

Image 2.1 **Coastal areas in Greece**



Coastal areas in Greece with medium (green colour) and high (red colour) vulnerability. Black colour indicates areas with altitudes below 20 m, usually of loose sedimentary deposits.
Source: Papanikolaou et al. (2010).

(b) The relationship between tectonic uplift and eustatic SLR. Quite important in several areas of Greece, the tectonic uplift may be significant enough to offset or locally even exceed SLR.

(c) The sedimentation of clastic materials in coastal areas, determined by geological and climatic conditions, as well as by human intervention (e.g. dams, river sand mining) and capable, e.g. in the case of river deltas, of altering the vulnerability to SLR (Velegrakis et al., 2008).

An estimation of the length of these three types of coastal areas showed that from a total of 16,300 km, 960 km (6%) correspond to deltaic areas of high vulnerability (marked in red),

Table 2.13 **Shoreline retreat and inundated area for potential SLR of 0.5 m and 1 m***
(For the case studies examined in this study)

		Shoreline retreat	Shoreline retreat due to				
Coastal area	SLR (m)	Bruun model (m)	SLR (m)	Coastal erosion (m)	Total shoreline retreat (m)	Inundated area (10^3 m²)	Source
Skala Eressos, Lesvos	0.3	-	-	-	-	28	Doukakis (2008)
Gulf of Nafplio	0.5	-	-	-	-	4,200	Doukakis (2005a)
	1	-	-	-	-	8,700	
Kotychi lagoon	0.5	-	-	-	-	720	Doukakis (2003)
	1	-	-	-	-	1,760	
Hersonissos, Crete	0.5	-	-	-	290	4,700	Doukakis (2004)
	1	-	-	-	320	5,200	
Aigio, Achaia	0.5	-	-	-	5-900	1,070	Doukakis (2005b)
	1	-	-	-	30-1300	1,800	
Lambi, Kos	0.5	-	-	-	114-153	35	Papadopoulou and Doukakis (2003)
	1	-	-	-	179-223	52	
Kardamaina, Kos	0.5	-	-	-	15-81	19	
	1	-	-	-	34-109	33	
Tingaki, Kos	0.5	-	-	-	28-101	161	
	1	-	-	-	69-167	322	
Afantou, East Rhodes	0.5	-	-	-	74 - 275	375	
	1	-	-	-	20 - 296	439	
Vartholomio, Ilia	0.5	-	-	-	31-107	190	
	1	-	-	-	68-154	300	
Acheloos River Delta	1	-	-	-	-	72	Doukakis (2007)
Plain of Thessaloniki	1	-	-	-	-	37,100	Kanellakis and Doukakis (2004), and Doukakis (2007)
Abdera, Macedonia	1	-	-	-	-	716	Doukakis (2007)
Lake Alyki, Lemnos	1	-	-	-	-	2,041	Pliakos and Doukakis (2004), and Doukakis (2007)
Kitros saltmarsh, Pieria	0.5	-	-	-	-	9,450	Stergiou and Doukakis (2003)
	1	-	-	-	-	11,800	

* Except for Skala Eressos, Lesvos (SLR: 0.3 m).

Table 2.13 **Shoreline retreat and inundated area for potential SLR of 0.5 m and 1 m *(continued)*
(For the case studies examined in this study)**

Coastal area	SLR (m)	Shoreline retreat	Shoreline retreat due to		Total shoreline retreat (m)	Inundated area (10^3 m²)	Source
		Bruun model (m)	SLR (m)	Coastal erosion (m)			
Porto Heli, Argolis	0.5	-	-	-	-	36	Seni and Karibalis (2007)
	1	-	-	-	-	161	
Ermioni, Argolis	0.5	-	-	-	-	19	
	1	-	-	-	-	278	
Evinos River Delta	0.5	-	-	-	-	12,500	Karibalis and Gaki-Papanastasiou (2008)
	1	-	-	-	-	21,300	
Mornos River Delta	0.5	-	-	-	-	2,580	
	1	-	-	-	-	3,710	
Kalamas River Delta	0.5	-	-	-	-	7,020	
	1	-	-	-	-	10,060	
Pineios River Delta	0.5	-	-	-	-	6,530	
	1	-	-	-	-	14,780	
Alfeios River Delta (northern part)	0.5	51.1	175	15	190	224	Poulos et al. (2009)
	1	102.2	810	-110	700	683	
Alfeios River Delta (southern part)	0.5	54.5	15-30	0-15	30	35	
	1	109	10-100	400	400-450	344	
Axios River Delta	0.5	52.7	250-2000	0	250-2000	10,825	
	1	213.6	2000-2500	0	2000-2500	28,482	
Aliakmon River Delta	0.5	63.6	50-1750	0	50-1750	4,875	
	1	195.4	250-2500	0	250-2500	8,950	
Loudias-Aliakmon deltaic plain	0.5	-	500-2750	0	500-2750	8,900	
	1	-	5000-6500	0	5000-6500	25,575	
South Euboean Gulf	0.5	-	-	-	-	7,890	Roussos and Karibalis (2009)

2,400 km (15%) correspond to non-consolidated sediments of medium vulnerability (marked in green), with the remaining 12,810 km (79%) corresponding to rocky coastal areas of low vulnerability. The total length of coastline presenting ‘medium to high’ vulnerability to SLR therefore roughly amounts to 3,360 km (21% of Greece’s total shoreline).

Presented in Table 2.13 are approximate estimates of shoreline retreat and inundated area (excluding possible corrections of tectonics and geodynamics) in the event of an SLR of 0.5 m and 1 m in ‘high risk’ areas. The table data were drawn from 27 case studies, identified during a review of the Greek and international literature for the needs of the present study. The shoreline retreat likely to result from a hypothetical sea level rise of 0.5 m ranges from 15 m to 2,750 m, while the respective range for a hypothetical rise of 1 m is from 400 m to 6,500 m.

2.2.4 Storm surges – wave storms

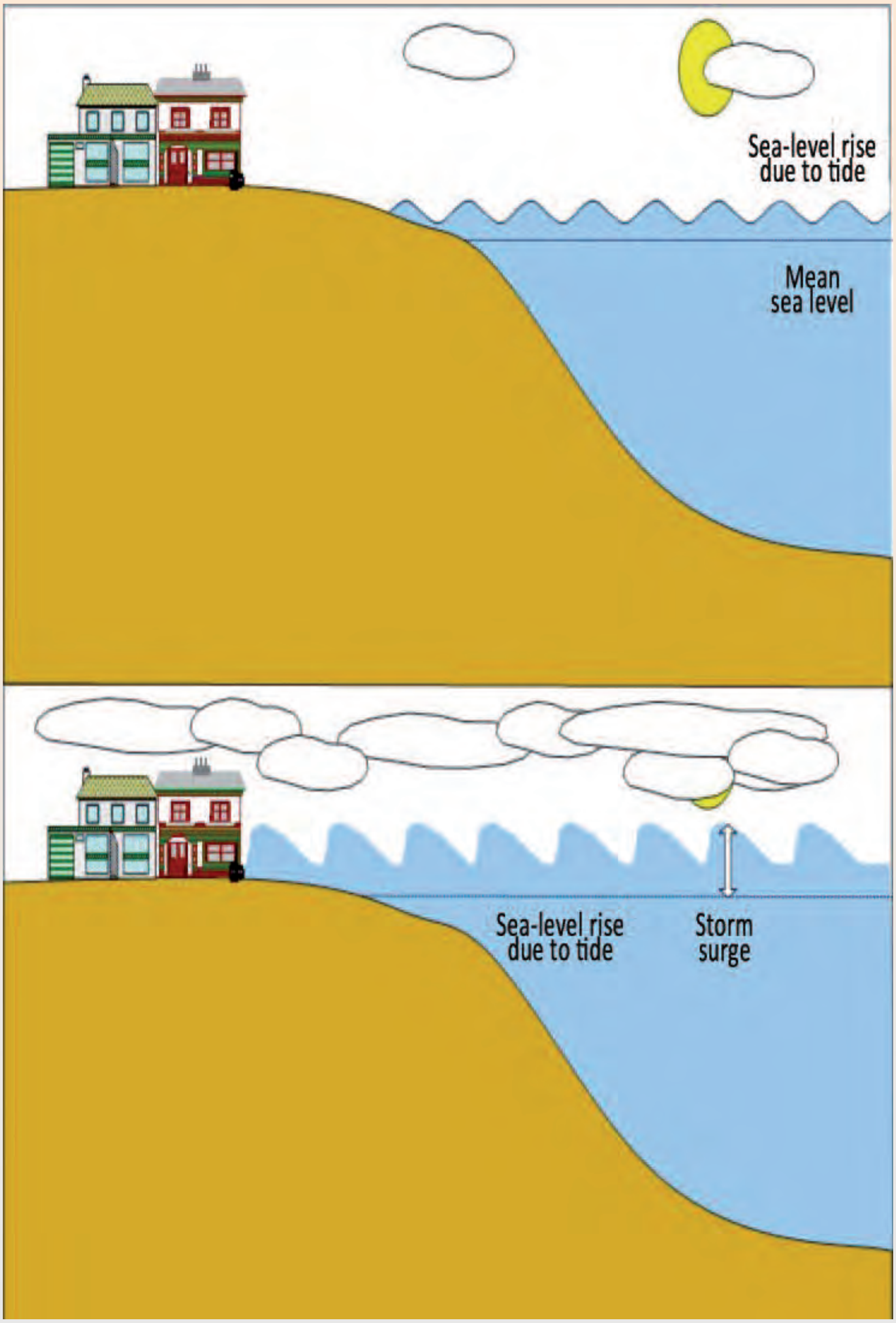
Apart from long-term SLR, other climate phenomena capable of causing coastal erosion are the anticipated increase in storminess and frequency of storm surges (IPCC, 2001, 2007). The strong coastal waves caused by stormy winds (and accompanying wave currents) cause erosion, whereas the normal, low-mid energy waves cause sediment deposition (Komar, 1998). Storm surges and SLR are distinct phenomena. However, SLR (which is caused by the thermal expansion of seawater as it warms and the melting of continental ice) may increase the intensity and frequency of storm surges. Changes in mean sea level and in storm intensity (amplified by climate change) may cause extreme wave phenomena and potentially serious damage to coastal areas. The reason for this is that strong winds affect larger water masses which unleash more energy in storm surges, while the height of the waves increases relatively to the mean sea level rise. As a result, the waves penetrate further into the coastal areas, producing significant impacts on coastline morphology (Krestenitis et al., 2010). The impacts of storm surges include (Karambas et al., 2008):

- flooding of coastal areas;
- destruction of coastal infrastructure (roads, coastal engineering works, etc.);
- coastal erosion; and
- intrusion of salt water in coastal habitats, lagoons, river, estuaries, etc.

2.2.5 Social perceptions of climate change, SLR and storm surges

Awareness of the vulnerability and adaptability to climate change —not only of natural systems but of the social system as well— is a crucial turning point for planning adequate policy. Adaptation is closely related to the notion of vulnerability, defined in the glossary of the IPCC Third Assessment Report as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes”. Vulnerability is a function of the nature, range and rate of climate change to which the system is

Image 2.2 **Sea-level rise due to storm surge**



Source: Kourogeni and Karambas (2010).

exposed, as well as of the system's sensitivity and adaptability. Reducing vulnerability therefore falls under the goals of preventive adaptation. The recent literature on vulnerability and adaptation stresses the need for measures and policy planning at two levels: (a) the technological level and (b) the institutional and behavioural level. Vulnerability and risk assessment (to be used as an input in decision-making) must also be conducted at two levels, i.e. objective and subjective. By subjective assessment of risk, we mean the social perceptions of risk, which are not necessarily identical to the objective assessment (Kontogianni et al., 2008).

For a more thorough understanding of the social perceptions of risk due to climate change in Greece, two research projects were designed and carried out, one in Lesvos in 2010 and one in Crete in January 2011. Their findings were comparable and show the dynamics in the respondents' perceptions, compared with a similar research project, conducted for the first time in Greece by the authors of present sub-chapter in 2003-2004 in Southern Euboia (Kontogianni et al., 2010b, c, 2011). Among the issues investigated by these projects were: whether the respondents were aware of climate change; whether they were aware of the causes and what they believed the causes to be; their level of trust in institutions; how important they assessed the various climate change impacts to be; whether they were prepared to cope with them; and whether they were willing to incur costs in order to protect themselves from the impacts.

2.2.6 Economic impacts of mean sea level rise in Greece[10]

2.2.6.1 Designing and assumptions of the present study

As time and other constraints in the context of the present study did not allow for a recording and valuation of all the potential impacts of SLR on Greece's coastal zone, we chose to focus on quantifying and assessing the impacts of SLR on the coastal land uses for:

- housing;
- tourism;
- agriculture;
- wetlands; and
- forestry.

One main reason for this selection was the availability of data from 27 case studies of Greece's coastal zone (Table 2.13). At a second level, an estimate was also made of the equally important aesthetic value of each area.[11] The estimated value of each 'coastal system' was taken as corresponding to the (future) cost to be incurred from its loss due to SLR. To properly appraise a

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[10] Detailed data and calculations for each case examined can be found (in Greek) in the full versions of the sea level study (Kontogianni et al., 2010a, b; Papanikolaou et al., 2010) posted on the webpage of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr).

[11] Some other services (e.g. coastal fishing) are discussed in other sub-chapters of the present study.

‘coastal system’ and its total economic value, *all* of the ecosystem services and goods it provides, as categorised in Table 2.12, would need to be evaluated. The results presented here therefore reflect only part of the value of the Greek coastal zone, taking into consideration the potential impact of SLR on the previously-mentioned five coastal land uses (tourism, housing, forestry, wetlands and agriculture). Our valuations of the ‘coastal zone’ resource represent a lower bound and an underestimate of its real value. The fact that the value of a coastal system is underestimated entails that the estimated future costs to be incurred due to SLR are also underestimated.

For a more thorough approach to the issue, we focused on assessing two different categories of economic impacts: **the long-term effects of SLR (by 2100)** and **the short-term effects of extreme weather events** (annually, base year: 2010). The valuation of long-term SLR damage took into consideration gradual SLR as specified by the IPCC scenarios, whereas the valuation of short-term SLR damage took into consideration the increased frequency of storm surges as an impact of climate change, taking place in parallel with SLR. It was considered important to include the impacts of short-term SLR in the present study, first because in accordance with IPCC methodology short-term SLR is associated with climate change, and second because several leading experts (Th. Karambas, Y. Krestenitis, A. Velegrakis and E. Doukakis in personal communications) concur that climate change increases storm surge intensity and frequency. Therefore, from a socioeconomic impact standpoint, a recurring phenomenon leading to short-term SLR and causing important economic damage is equally important as long-term and accelerating SLR (over a horizon of 90 years). To our knowledge, economic impact studies of past storm surges in Greece are rare and their results can therefore not be extrapolated to the entire coastal zone. For this reason, an additional stated preference survey economic assessment was conducted to assess the social cost of storm surges (Kontogianni, 2011).

In order to estimate the impacts of long-term SLR —on the basis of the 27 case studies— we calculated the total land area that would be lost for each of the five uses under study and the total loss of coastal area. A market pricing approach was then used for housing, tourism and agriculture uses, in order to estimate unit and total financial loss from inundation due to SLR. For wetlands and forestry, we relied on the widely used application of value transfer. The value transfer approach was also used to estimate the loss of aesthetic values. Loss of public infrastructure (airports, ports) and industrial zones were not taken into account.[12] More specifically:

- **The loss of farmland use**

The cost of farmland loss was estimated by multiplying the lost area with the Special Basic Value (SBV) of farmland in each investigated location. The SBV represents the value per square metre (m^2) of non-irrigated farmland for yearly crop cultivations. The SBV applies only to areas facing roads or located within 800 m of the sea.

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[12] For the cost valuation of damage to transport infrastructure, see Sub-chapter 2.9.

• The loss of wetland use

The cost of wetland loss was based on estimated wetland value. More specifically, the total area of wetlands expected to be lost to SLR was multiplied with their unit value. The wetland unit value (€4.8 million/km^2) was 'transferred' from Darwin and Tol (2001), a well-known study of SLR impact assessment.

• The loss of forest use

The cost of forestland loss was estimated by multiplying the total area of forestland expected to be lost with its unit value (€89.25/ha), as determined by Merlo and Croitoru (2005) for Greek forests.

• The loss of housing and tourism uses

The cost assessment of these impacts —both in the case studies where data was available on the present built environment and in the wider coastline area— was achieved by multiplying the total area lost in each case by the mean market value of property in the specific area. Using this assumption, we estimated the total tourist value of the coastline. Owing to the sparse data regarding land uses in the case studies and the wide variation of land prices, we adopted a mean estimated market value of property of €1,200/m^2, which properly reflects the mean land value for housing and tourism uses.

Using the cost assessments of the impacts attributable to the loss of housing, tourism, wetland, forest and agriculture land uses, as well as the total length and area of coastline examined in each case study, we then calculated a cost index, which estimates the financial cost of SLR per km or km^2 of coastline, depending on the data available in each case. All unit values used were adjusted across locations (to Greece) and time (2010) on the basis of the Purchasing Power Parity Index (PPPI) and the Consumer Price Index (CPI) (Pattanayak et al., 2002).

Lastly, we estimated the net present value of the losses by discounting the total amounts at rates of 1% and 3%. Choosing the proper (social) discount rate is crucial in such long-term assessments. Economic theory and practice cannot provide a definite answer, as the discounting rate issue is in essence an ethical one, involving intergenerational equity. Thus, in the OECD countries, the proposed discount rates range from 3% to 12% (OECD, 2007). The European Commission recommends a rate of 4% for medium- and long-term investments, but also accepts the use of lower rates in the case of extended timelines, like in the case of climate change (European Commission, 2005).

2.2.6.2 Results

2.2.6.2.1 Economic impacts of long-term SLR

The total loss of coastal land under the SLR scenarios of 0.5 m and 1 m, as estimated based on the methodological approaches of the case studies examined, is presented in Table 2.13. The total losses and the cost indexes were calculated for SLRs of 0.5 m and 1 m and for the five land

Table 2.14 **Average cost coefficients and total length/area of shoreline per land use**

Land use	Average cost coefficient		Length/ area of shoreline
	SLR 0.5 m	SLR 1 m	
Housing & tourism	€144,891 10^3/km	€262,851 10^3/km	2,400 km
Wetlands	€138 10^3/km^2	€247 10^3/km^2	1,000 km^2
Forests	€0.04 10^3/km^2	€0.13 10^3/km^2	4,000 km^2
Agriculture	€222 10^3/km^2	€514 10^3/km^2	35,511.5 km^2

uses under study (housing, tourism, wetlands, forestry and agriculture).The total losses were calculated as the area to be flooded times the respective unit value for each specific land use. The cost indexes were calculated by dividing the total losses with the length of coastline in the case studies. The cost indexes therefore represent quantified indicators of total land loss, which is ‘incorporated’ and expressed per kilometre of coastline for the five land uses under investigation. The estimated financial losses from the case studies were then extrapolated to the national level. The values used as average cost indexes, as well as the length and area of coastline per land use, are presented in Table 2.14.

The total cost of the impacts of SLR by 2100 for Greece as a whole is presented per land-use in Table 2.15.

The present values of the estimated total costs by 2100, calculated using discount rates of 1% and 3%, are given in Tables 2.16 and 2.17, respectively.

It should be recalled here that the estimated losses presented in Tables 2.15, 2.16 and 2.17 essentially express ‘use values’, except for wetlands, for which the estimated cost index also

Table 2.15 **Total economic cost of SLR in 2100 per land use (EUR thousands)**

Land use	SLR 0.5 m	SLR 1 m
Housing & tourism	347,738,400	630,842,400
Wetlands	138,000	247,000
Forests	160	520
Agriculture	7,883,553	18,252,911
Total	355,760,113	649,342,831

Table 2.16 **Present value of total economic cost of SLR per land use (Discount rate 1%, EUR thousands)**

Land use	Present value (2010)	
	SLR 0.5 m	SLR 1 m
Housing & tourism	142,013,297	257,630,475
Wetlands	56,358	100,873
Forests	65	212
Agriculture	3,219,574	7,454,328
Total	145,289,294	265,185,888

Table 2.17 **Present value of total economic cost of SLR per land use (Discount rate 3%, EUR thousands)**

Land use	Present value (2010)	
	SLR 0.5 m	SLR 1 m
Housing & tourism	24,316,576	44,113,412
Wetlands	9,650	17,272
Forests	11	36
Agriculture	551,279	1,276,386
Total	24,877,517	45,407,106

partly includes ‘non-use’ values. However, the ‘non-use’ (e.g. cultural and spiritual) value of many coastal ecosystems is a non-negligible part of their total economic value. A similar approach is the widespread use of ‘hedonic pricing’ in the real estate market, according to which the price of non-built land also encompasses such location factors as view, proximity to areas of cultural and spiritual importance, etc.

In line with this approach and in an attempt to express the magnitude of the possible cost from land value loss to SLR, we subsequently attempted to quantify the aesthetic/recreational and cultural/heritage values of residential and tourism land and wetlands. This was done based on value transfer from the study by Brenner et al. (2010), which estimates in economic terms the aesthetic/recreational and cultural/spiritual value of sandy and wetland coastal areas of Catalonia, Spain. To avoid double counting, these values were not taken into account when calculating the final loss figures attributable to SLR, but are nonetheless presented in the conclusions to this sub-chapter to give a sense of the real coastal values at stake.

2.2.6.2.2 Economic impacts of storm-driven wave and surge events: the short-term aspect of SLR

Storm-driven wave and surge events, which make up the short-term aspect of SLR, account for substantial annual impacts on the coastal area. Recording such impacts under the present study was considered important, due both to their economic weight and to the possibility of annual recurrences, making them factors of increased coastal vulnerability. Given, however, the limited data from on site research and, as a result, of the inability to generalise the losses to the entire coastal zone, an open-ended contingent valuation survey was conducted on the economic assessment of loss (damage) from short-term SLR (Kontogianni, 2011). The participants were asked about their 'willingness to pay' (WTP) for the construction of storm surge protection works in their area. The mean willingness to pay was estimated at €200.7 per household (standard deviation: €286).

According to the Report of Greece on Coastal Zone Management (Ministry of the Environment, Physical Planning and Public Works, 2006), the country's coastal population amounts to 9,293,982 or 85% of the total population (10,934,097 inhabitants). Assuming an average of three members per household, the total number of Greek households comes to 3,674,381, of which 3,097,994 live in coastal areas. Using a mean willingness to pay of €200.7 per household and extrapolating it to the Greek coastal population, the total value of protection from short-term SLR for Greek households comes to €621,767,426.

2.2.6.3 Adaptation policies

As estimated by the authors, the impacts on Greece's coastal areas of gradual long-term SLR and of storm-driven wave and surge events are expected to be particularly important in the next decades. The implementation of a coordinated adaptation policy is thus warranted to ensure the protection of Greece's extensive coastline of 16,300 km. As pointed out in the latest national report submitted to the UNFCCC regarding climate change (Hellenic Republic, 2006), no coordinated effort to assess the long-term impacts of SLR and to design appropriate adaptation policies has, as yet, been conducted in Greece. The basic adaptation policy suggested involved a total estimate of the risk that Greece's coastal regions face on account of climate change and SLR.

A number of studies have already presented interesting data on the cost of implementing adaptation policies.[13] For instance, the Scottish Natural Heritage (SNH, 2000) estimated the cost of various 'soft' and 'hard' engineering works for effective shoreline management against the impacts of erosion impacts. In the US, the Mississippi-Alabama Sea Grant Consortium (MASGC, 2007) has estimated the cost of shoreline protection products. Estimates of costs for coastline protection works can also be drawn from Sorensen et al. (1984), while both Koch

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[13] See footnote 10.

(2010) and the study for the valuation of SLR impacts on the coasts of California financed by the California Energy Commission (CEC, 2009) used identical cost estimates for selected adaptation policies. Finally, the adaptation policies studied under the PESETA programme (Richards and Nicholls, 2009) were dike construction and beach nourishment.

Greek case studies on adaptation to SLR

In the context of the present study, four case studies were selected for a cost/benefit analysis of selected adaptation policies to the SLR impacts. The study sites and adaptation measures considered were:

- Case Study 1 (CS1): Groynes, in the Lambi area on the island of Kos.
- Case Study 2 (CS2): Artificial beach nourishment, in the Kardamaina area on the island of Kos.
- Case Study 3 (CS3): Placement of riprap revetments and geotextile filter, in the Afantou area on the island of Rhodes.
- Case Study 4 (CS4): Concrete seawall, in the Tingaki area on the island of Kos.

Figure 2.5 Cost and benefit of adaptation measures in the case studies (CS) (EUR thousands)

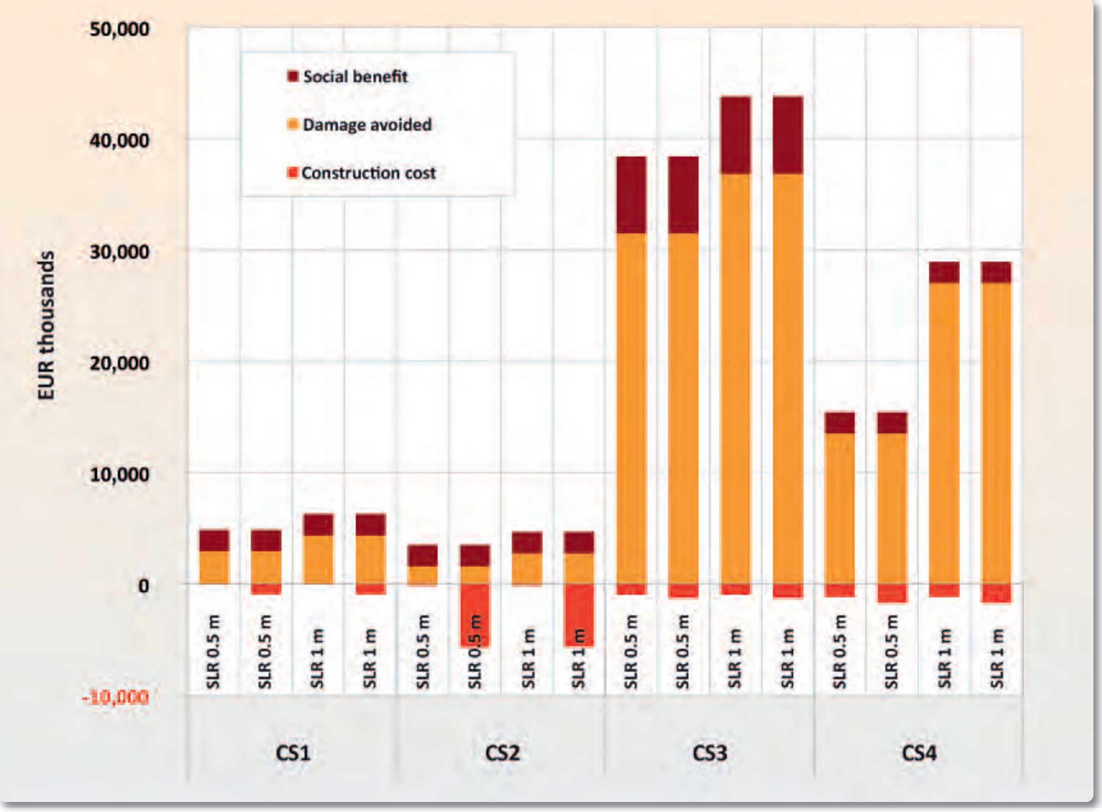


Table 2.18 **Damage avoided as a result of breakwater construction in medium vulnerability areas (Discount rate 1%, EUR thousands)**

Land use	Present value (2010)	
	SLR 0.5 m	SLR 1 m
Housing & tourism	142,013,297	257,630,475

Table 2.19 **Damage avoided as a result of breakwater construction in medium vulnerability areas (Discount rate 3%, EUR thousands)**

Land use	Present value (2010)	
	SLR 0.5 m	SLR 1 m
Housing & tourism	24,316,576	44,113,412

As can be seen from Figure 2.5, which illustrates the cost effectiveness of the adaptation measures considered, the **net benefit is positive** in all cases, except for the artificial beach nourishment in CS2 where the net benefit was negative only when a discount rate of 3% was used (which, by the way, is rather high) and only for the upper estimates of the work under construction. This figure is a visual representation of the cost/benefit analysis using a 3% discount rate, in which: the ‘construction cost’ is the implementation cost of the adaptation measure for coastal protection, ‘damage avoided’ from long-term SLR is equal to the estimated value of the land area saved as a result of protection works, and the ‘social benefit’ is the benefit for society (measured by the WTP) arising from the adoption of measures to avoid short-term impacts such as storm surges.

The cost effectiveness of adaptation measures can be easily substantiated at a countrywide level. As a working hypothesis, we examined the construction of breakwaters as an adaptation to climate change impacts (short- and long-term SLR) along the entire length of coast (2,400 km) consisting of newly-formed soft sediments of medium vulnerability. Considering that the cost of breakwater constructions was estimated at between €558/m and €1,394/m by the SNH (2000) and between €159/m and €613/m by the MASGC (2007), we set the minimum cost of breakwater construction at €159/m and the maximum cost at €1,394/m. The total cost of the measure’s implementation was thus estimated to amount to between €381.6 million and €3,345.6 million.

The corresponding avoided losses in present values, given in Tables 2.18 and 2.19, confirm that the benefits of adaptation are clearly higher than the corresponding costs, even when benefits are discounted at a relatively high rate (3%).

2.2.7 Conclusions

The Greek coastline is already subject to serious erosion problems, which are likely to be compounded by two major threats from climate change: long-term and short-term SLR. The impacts are as much a concern to the built environment and human populations as to major environmental systems. Given the importance of the coastal zones in the economy of Greece —a country with some 16,300 km of coastline, 12 of its 13 administrative regions open to the sea, and coastal tourism accounting for 15-18% of national GDP— to consider 'business as usual' a viable option would be irrational, to say the least.

The present study attempted to assess the economic impact of climate change from SLR for the entire Greek coastal zone. After a brief presentation of the main characteristics of the Greek coastal zone and its uses, we analysed the main long-term and short-term impacts to be expected and, in Image 2.1, mapped out the areas of low, medium and high vulnerability. The forecasts of SLR by 2100 ranged between 0.2 and 2 m.

The estimated economic losses from the 27 case studies examined (for 'housing', 'tourism', 'wetland', 'forest' and 'agricultural' land uses) were then extrapolated to the national level using the respective cost coefficients. The results are presented in Table 2.20.

The costs estimated so far essentially correspond to the *use* values of coastal ecosystem services. For the sake of completeness, we therefore made a **separate estimate** of the costs likely to arise from the coastal loss of aesthetic/recreational and cultural/spiritual values. To avoid any double counting, the estimates of these **non-use impacts were not included** in Table 2.20, but presented separately in Table 2.21.

We then estimated the economic impact of storm-driven wave and surge events as an expression of the short-term aspect of SLR. Having estimated the mean 'willingness to pay' to be €200.7 per household and extrapolated this figure to the entire coastal population, the **total value of protection from short-term SLR** for Greek households was estimated at €621,767,426 per year.

Table 2.20 **Total economic cost of long-term SLR in the Greek coastal zone (EUR thousands)**

	SLR 0.5 m	SLR 1 m
Total loss (2100)	355,760,113	649,342,831
Net present value (1%)	145,289,294	265,185,888
Net present value (3%)	24,877,517	45,407,106

Table 2.21 **Total economic cost of SLR as a result of the long-term loss of aesthetic/recreational and cultural/spiritual values in the Greek coastal zone (EUR thousands)**

	SLR 0.5 m	SLR 1 m
Total loss (2100)	847,340	1,538,100
Net present value (1%)	346,046	628,146
Net present value (3%)	59,253	107,556

As indicated by the estimates this far, the impacts on Greece's coastal areas from both gradual SLR and storm-driven wave or surge events are expected to be particularly important in the next decades. The implementation of a coordinated adaptation policy is thus considered necessary to ensure the protection of Greece's extensive coastline of 16,300 km. The four case studies for which adaptation costs and benefits were estimated show a clear cost effectiveness of the adaptation measures considered (in almost all cases the net benefit was positive). If, as a working hypothesis, the coastal protection measures are extrapolated to a national scale (specifically, to the 2,400 km of shoreline consisting of newly-formed soft sediments of medium vulnerability, and excluding the 960 km of shoreline corresponding to deltaic coastal areas of high vulnerability), the evidence (presented in Tables 2.18 and 2.19) once again supports the cost effectiveness of adopting immediate coastal protection measures.

The estimated value of each 'coastal system' was taken as corresponding to the (future) cost to be incurred from its loss due to SLR. To properly appraise a 'coastal system' and its total economic value, *all* of the ecosystem services and goods it provides, as categorised in Table 2.12, would need to be evaluated. The results presented in this study therefore reflect only part of the value of the Greek coastal zone, taking into consideration the potential impact of SLR on five coastal land uses (tourism, housing, forestry, wetlands and agriculture). Our valuations of the 'coastal zone' resource represent a lower bound and an underestimate of its real value. The fact that the value of a coastal system is underestimated entails that the estimated future costs to be incurred due to SLR are also underestimated.

Our study found a pressing need for a study of the Greek coastal areas at high risk of inundation. This need should extend to a detailed diagnosis/forecasting of coastal zone vulnerability also due to changes in frequency/intensity of extreme weather phenomena (storm surges). At an institutional level, the EU Member States are required, in accordance with Directive 2007/60/EC, to have undertaken by 2011 a preliminary assessment of river basin flood risk (including the coastal zone), with a view to identifying areas where flooding is likely to occur. Moreover, the EU Member States are required to have completed flood hazard maps and flood risk maps of these areas by end-2013, and to have completed and published flood risk management plans for these areas by end-2015.

With regard to the impact valuation performed, its reliability depends first and foremost on the reliability of the physical primary data. For the purposes of the present study, all available case studies of the physical impact valuation of SLR in Greece were consulted in a first attempt at a valuation of the phenomenon. If, for instance, the physical impacts of long-term SLR (inundated area) are overestimated, this would mean that the economic impacts are also overestimated. In order to minimise overestimating our economic assessments, we adopted conservative estimates of the economic losses. An effort was also made to avoid any double counting. For instance, reference could also have been made to the additional economic losses pointed out by the IPCC, while the authors also chose not to take into account —due to the uncertainty surrounding SLR data and forecasts— the change in economic values in cases where, owing to incomplete knowledge, the consequences of SLR are uncertain. Given that the housing/tourism land use value of the coastal zone represents an important measurable parameter in our damage estimates, and that the analysis of social vulnerability showed the social perception of risk from SLR to be rising, it is fairly safe to presume that, if the coastal real estate market were to discount and internalise the future risk of coastal disasters, coastal land values would gradually depreciate, solely as a consequence of coastal risk anticipation. The need for immediate adaptation measures therefore becomes all the more imperative, in the light of the scientific confirmation of short-term and long-term risks from SLR.

2.2.8 Recommendations

There are three main lines of approach to policy planning for adaptation to SLR-induced impacts (Nicholls 2007a, IPCC-CZMS, 1990; Bijlsma et al., 1996; and Klein et al., 2001; see also Image 2.3):

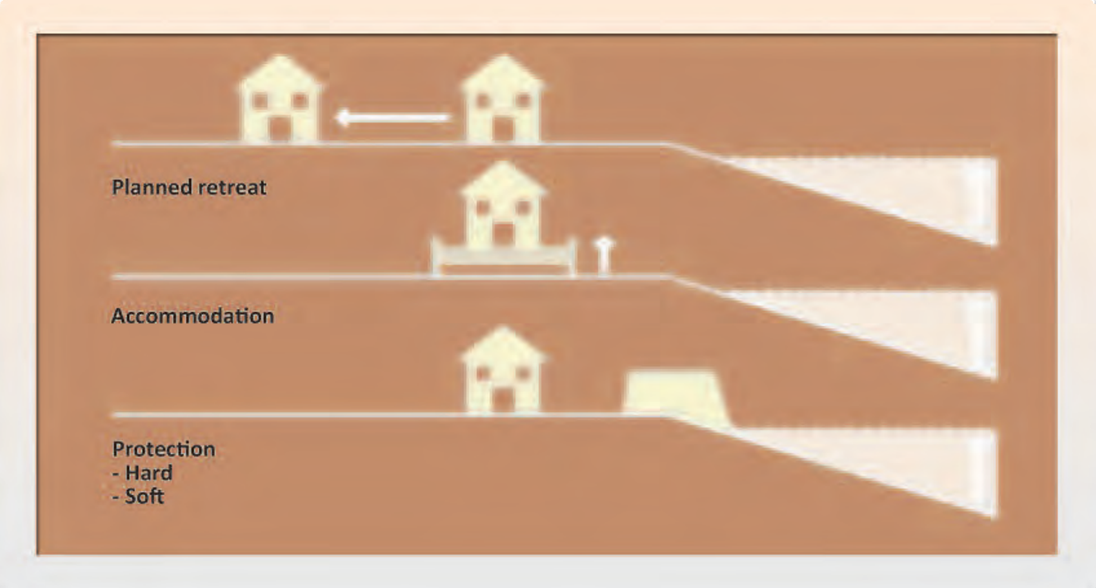
I. Retreat: SLR materialises and the impacts on society are minimised through a managed retreat from the affected coastal areas of all human activities and uses.

II. Accommodation: SLR materialises, and the impacts on society are minimised accordingly in the affected coastal areas through a modification of human activities and uses.

III. Protection: SLR materialises, and the impacts are addressed through soft and hard protective engineering, which minimises the social impacts that would have otherwise occurred.

Protection via coastal engineering works was discussed earlier in the study. Managed retreat from the coastal areas is one available option for an effective adaptation to SLR-induced risk

Image 2.3 An illustration of the possible adaptation responses to sea-level rise



Source: Nicholls (2009).

and losses, and for a prevention of a potential coastal squeeze on ecosystems. Some managed retreat actions are:

- The planning and development of protection zones between the shoreline and the residential development zone.
- Discouraging residential and business development in coastal areas at a high risk of erosion, and even prohibiting land use (where necessary) in threatened coastal areas.
- Evacuating coastal areas facing immediate risk.
- Relocating buildings and facilities to safer locations and higher grounds. All new constructions in coastal areas would, from the start, have to be relocatable.

Immediate adoption and implementation of a national adaptation plan is necessary to reduce the impacts of SLR. The main pillars of such an integrated plan should include: the elaboration a coastal cadastre; the designation of high-, medium- and low- risk zones depending on the characteristics of each coastal area so that soft or hard engineering works can be envisaged; the proper selection and construction of the necessary engineering works, and the setting-up of a permanent coastal monitoring system. Determining the implementation costs of the different adaptation policies is necessary to establish their cost effectiveness. Aside from engineering works, a national adaptation plan also has to recognise the need, and support the relevant potential, for mild institutional and behavioural adaptation policies, to encourage the relevant markets to internalise the risks from SLR and to bolster all efforts geared towards enhancing the country's social capital in the management of its coastal resources.

2.3 Fisheries and aquaculture*

2.3.1 Introduction

The main factors of climate change that will affect the goods and services provided by the country's fisheries and aquaculture sector are related, first, to the expected rise in temperature and in CO_2 dissolved in various water bodies, and, secondarily, to rising sea levels. A reliable estimate of these changes should, apart from direct measurements (very few of which exist today) also take changing ecological and physico-chemical parameters into account. Sustainable ecosystem management when applied to fisheries and aquaculture must aim to conserve the ecosystem structures and ensure the livelihood of the local human population, while also focusing on water quality parameters (e.g. nutrients, biodiversity at different trophic levels, plant/animal species production, temperature, stratification, transparency, dissolved oxygen and carbon dioxide concentrations, pH, ammonia) and the interactions between them (Papoutsoglou, 1981, 1990).

Overexploitation and non-selective fishing gear, together with pollution and aquatic environment disruption (e.g. seafloor disturbance) are the main reasons for the reduced yield of natural fisheries. In addition, the impacts of changing climate on the physico-chemical and biological properties of water bodies (rivers, lakes, lagoons, seas) are expected to have different repercussions in each case on output potential and uses. The aim of present sub-chapter is to estimate the likely impacts of climate change on fisheries and aquaculture production.

2.3.2 The current productive capacity of Greece's water bodies

2.3.2.1 Fisheries production

2.3.2.1.1 Inland water bodies

The total approx. area of Greece's lake water bodies is roughly 910 km^2 (natural lakes: 580 km^2; artificial lakes: 330 km^2). The seven largest natural lakes (Trichonis, Volvi, Vegoritis, Vistonis, Koronia, Little Prespa and Great Prespa) are situated for the most part in the plain areas of Northern Greece, while the five largest artificial ones (Kremasta, Polyphytos, Kerkini, Kastraki and Plastiras) are situated in mountainous/semi-mountainous areas of the country's central districts. The ecological status of most lakes in Greece (30-32) has not been fully determined. The average fish production capacity of Greek lakes is estimated at 20-25 kg/ha per year (Kagalou et al., 2008; Konstantinou et al., 2006; Markou et al., 2007; Mitraki et al., 2004; Ministry of Agricultural Development and Food, 1986-2005).

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* Sub-chapter 2.3 was co-authored by: Sofronios Papoutsoglou, Costas Papaconstantinou, Phoebe Koundouri, Kyriaki Remoundou, Stefanos Kavadas, Areti Kontogianni, Kostas Eleftheratos and John Kapsomenakis.

Of Greece's 26 rivers, three (i.e. rivers Evros, Nestos and Strymon) have their source in Bulgaria, one (river Axios) has its source in FYROM, while another one (river Aoos) has its source in Greece (in the northern part of the Pindos range) but its estuary in Albania. The total length of rivers within Greek borders is 2,780 km, the longest river being river Aliakmon (297 km). The total average annual discharge for all rivers combined is 800 m^3/sec, with the highest flows recorded by the rivers Evros, Acheloos, Strymon and Axios, in that order. In terms of total riverbed area, the five largest rivers are rivers Evros (~54 km^2), Axios (~25 km^2), Strymon (~17 km^2), Pineios (~11 km^2) and Aliakmon (~9 km^2). The overall ecological status of Greek rivers can be described as unstable and unpredictable, particularly in the plain regions they run through. Most rivers support organisms of the upper trophic levels, mostly fish. Due to limited data availability, safe conclusions cannot be drawn about river fish production (Iliopoulou-Georgudaki et al., 2003; Konstantinou et al., 2006; Skoulikidis, 2009; Vieira et al., 2008; Ministry of Agricultural Development and Food, 1986-2005).

2.3.2.1.2 Lagoon areas

Mainland Greece comprises a total of 76 lagoons, covering a total area of roughly 350 km^2 (72% landlocked). Messolonghi (86.5 km^2) is the largest, followed by lagoons Vistonis (45 km^2) and Logarou (35 km^2). The overall ecological status of the above lagoons can be described as unstable due to their varying physico-chemical properties and their level of eutrophication. More predominant are the euryhaline species of fish, followed by certain stenohaline (marine) species, various invertebrates, and in some cases freshwater species. Greece's lagoons are an important present or potential source of fisheries and aquaculture production. Official data on fisheries production using fishing gear other than traditional traps are not available (Dassenakis et al., 1994; Kagalou et al., 2008; Markou et al., 2007; Ministry of Agricultural Development and Food, 1986-2005).

2.3.2.1.3 Coastal and marine areas

Greece has the longest coastline of all the countries of the Mediterranean and the EU, with a total length of roughly 16,300 km and a total 1,354 gulfs and bays. The total sea area of Greece (470,000 km^2) is 3.6 times its total land area. Administratively, the country is divided into 13 regions, 12 of which are coastal (only one is land-locked). The length of coastline prone to erosion has been estimated at 3,945 km (28.6%). More than 85% of the total population lives within 50 km of the coast, and 69% of the national GDP (€140,268 million) is produced there.

Greece's larger gulfs – such as the Thermaikos, Pagassitikos, Saronikos (Saronic), Corinthiakos (Corinth), Evoikos (Euboean), Amvrakikos – are the more ecologically degraded. Some of the more closed gulfs, such as the Thermaikos, experience seasonal toxic phytoplankton blooms. The marine environment's ecological degradation is primarily due to the disposal of

Table 2.22

Annual fish catches, 1990-2009
(In tonnes, fishing vessels with horsepower >20 HP)

Year	SST*	Benthic	Small pelagic	Mesopelagic	Large pelagic	Total
1990	19.22	70,397	25,812	13,508	2,726	112,442
1991	18.95	78,986	28,189	13,872	2,716	123,763
1992	18.93	88,215	32,887	17,749	2,473	141,324
1993	19.05	93,946	35,858	22,715	2,757	155,276
1994	19.87	109,834	38,864	29,749	3,572	182,019
1995	19.40	92,987	35,320	18,716	3,124	150,146
1996	19.03	92,203	35,237	18,638	2,637	148,714
1997	19.06	92,391	36,580	15,471	3,253	147,695
1998	19.61	57,304	38,005	8,807	2,826	106,942
1999	20.16	65,925	33,669	7,553	2,371	109,517
2000	19.72	49,299	27,434	8,406	2,925	88,063
2001	20.05	44,652	27,854	7,720	3,036	83,261
2002	20.06	45,482	29,206	8,981	2,242	85,910
2003	20.02	51,059	24,252	7,849	1,913	85,072
2004	19.69	53,160	25,220	8,030	1,526	87,936
2005	19.60	52,395	24,475	9,143	1,890	87,903
2006	19.36	52,905	28,312	9,316	1,886	92,419
2007	19.72	51,939	28,418	8,464	1,526	90,348
2008	19.47	47,480	29,843	7,187	991	85,501
2009	19.76	45,396	26,533	6,917	1,208	80,054
Mean value	19.53	66,798	30,598	12,439	2,380	112,215

* Sea-surface temperature.
Source: NSSG.

solid and liquid waste from the coast, navigation (e.g. crude oil tankers), and overfishing, and, to a lesser extent, to the unorthodox use of floating cages in coastal fish farming. The open seas are, on the other hand, less affected by human activities, and their overall ecological status is satisfactory to very good.

The few measurements of physico-chemical and biological properties available are sporadic measurements of temperature, salinity, dissolved oxygen, nutrients, primary production and benthic species. Heavy metals were measured in the previous decade, under the UNEP programme. POSEIDON —a marine environmental monitoring, forecasting and information system for the Greek seas— provides in situ measurements of a large number of physical parameters, as well as wave height data. In their vast majority, the fish species encountered in the Greek

Table 2.23 **Greek sea fisheries production and percentage share of the 10 most commercially important fish species, at 5-year intervals, 1987-2009 (Production in tonnes, fishing vessels with horsepower >20 HP)**

Year	Northern Aegean		Central Aegean		Southern Aegean		Ionian Sea		Total	
	Production	%	Production	%	Production	%	Production	%	Production	%
1987	56,178.0	42.60	18,960.1	54.32	26,165.9	41.87	5,022.6	51.67	106,326.6	46.78
1992	78,631.9	41.05	25,097.6	65.19	25,371.4	45.65	12,177.1	63.57	141,278.0	48.10
1997	74,624.3	38.06	20,213.6	52.49	38,192.7	50.80	14,658.0	48.97	147,688.6	44.41
2002	46,529.9	56.14	9,254.5	67.34	17,867.6	39.76	12,259.5	43.22	85,911.5	52.09
2007	47,483.5	52.70	17,355.7	63.33	14,828.2	45.67	10,682.7	49.13	90,350.1	53.17
2009	36,732.3	57.11	17,906.9	61.89	15,716.6	45.71	9,699.2	52.54	80,055.0	55.39

%: Percentage share of the 10 most commercially important fish species: sardines, anchovies, chub mackerels, cods, bogues, red mullets, horse mackerels, mackerels, tunas and monkfish.
Source: NSSG.

seas are stenohaline and relatively stenothermal. It should be noted that in recent years the Greek seas have seen a gradual increase in warmer-water species (mostly phytoplankton and jellyfish), as well as fish and other aquatic organisms. These invasive species are presumed to be in competition with species native to the Greek seas. Their appearance in recent years and faster expansion northward in the Aegean may be related to a rise in Greek sea temperature and to underlying climatic changes (Pancucci-Papadopoulou et al., 2005). The ‘Lessepsian’ migrants present today in Greece’s seas include 28 fish, 11 crustacean and 1 cephalopod species, and a larger but unspecified number of phytoplankton and zooplankton species (ELNAIS, 2010).

An analysis of the variations in total annual catch production over the period 1990-2009 (Table 2.22) for fishing vessels >20 HP reveals that almost all categories of catches peaked in the years 1993-1997. Since then, production has been trending downward across all categories, except small pelagic fish, with the 2009 catch levels in the more important categories falling below 50% of earlier peaks. Over the same period, the fishing fleet decreased by roughly 27% and sea surface temperature (SST) rose by 0.7ºC.

The abundance distribution of the 10 most commercially important species fished by boats >20 HP, presented in Table 2.23 at 5-year intervals from 1987 to 2009, is rather difficult to interpret, basically because of the statistical data collection method used. As of 2002, all EU Member States are required to collect fisheries data using a specific methodology, as outlined in Council Regulations (EC) Nos 1543/2000 and 199/2008. Greece, however, has not been very compliant in this respect, hence the lack of a complete time series from 2002 onward (Kavadas et al., 2007).

Table 2.24 **Freshwater fish production, 2006 (In tonnes)**

Type of catch	Number of enterprises	Annual production
Rainbow trout	94	2,450
European eel	8	375
Common carp	9	110
Atlantic salmon	5	5
Total	126	2,950

2.3.2.2 Aquaculture production

2.3.2.2.1 Freshwater fish production

The total production of freshwater fish farmed in controlled intensive aquaculture systems is rather limited (Table 2.24), yet gradually increasing (1980: 2,150 tonnes; 2006: 2,950 tonnes).

The farming of rainbow trout and Atlantic salmon requires very clean waters, high levels of oxygen saturation, and temperatures of 13-17ºC. The common carp and the European eel can tolerate less clean water conditions, lower oxygen levels and a temperature range of 6-28ºCand above 12ºC, respectively. The fish farming tanks must have a depth of at least 1-1.5 m, except in the case of the European eel where shallower waters can be used (~50 cm, D'Orbcastel et al., 2008; Papoutsoglou, 1997; Papoutsoglou, 2004; Ministry of Agricultural Development and Food, 1986-2005; Greek Fishing Development Corporation; Hellenic Statistical Authority).

2.3.2.2.2 Production of euryhaline and stenohaline species

The production of euryhaline and stenohaline fish species is limited in extensive aquaculture production systems in coastal sea regions (2,000 tonnes/year), but far more important in modern intensive systems (~120,000 tonnes/year), with the production of gilthead sea bream and European bass accounting for 48% of the European total. Greece counts some 100 private companies (with 318 operating units) using floating cages. Compared with their extensive counterparts, the intensive aquaculture systems obviously pose a greater threat to the environment, although this impact is highly localised (Anagnostou et al., 2005; Cochrane et al., 2009; Daw et al., 2009; Papoutsoglou, 1996; Papoutsoglou et al., 1996; Vieira et al., 2008; Papoutsoglou, 1992; Ministry of Agricultural Development and Food, 1986-2005; Greek Fishing Development Corporation; Hellenic Statistical Authority).

The controlled mass production of mussels (24,000-25,000 tonnes/year) is practiced in a total area of ~40 ha, mainly in the coastal areas of Northern Greece (Thermaikos gulf, Pieria prefecture) which yield 80-90% of total national production. More than 400 companies in

Greece use floating or suspended facilities in eutrophic areas, i.e. areas of high primary production. The ecological status of these areas is fragile and their management calls for particular attention, as noted by the Ministry of Agricultural Development and Food (1986-2005), the Greek Fishing Development Corporation and the Hellenic Statistical Authority.

2.3.3 Physical impacts of climate change on Greece's fisheries production

The apparent rise in temperature, combined with lower precipitation levels, can lead to unexpected fluctuations in river flows and to unpredictable ecological degradation downstream, as competition for water obviously reduces water availability. Numerous lakes are also projected to be at similar risk, particularly at times of prolonged drought. This is expected to lead to a degraded environment for the ichthyofauna and to a possible decrease in the productive potential of inland waters (Allison et al., 2009; Bobori and Economidis, 2006; FAO, 2008; Mavrakis et al., 2004).

The rise in sea temperatures is likely to accelerate the growth rate of poikilothermal aquatic animals. It is difficult, however, to predict whether this could translate into higher fisheries production, given that verification would require an area that is not fished and that the fisheries status of an area is predominantly determined today by overfishing, rather than by natural factors. Interestingly, despite the fact that the SST of the Aegean has risen in recent decades by 1.5ºC, catches have not increased (in fact, they have decreased). It has been estimated that for every increase of 1ºC in SST over the period from 1990 to 2008, the average fish production in almost all categories fell by 0.8% (taking into account the reduction in the fishing fleet, and leaving all other factors unchanged). These lower production levels may, apart from overfishing, also be attributable to changes in nutrient levels in the Greek seas.

The temperature rise will in addition to a sea level rise (SLR) also bring about changes in biodiversity, fishing ground characteristics (biological, physical, chemical and hydrological) and available stocks of commercial importance. The total area of wetlands, which provide important spawning and nursery grounds, would be greatly diminished. The rise in temperature would also affect the migration of fish to and from their spawning and feeding grounds. A generalised change in sea temperature could quite possibly cause changes in water circulation (surface, toward the coast, upward, downward, coastal currents), with all that this would entail for the ecological/productive capacity of different water bodies. At this stage, it should be pointed out that changes in rainfall seem to affect only cephalopods and malacostraca (with decreases of 20 mm in rainfall translating into 2% less production).

2.3.4 Physical impacts of climate change on aquaculture in Greece

The continued use of intensive aquaculture production systems is soon expected to generate serious ecological/environmental problems, particularly in cases where coastal floating cages are used. As a result, production is likely to decrease. In addition, the increased frequency and intensity of extreme weather events, e.g. tornados, could cause considerable damage not only to fishing boats and floating cages, but also to fish and mussel farming facilities along the coast (Anagnostou et al., 2005; Pagou, 2005; Papoutsoglou, 1991; Papoutsoglou and Tsiha, 1994; Papoutsoglou, 1996; Papoutsoglou, 1997; Papoutsoglou, 2004).

Finally, because of the apparent rise in sea and lagoon water levels, aquaculture systems and methods are likely to be seriously reconsidered (e.g. the need to avoid coastal areas). The rise in coastal sea levels is also likely to affect the reproduction and growth of various species of fish, as well as the overall level of fisheries productivity (Doukakis and June, 2004; European Commission, 2008; FAO, 2008; Flemming and Woodworth, 1988).

2.3.5 Analysis of fish catch variations in Greece and future estimates

In order to determine the link between SST variation and fisheries yields, we analysed fish catch data from a large statistical sample of 2,244,304 tonnes, collected by the Hellenic Statistical Authority (ELSTAT) for the period 1990-2009. Fish catches were categorised as benthic, small pelagic, mesopelagic and large pelagic (see Table 2.22). Relative to total catches, benthic fish accounted for 60% (1,335,953 tonnes), small pelagic fish for 27% (611,967 tonnes), mesopelagic fish for 11% (248,789 tonnes), and large pelagic fish for 2% (47,595 tonnes).

The ELSTAT statistical catch data were used both to analyse catch variation in relation to SST variation and to measure certain catch variations against rainfall variation.

The analysis was conducted at the countrywide level for the period 1990-2009, using the annual of fish catch quantities presented in Table 2.22 and monthly mean values, adjusted for seasonality. This analysis only omitted the effect of overfishing over time, due to changes in the fishing fleet and not to long-term changes in fish populations. The main results can be summarised as follows:

(a) Analysis of fish catch variations in Greece in relation to SST variations, and future estimates

We analysed the annual catch quantities for the period 1990-2009, adjusting for the declining trend in the fishing fleet, estimated at 1.34% per year. The statistically significant variation trends in catches were as follows: Total fish catches amounted to 2,244,304 tonnes/year, with an overall decrease of 2,491 tonnes/year. Benthic fish catches decreased by 1,854 tonnes/year, mesopelagic fish catches decreased by 571 tonnes/year and large pelagic fish catches decreased by 66 tonnes/year. In contrast, small pelagic fish catches increased by 0.3 tonnes/year. The variation in SST over the 1990-2009 period was 0.035ºC/year or 0.7ºC in total over the two decades. The variation in catches over 1990-2009 are presented in Table 2.25.

Monthly catch time series, adjusted for changes in fishing fleet size and for seasonality, were used to calculate the effect of each 1ºC rise in SST on catch variation. As shown in Table 2.26,

Table 2.25 **Total fisheries production and variations, 1990-2009 (in tonnes)**

Types of fish	Total	Annual variation	Variation over 20 years
Benthic	1,335,953	-1,854	-37,080
Small pelagic	611,967	+0.3	+6
Mesopelagic	248,789	-571	-11,420
Large pelagic	47,595	-66	-1,320
Total	2,244,304	-2,491	-49,814

Table 2.26 **Variation in fish catches with each 1°C rise in SST (in tonnes)**

Types of fish	Variation, in tonnes
Benthic	-724 *
Small pelagic	+12
Mesopelagic	-160 *
Large pelagic	+12
Total	-859 *

* Statistically significant changes, at 99% confidence interval.

for every 1ºC rise in SST, benthic fish catches decrease by 724 tonnes (1.1% of the mean) and mesopelagic fish catches decrease by 160 tonnes (1.3% of the mean).

An increase of 3.3ºC in SST by 2100 (according to the climate model simulations, Chapter 1) would, based on the foregoing analysis, translate into decreases in Greece of benthic fish catches by 3.6% of the mean and of mesopelagic fish catches by 4.2% of the mean. Large and small pelagic fish catches would increase by 40 tonnes respectively, i.e. by 1.7% and 0.13% of the mean. Total catches would fall by roughly 2.5% of the mean.

(b) Correlating catch variations with variations in rainfall

Our investigation of possible correlations between different catch categories and rainfall in Greece showed that there is no statistically significant correlation between rainfall and fish and invertebrates/bivalve molluscs. In contrast, statistically significant correlations with rainfall (around 0.15) with a lag of 11 and 17 months, respectively, were found for cephalopods and malacostraca. Based on these correlations, we estimated that a 20% decrease in rainfall (corresponding to Scenario A1B) would lead to a decrease in cephalopod and malacostraca catches in the order of 2%. For all other species, reduced rainfall was not found to have an impact on production.

The impacts of anthropogenic climate change on fisheries production, as estimated on a global scale by the Intergovernmental Panel on Climate Change (IPCC), can be summarised as follows:

1. Changes and local fluctuations in sea and inland water fisheries production are to be expected, as well as a mixing of different species.
2. The stock of sea fish species that reproduce in inland waters (e.g. the European eel) or needing low salinity wetlands is also expected to decrease.

2.3.6 Measures and strategies for mitigating climate change impacts

The impacts of rising temperatures on marine ecosystem structures and fish populations have already been felt with the ‘El Niño’ phenomenon off the coasts of Peru. In the early 1960s, Israel was forced to modify its fishery targets and techniques because of the ‘Lessepsian migrants’ invasion, basically at the expense of native species. Similarly, the appearance of the comb jelly species *Mnemiopsis leidyi* in the Black, Caspian and Aral Seas drastically reduced the anchovy population because the invader feeds on anchovy eggs and larvae. The anchovy population has since recovered, implying that a natural enemy of the *Mnemiopsis leidyi* may have appeared and/or that the *Mnemiopsis leidyi* may have been affected by the dwindling numbers of anchovy. Further down the line, such changes in fish populations inevitably impact employment levels in the fisheries sector as well as consumer options.

This is what makes the timely designing of strategies and measures geared towards mitigating the ecological, economic and social impacts of climate change so important. The following actions are needed:

1. Fishery production determinants and the sector’s employment potential must be recorded, and the active involvement of those employed in fisheries ensured through open dialogue and cooperation to achieve best possible information and awareness levels.
2. Institutional mechanisms and bilateral international agreements need to be established to activate or expand fisheries interests beyond national borders, with a view to spreading out the fishing power and making more resources available.
3. Emergency plans need to be designed for specific fisheries sectors (e.g. artisan fishing) that are unable to relocate and are likely to be most affected by climate change.
4. Fisheries management must be coupled with broader coastal zoning to ensure that coastal protection measures also include spawning and nursery ground protection.
5. Provisions for coastal protection and for maintaining aquaculture productivity, resilience and viability must be handled under a framework of ecological regional development. Provisions will also be needed for changes in production systems, including possible relocation, as well as for possible changes in species farmed.

6. Research funding needs to be redirected to the analysis and study of local and regional problems, adaptation, fishing fleet/gear size and composition, and interdisciplinary research.
7. Adaptation infrastructure for new species or fish populations needs to be provided for and designed. Fishing vessels will need to be replaced with larger ones and their onboard catch-processing capacity increased to achieve greater catch management efficiency.
8. Coastal regions must be clearly delineated (zoning) to ensure that aquaculture does not infringe on other activities (e.g. tourism).
9. Incentives must be given for various fishery activities to relocate.
10. Incentives will also have to be given for hyper-intensive systems, mainly for farming sea fish and euryhaline species in land/coastal facilities of closed and semi-closed water systems.
11. Regulations must be established and enforced to prevent the misuse/disruption of water bodies and to cultivate an ecological conscience in present and future generations.

2.3.7 Economic impacts

The present study has combined market information with benefit transfer estimates to assess the total economic cost of climate change for fisheries and aquaculture in Greece. The study has performed a cost valuation of the loss of domestic biodiversity (as a result of the spread of invasive alien thermophilic species) and the loss of income for the human populations employed in fisheries activities (as a result of fishery resource depletion) (Greek Biotope/Wetland Center, 2010). The fact, however, should not be overlooked that the settlement of stocks of a higher economic value, associated with higher water temperatures, is likely to increase fishermen income or at least to limit income loss.

With respect to the economic cost assessment of climate change for commercial fisheries, the average annual volume of fish catches between 1990 and 2009 came to 112,215 tonnes (Table 2.22). Assuming that this average annual fish catch volume will remain unchanged until 2100 and based on our earlier estimates that a 3.3ºC rise in SST by 2100 would entail reduced total catches by 2.5% (or 2,805.37 tonnes) and that, according to NSSG data (2009), 2007 catch prices ranged from €0.6 to €25.1 (with a mean of €5.3 and a median of €4.2), the income loss at 2007 prices in 2100 would amount to €14,868,461 (based on the mean), or €11,782,554 (based on the median). The present value of these income losses based on mean and median figures and assuming discount rates of 1% and 3%, as well as the corresponding equivalent annual costs (annuities) are presented in Table 2.27.

To elicit the monetary cost associated with the decrease in biodiversity levels, a benefit transfer approach was adopted. Of all the benefit transfer methods available, we chose the single value transfer approach, which consists in transferring estimates from the field where the primary study was conducted to the field of interest, after making the necessary adjustments

Table 2.27 **Present Value (PV) and Annuities (A) of the loss of income in fisheries due to climate change (Euro, 2007 prices)**

	Mean		Median	
Discount rate	PV	Mean	PV	A
0%	14,868,461		11,782,554	
1%	6,072,148	102,638	4,811,891	81,336
3%	1,039,719	33,537	823,928	26,576

Source: GEM-E3.

(Navrud and Ready, 2007; Ready and Navrud, 2006; Brouwer, 2000). This method has the advantage of being reliable and of significantly reducing transfer errors when available data are insufficient to describe the quality and quantity of the valuated good in the field of interest. For the purpose of the present study, we searched for studies carried out in Europe (European Turkey, Sweden, Ukraine), where climatic characteristics are similar to those of Greece.

The welfare loss due to the effect of climatic changes on biodiversity is estimated at €37.91/person according to Remoundou et al. (2010), and at €602/household according to Egger and Olsson (2009). The difference between these estimates is due to the fact that Remoundou et al. (2010) use the redistribution of present taxation as a payment vehicle in their valuation study. A review of the relevant literature shows that, in this case, estimates are higher than in studies where new taxes are used to finance the good in question. Consequently, when carrying out a cost/benefit analysis, it is preferable to use the more conservative estimates of Egger and Olsson (2009). We defined the relevant population affected by the climate change-related impacts on marine biodiversity to be the population living within 50 km of the coast. By extrapolation, the total economic cost due to biodiversity loss ranges from €287,457,124 (Egger and Olsson, 2009) to €1,895,654,656 (Remoundou et al., 2010).

Given the lack of specific quantitative estimates of the impacts of climate change on fisheries in Greece under different climate scenarios, we based our estimates on values drawn from the literature, which however can be used only for approximation. The difficulty of isolating and valuing the effects related directly to climate change must also be noted, as variations in stock abundance result from an interaction between a large number of anthropogenic and natural factors that differ considerably across water ecosystems. Primary valuation studies, taking into account the country's geographic and topographic diversity, are thus needed for a more accurate estimate of the cost impact of climate change on fishermen and Greek society as a whole.

Despite the inability —due to limited available data— to measure the full range of possible climate change impacts on fisheries and aquaculture in Greece, our study shows that climate change is expected to negatively affect the ability of fishery resources to provide goods and services of value to man. This clearly entails a loss of social welfare, a large part of which is associated with the loss of non-use values (including the value of the natural resource's existence, the value of being able to bequest these resources to future generations, and the value of conserving the biodiversity and stability of the specific ecosystems). This loss of social welfare needs to be taken into account when elaborating mitigation or adaptation policies to address climate change impacts.

2.3.8 Conclusions

- We analysed fish catch production data from a large statistical sample of 2,244,304 tonnes, collected by the Hellenic Statistical Authority (ELSTAT) for the period 1990-2009, as well as annual fish catch volumes, adjusting for the downward trend of the fishing fleet, estimated at 1.34% per year. The rise in SST over the 20-year period was estimated to have been of 0.7ºC.
- As we were able to show from the examined sample, for every 1ºC rise in SST benthic fish catches would decrease by 724 tonnes (1.1% of the mean) and mesopelagic fish catches would decrease by 160 tonnes (1.3%), while large and small pelagic fish catches would increase by 12 tonnes each, i.e. by 0.5% and 0.04%, respectively. Total catches would thus decrease by 859 tonnes or 0.8%.
- An increase of 3.3ºC in SST by 2100 (according to the climate model simulations, Chapter 1) would, based on present data, translate into decreases of benthic fish catches by roughly 3.6% and of mesopelagic fish catches by 4.2%. Large and small pelagic fish catches would increase by 1.7% and 0.13%, respectively. Total catches would fall by roughly 2.5%. It should be stressed that these rough estimates do not take account of the impacts on fisheries from factors that are difficult to quantify due to lack of data.
- Given that the rise in temperature is expected to benefit warmer-water species, total fisheries production may decrease only insignificantly, if at all. There will, however, be a redistribution of fish catches. With the rise in temperature, catches are also expected to include migrant species.
- Rainfall and river runoff into the sea typically increase an area's productivity due to the transfer of nutrients (with a lag of one or two years). Our analysis of catch trends in correlation with rainfall showed that 20% less rainfall (based on the climatic simulations of Scenario A1B) would lead to a small decrease in the production of cephalopods and malacostraca, in the order of 2%. Lower rainfall was not shown to have an impact on the production of other species.
- The present value of the income loss for commercial fisheries will range from €823,928 to €6,072,148, depending on the discount rate and on whether mean or median fish prices are used.

- The cost of biodiversity loss is estimated to range from €287 million to €1,896 million.
- In cases where coastal cages used in intensive fish farming units will need to be relocated on account of excessive pollution and changes in sea current circulation, the relocation costs are expected to be significant and still need to be accurately estimated.

2.4 Impacts of climate change on agriculture*

2.4.1 Introduction

Global concern about climate change has been mounting, in response in particular to the devastating impacts on the agriculture of developing countries (Parry et al., 2001; FAO, 2009). According to UN figures, in Africa alone 220 million suffer from a lack of drinking water due to climate change. The risks to agricultural production are associated with the loss of cultivable land, shorter growing seasons and uncertainty about what and when to plant. By 2100, it is estimated (UNFCCC, 2007) that net crop revenues in Africa could fall by 90%, millions in Asia could be at risk from hunger, while independent research efforts in Europe show that climate change will exacerbate regional economic inequalities within the EU (EEA, 2008; Stern, 2007).

The need to identify the impacts of climate change on agriculture (higher CO_2 levels, warmer temperatures, variations in precipitation, increase in weather extreme intensity and frequency, changes in the spatial distribution of crop pests and diseases; Tubiello et al., 2007) is heightened by the fact that these changes are expected to impact global food reserves, thereby leading to acute food shortages. Moreover, the increase in weather extremes can lead to a dramatic increase in food prices and to changes in the trade balance between countries (Lobell et al., 2008).

The Intergovernmental Panel on Climate Change (IPCC, 2007a) reports that a moderate temperature rise in the first half of this century is likely to increase crop yields in the temperate zone, but to reduce them in the subtropical and tropical zones. In the EU, as reported by the PESETA research project, crop production may, depending on the scenario, drop by 0-27% in Southern Europe, while increasing by as much as 40% in Central and Northern Europe. Using the HadCM3 model (Giannakopoulos et al., 2009) for Scenarios A2 and B2 (temperature rise of 2ºC, period 2031-2060) for the Northern Mediterranean, including Greece, bulb crop production is projected to decrease by 9.33% (Scenario A2), while cereal production is projected to increase by as much as 12.49% (Scenario B2). Kapetanaki and Rosenzweig (1997) have forecast a drop in maize yields in Thessaly by as much as 20%, while a study by

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* Sub-chapter 2.4 was co-authored by: Andreas Karamanos, Michalis Skourtos, Demetrios Voloudakis, Areti Kontogianni and Athanasios Machleras.

the Greek Ministry of the Environment (1997) for the period 2071-2100 forecasts decreases in maize production by as much as 55% and variations in durum wheat production from -67% to +15%, depending on the scenario. According to the same study, the cotton production is expected to decrease by as much as 29% in Macedonia and Thessaly, but to increase in Thrace by as much as 21%, while viticultural crops will vary from -59% to +55% depending on the scenario and region. The impact on tree crops is expected to be negative, particularly in Southern Greece and Crete. All studies point to an increased vulnerability of crop production in the years ahead in Southern Europe and the Mediterranean region in particular, a projection of great importance to Greece.

2.4.2 Impacts of climate change on agricultural production

Methodology

Estimating the impact of climate change on plant physiology is extremely complex and involves considerable uncertainty, due to the ‘futuristic’ aspect of the produced estimates and to the fact that several determinants are likely to play out differently (slower or faster) than anticipated.

To estimate the impact of climate change on Greek agriculture, we drew on recent research and publications and used modelling tools that help forecast crop response to climate change (Geerts and Raes, 2009). Crop growth models integrate climatic, meteorological, soil properties, phenology and crop-physiology variables in order to limit prediction errors (Soussana et al., 2010). Such models can be divided into two main groups: statistical models (Lobell et al., 2008; Paeth et al., 2008) and crop simulation or mechanistic models (CropSyst, AquaCrop, CERES, etc.).

We chose to use the AquaCrop model (version 3.1, 2010), derived from the revised FAO report (Doorenbos and Kassam, 1979), for the following reasons: it assesses the effect of water on both plant growth and crop productivity; compared with other models, it requires fewer parameters; it is simpler to use; and, lastly, it is more accurate, with lower error probabilities (Raes et al., 2009). We drew our data from research on wheat (Karamanos et al., 2008), cotton

Table 2.28 **Changes in CO_2 concentration and temperature levels per climate scenario relative to 1991-2000**

Climate scenarios	**A1B**		**A2**		**B2**	
Time periods	**2041-2050**	**2091-2100**	**2041-2050**	**2091-2100**	**2041-2050**	**2091-2100**
CO_2 concentration	+40%	+89%	+40%	+125%	+26%	+63%
Temperature	+1.95 °C	+3.5 °C	+2 °C	+4.5 °C	+1.98 °C	+3.1 °C

Table 2.29

Assessment of possible impacts of climate change in different climate zones in Greece

Climate zones	Scenarios	A1B		A2		B2	
	Periods	**2041-2050**	**2091-2100**	**2041-2050**	**2091-2100**	**2041-2050**	**2091-2100**
Eastern Macedonia and Thrace	Cotton	🟩	🟩	🟢	🟩	🟩	🟩
	Wheat	🟢	🟢	🟧	🟧	🟩	🟩
	Maize	🟢	🟢	🟢	🟧	🟢	🟢
	Nuts & fruits	🟢	🟩	🟢	🟢	🟢	🟩
	Olives	🟢	🟩	🟢	🟢	🟢	🟩
	Vines	🟢	🟩	🟢	🟢	🟢	🟩
	Vegetables	🟩	🟩	🟩	🟢	🟩	🟩
Western and Central Macedonia	Cotton	🟩	🟩	🟩	🟩	🟩	🟩
	Wheat	🟧	🟨	🟧	🟢	🟩	🟩
	Maize	🟢	🟧	🟢	🟢	🟢	🟢
	Nuts & fruits	🟢	🟢	🟢	🟢	🟢	🟩
	Olives	🟢	🟢	🟢	🟢	🟢	🟩
	Vines	🟢	🟢	🟢	🟢	🟢	🟩
	Vegetables	🟩	🟢	🟩	🟢	🟩	🟩
Central and Eastern Greece	Cotton	🟨	🟧	🟨	🟧	🟩	🟩
	Wheat	🟥	🟧	🟥	🟧	🟨	🟨
	Maize	🟢	🟥	🟢	🟢	🟢	🟢
	Nuts & fruits	🟨	🟧	🟨	🟧	🟨	🟢
	Olives	🟨	🟧	🟨	🟧	🟨	🟢
	Vines	🟨	🟧	🟨	🟧	🟨	🟢
	Vegetables	🟢	🟥	🟢	🟥	🟢	🟢
Western Greece	Cotton	🟢	🟩	🟩	🟩	🟩	🟩
	Wheat	🟥	🟢	🟥	🟥	🟢	🟢
	Maize	🟢	🟨	🟧	🟧	🟩	🟢
	Nuts & fruits	🟢	🟢	🟢	🟨	🟢	🟢
	Olives	🟢	🟢	🟢	🟨	🟢	🟩
	Vines	🟢	🟢	🟢	🟨	🟢	🟩
	Vegetables	🟢	🟢	🟢	🟨	🟢	🟢
Ionian Sea	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	🟢	🟧	🟢	🟧	🟢	🟢
	Olives	🟢	🟨	🟢	🟨	🟢	🟩
	Vines	🟢	🟨	🟢	🟨	🟢	🟩
	Vegetables	🟢	🟨	🟢	🟨	🟢	🟢
Western Peloponnese	Cotton						
	Wheat						
	Maize	🟨	🟧	🟨	🟧	🟢	🟢
	Nuts & fruits	🟨	🟨	🟨	🟧	🟨	🟢
	Olives	🟨	🟨	🟨	🟨	🟨	🟢
	Vines	🟢	🟨	🟨	🟨	🟢	🟢
	Vegetables	🟢	🟧	🟢	🟧	🟢	🟢

Table 2.29

Assessment of possible impacts of climate change in different climate zones in Greece *(continued)*

	Scenarios	A1B		A2		B2	
Climate zones	**Periods**	**2041-2050**	**2091-2100**	**2041-2050**	**2091-2100**	**2041-2050**	**2091-2100**
Eastern Peloponnese	Cotton						
	Wheat						
	Maize	🟨	🟧	🟨	🟥	🟨	🟨
	Nuts & fruits	🟨	🟨	🟨	🟧	🟨	🟨
	Olives	🟨	🟧	🟨	🟧	🟨	🟨
	Vines	🟨	🟧	🟢	🟧	🟢	🟨
	Vegetables	🟨	🟥	🟢	🟥	🟢	🟨
Cyclades	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	🟨	🟧	🟨	🟥	🟨	🟧
	Olives	🟨	🟧	🟨	🟥	🟨	🟨
	Vines	🟨	🟧	🟨	🟥	🟨	🟨
	Vegetables	🟧	🟥	🟧	🟥	🟧	🟧
North-Eastern Aegean	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	🟢	🟧	🟢	🟢	🟢	🟢
	Olives	🟢	🟨	🟢	🟢	🟢	🟩
	Vines	🟢	🟨	🟢	🟢	🟢	🟩
	Vegetables	🟢	🟨	🟢	🟨	🟢	🟩
Dodecanese	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	🟨	🟧	🟨	🟥	🟧	🟢
	Olives	🟨	🟧	🟨	🟧	🟨	🟢
	Vines	🟨	🟧	🟨	🟧	🟨	🟢
	Vegetables	🟧	🟥	🟧	🟥	🟧	🟢
Crete	Cotton						
	Wheat						
	Maize						
	Nuts & fruits	🟨	🟧	🟨	🟥	🟧	🟧
	Olives	🟨	🟧	🟨	🟧	🟨	🟨
	Vines	🟨	🟧	🟨	🟧	🟨	🟨
	Vegetables	🟧	🟥	🟧	🟥	🟧	🟢

Key	🟩	increase>10%
	🟢	increase<10%
	🟨	roughly the same
	🟧	decrease<10%
	🟥	decrease>10%
		not cultivated

(Kotoulas, 2010) and maize (Voloudakis et al., unpublished data). To calibrate the model's parameters to different levels of CO_2, we used data drawn from Alexandrov and Hoogenboom (2000), Li et al. (2000), Pleijel et al. (2000), Bindi et al. (2001), Kimball et al. (2002), Kimball et al. (2007) and Taub (2010). In the cases where the AquaCrop model was not used (vegetables, tree crops, etc.) we used earlier research results (Mortensen, 1994; Rosenzweig et al., 1996; Kimball and Idso, 2001; Olesen and Bindi, 2002; Chartzoulakis and Psarras, 2005; Kimball et al., 2007; Garnaut, 2008; Moriondo et al., 2008; Ventrella et al., 2008; Gutierrez et al., 2009; Moretti et al., 2010; Orduna et al., 2010).

The results obtained for Scenarios A1B, A2 and B2 for the periods 2041-2050 and 2091-2100 compared to baseline period 1991-2000 are presented in Table 2.28. The detailed climate and meteorological data used in the simulation (daily maximum and minimum temperature, daily rainfall, daily evapotranspiration) were drawn from the Research Centre for Atmospheric Physics and Climatology of the Academy of Athens (Zerefos et al., unpublished data). The assumption was made that crop management practices (sowing, harvesting, etc.), and irrigation and fertiliser use (quantity and frequency) will remain unchanged at current levels. We did not estimate the likely variation in impact on agricultural production from invasive weeds and diseases. However, the study did take into consideration the impact of desertification on crop yield. Desertification was estimated based on the data of a special study (Yasoglou and Kosmas, 2004), which made it possible to estimate the annual rate of land loss by climate zone (Kalyvas, unpublished data). In all, we estimated the impact of climatic change and desertification on the production of a number of crops. The desertification data used are linear projections of the outcomes of the above studies, since there are no scenarios forecasting the course of desertification in relation to climate change. However, in light of the anticipated decrease in rainfall and the higher intensity of extreme weather events, current forecasts may need to be revised upward, by an additional 5-10%.

To increase the accuracy of our predictions, we divided Greece into the following 11 climate zones: Eastern Macedonia-Thrace, Western-Central Macedonia, Central-Eastern Greece, Western Greece, the Ionian coast and islands, the Western Peloponnese, the Eastern Peloponnese, the Cyclades islands, the North-Eastern Aegean, the Dodecanese islands, and Crete. For practical reasons, the zones of the Northern Aegean and the Eastern Aegean were taken as one.

As shown in Table 2.29 using the AquaCrop model and research data from the Greek and international literature, of the three scenarios considered, Scenario B2 appears to be most favourable to crop production. The impacts of climate change become increasingly 'less negative to positive' the further one moves north and east: consequently, Eastern Macedonia-Thrace and Western-Central Macedonia are the zones that will benefit the most or suffer the least depending on the crop/case. The most vulnerable arable crop was shown to be wheat, while cotton production is projected to decrease the most under both Scenarios A1B and A2 in Central-

Eastern Greece. The impact of climate change on tree crop production by mid-century will range from neutral to positive but will become increasingly negative by 2100, especially in the country's southern and island regions. Vegetable crops will move northward and the growing season, longer than it is today due to milder-warmer winters, will result in increased production

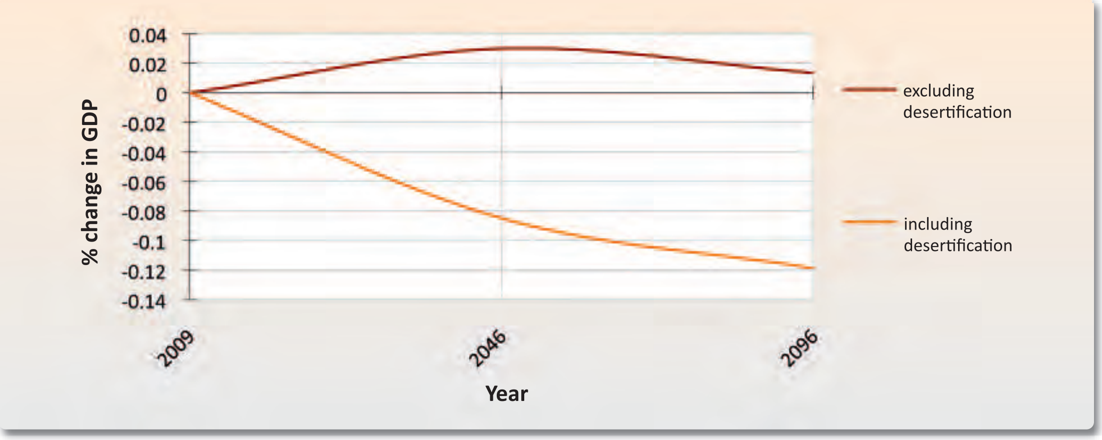
Moreover, as regards the effect of invasive pests, diseases and weeds on crop production, the prevailing view is that warmer climatic conditions will generally favour the proliferation of pests, since insect pests are able to complete a larger number of biological cycles during the course of a year. In addition, warmer winters will allow crop-threatening insects to survive the winter in places where this is not possible today, thereby giving them a 'head start' during the next growing season (Gutierrez et al., 2009). Similarly, thermophilic weed species (*Cassia, Amaranthus, Sesbania, Crotalaria, Rottboellia, Imperata, Panicum, Striga,* etc.) are also expected to expand into colder zones and higher altitudes (Karamanos, 2009).

2.4.3 Economic impacts

Despite its contraction in recent decades, agriculture remains important to the Greek economy, with agricultural production accounting for 5-6% of GDP and agricultural employment accounting for 17% of total employment (Pezaros, 2004). The agroindustry, which represents one fourth of the national industry, contributes one third of the industrial product and accounts for one third of industrial sector employment (Papanagiotou, 2005). The impact of climate change on Greek agricultural production was analysed by downscaling IPCC Scenarios A1B (3.5ºC), A2 (4.5ºC) and B2 (3.1ºC) (IPCC, 2007a) to the regional climate zone level of Greece. Due to time and data availability constraints, we focused our study on arable and tree crops, and more specifically on wheat, cotton, maize, olive and vines. The impact analysis was conducted both factoring in and excluding soil desertification.

Climate is key to agricultural production, and largely determines the type, quantity and quality of agricultural produce. The climate variables that most affect crop productivity are: temperature, precipitation, solar radiation (intensity and duration of exposure) and atmosphere composition (IPCC, 2007b; Tubiello et al., 2007; Mendelsohn and Dinar, 2009). Impacts on productivity affect farmer income and employment. A number of approaches, derived from the field of environmental economics, can be used to assess the economic impacts of climate change. Depending on the welfare measure used (price, cost or value), the methodologies developed can be classified into one of the three following categories: pricing, cost-pricing and valuating. The most suitable methodologies for valuating the impacts of climate change on the agricultural sector are market-based methods based on the change in agricultural output. If, for instance, climate change causes the cotton production to fall by 20%, then the farmer's income from cotton will fall accordingly. This change reflects the cost of inaction to climate change to be incurred by the cotton producer. If the producer resorts to using more fertiliser to make up

Figure 2.6 **Economic impact of Scenario A1B on farmer income (Percentage of GDP)**



for his production loss, he will incur higher production costs. These costs represent the cost of adaptation to climate change.

For the needs of the present study, the approach used to estimate the economic impact of climate change consisted in calculating (V), i.e. the change in agricultural production due to climate change multiplied by the market price of the agricultural product. This approach can be expressed by the formula:

$$V = \sum_{a}^{b} [(Q^b\text{-}Q^c)\text{x}P^b]$$

where:

V = the cost of climate change;

Q^b = the anticipated quantity produced in year b;[14]

Q^c = the average quantity produced during the baseline period 1990-2000; and

P^b = the expected producer price for the product in year b.

Parameter ‘a’ was given the values 2041 and 2091. Parameter ‘b’ is equal to a+x, with x given the values [0 to 9] so that estimates are produced for all the years within the decades studied, 2041-2050 and 2091-2100, respectively.

For the average quantities produced during the baseline period 1990-2000, we used the AquaCrop model estimates for wheat, cotton and maize crops. For the other crops (oil olives, table olives, table grapes, Corinthian currants, sultana raisins and grape must production), the average quantity produced was estimated from data from the Ministry of Agricultural Devel-

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[14] The estimates of productivity variation with the AquaCrop model use corresponding values, while ‘production forecast’ estimates use the average annual production level for the period 1990-2000.

Figure 2.7 **Economic impact of Scenario A2 on farmer income (Percentage of GDP)**

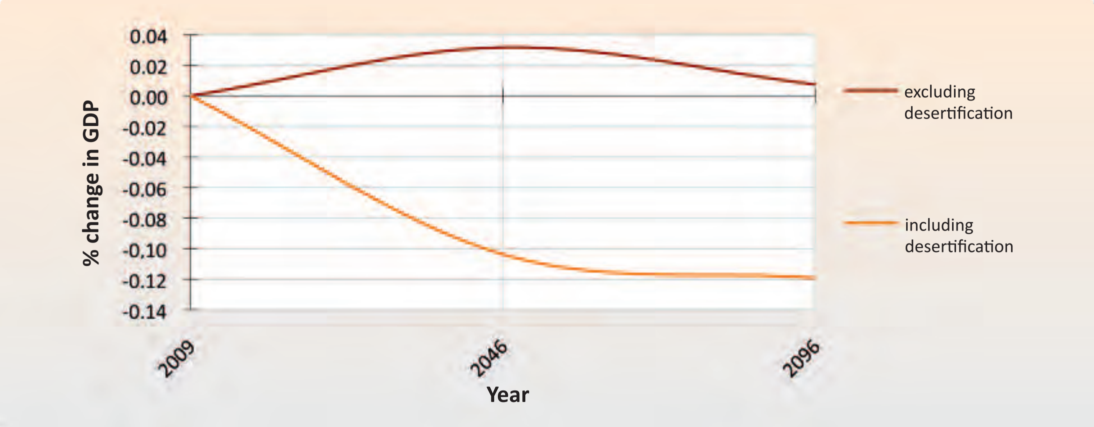
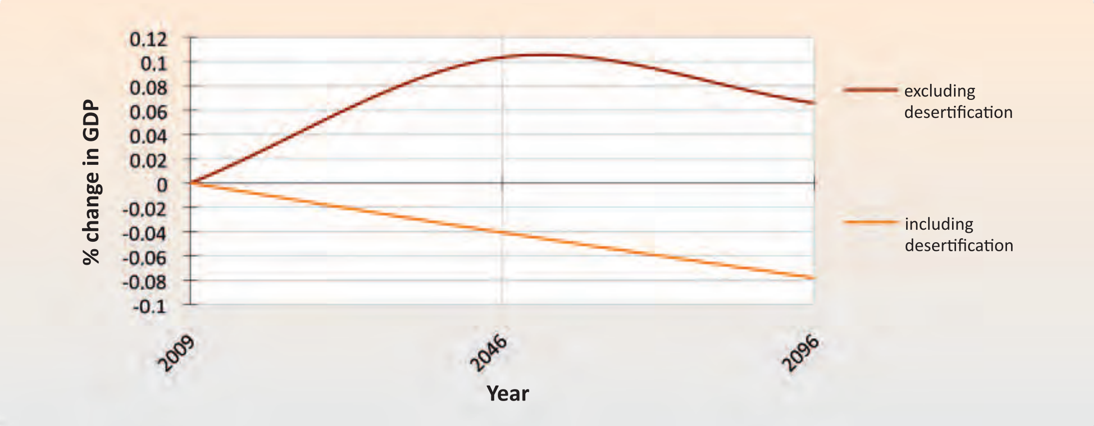


Figure 2.8 **Economic impact of Scenario B2 on farmer income (Percentage of GDP)**



opment and Food.[15] Finally, the expected producer prices per year and product was also estimated with data from the Ministry's website.[16]

Figures 2.6, 2.7 and 2.8 plot the impact of climate change on farmer income for each of the respective scenarios considered, assuming in one case (dark curve) that the climate will evolve smoothly till 2100 and, in a second case, taking desertification into account (orange curve).

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[15] http://www.minagric.gr/greek/agro_pol/3.htm
[16] http://www.minagric.gr/greek/agro_pol/3.htm

The effects of climate change alone, excluding desertification, were found to have an immediate positive effect on farmer income until 2041-2050, a turning point, after which the economic impacts (for 2051-2100) worsen, relative to 2041-2050. As can be clearly seen from Table 2.30, the economic impact of all three scenarios on farmer income (excluding desertification) remains positive throughout the period 2010-2100. In contrast, the impact of climate-change induced desertification is expected to be negative. As is well-established, desertification negatively impacts agricultural production and, consequently, farmer income, due to the loss of fertile farmland and the decrease in cultivable area. The overall impact of climate change on farmer income, factoring in desertification, was found to be negative under Scenarios A1B and A2, but positive under Scenario B2. Unless measures to counter desertification are taken, climate change will thus negatively impact farmer income. Taking the impacts of the climate scenarios into account, our estimates point to the need for immediate drastic intervention to contain desertification and achieve farmer income growth.

It should be stressed that our estimates do not take into account changes in other determinants of agricultural production directly affected by climatic change, such as the impact of weeds and insect pests (including invasive species) and possible changes in pollinator efficiency. In addition, the economic estimates also involve a priori a number of uncertainties from the previous stages of analysis, as is the case with the climate data projections which were not based on future product prices, but on data from previous years, and depend on a series of uncertainties inherent in economic analysis (such as long-term variation of agricultural product prices, developments in international food markets, the discount rate used, etc.). For example, unpredictable factors concerning global production levels and agricultural trade or the possibilities of global oversupply or shortage were not taken into account. It is not inconceivable that decreases in production and expected losses of farmer income in Greece could be offset by a far greater drop in global production causing commodity prices to increase so much as to make the respective agricultural cultivations in Greece economically profitable. It should also be noted that we used a discount rate of 1% for our calculations, whereas the Stern report, for instance,

Table 2.30 **Change in farmer income due to climate change by 2100 (Percentage of GDP)**

Scenario	Impact of climate change excluding desertification	Impact of climate change including desertification	Total impact
A1B	+ 3.26	- 16.91	- 13.63
B2	+ 2.92	- 17.81	- 14.89
A2	+ 13.37	- 10.05	+ 3.31

uses a discount rate of 1.4%. Had we used Stern's discount rate, each estimated change in GDP of 0.1% for the decade 2041-2050 would have come close to 0.15% (up by 50%) and would have exceeded 0.25% (up by 250%) for the decade 2091-2100.

2.4.4 Adaptive management

'Adaptation' is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects (IPCC, 2007a). As the impacts on agricultural production are expected to be significant, the EU has launched a debate in view of adopting measures and adjusting its Common Agricultural Policy to climate change. All studies seem to concur that even a 2ºC global temperature rise would have considerable effects on agricultural production, thereby making mitigation and adaptation measures imperative (Copenhagen Diagnosis, 2009).

The overall goal (Tsiros et al., 2009) should be to achieve sustainable management of natural resources, geared toward maximising viable food production. This presupposes rational land management and the prevention and minimisation of land loss to drought, extreme weather events, flooding, etc. In the short run, emphasis would need to be placed on adjusting farming methods and practices, such as sowing densities, the timing of ploughing, sowing, harvesting, etc. (Orlardini et al., 2009). Other targets would, at the same time, include the preservation and improvement of soil productivity, more efficient water use, and the rational use of fertilisers and pesticides. In the long run, new crop varieties will have to be developed and the use of innovative technologies increased (greenhouse farming, frost protection, crop pollination).

Given that there will be differences across Greece's agroclimatic zones (with Southern Greece, Crete and the Aegean islands the most vulnerable) and because of geographic specificities within each zone (rivers, land at risk of degradation from erosion or salination, etc.), the recommended measures will also need to be tailored to the local level. Choosing the wrong course of action, such as drilling too deep for water (McKeon and Hall, 2000), could have devastating consequences for farming units (e.g. soil salination). For all these reasons, the diversity of the Greek landscape will have to be taken into account in any plan to consolidate, reorganise and restructure farming practices. Particular emphasis would need to be placed on water management and water use efficiency, soil fertility, greenhouse technology, crop selection tailored to specific agroclimatic conditions, as well as the development of new, improved/adapted crop varieties.

2.4.5 Impact mitigation

Climate change impact mitigation refers to all measures and actions to reduce the anthropogenic forcing of the climate system, including strategies to reduce greenhouse gas sources and emissions or to enhance greenhouse gas sinks (IPCC, 2007a). A major source of greenhouse gas (GHG) emissions, agriculture is also a huge 'sink' for sequestrating carbon, which could offset GHG emissions by capturing and storing carbon in agricultural soils (OECD, 2010).

According to a recent working document (EC, 2009), there is unused potential for cost-effective mitigation activities in EU agriculture. The viability of farms is a necessary basis for climate-friendly farming practices to become more widespread, while there is also a need to improve awareness and technical knowledge among farmers on climate change mitigation.

To mitigate GHG emissions, incentives need to be provided to promote organic farming and extensive livestock production systems (which help build up soil organic matter), modern animal waste processing, efficient fertiliser and pesticide use (with an aim to reducing present-day use by as much as 30%), integrated farm management plans aimed at controlling nitrate emissions, the development of small-scale renewable energy capacity (mainly biogas from animal waste) and the restoration of degraded soils.

2.4.6 Future challenges

Forecasting the impact of climate change on agriculture involves difficulties and uncertainties, stemming from a number of sources (Hansen et al., 2006). The reliability of the forecasts depends mainly on the accuracy of climate models, whether global (GCM) or regional/local (RCM). Scientific advances are constantly broadening our understanding of the complex system of interaction between natural and anthropogenic forcing that affects agricultural output. Agro-climatology has in recent years helped develop more reliable crop growth models (AquaCrop, Free Air CO_2 Enrichment (FACE) experiments), broadening available information and improving forecasting accuracy for future farming yields. Research efforts at the national level —regarding the impact of climate change on crops of national interest and the creation of a larger and more comprehensive database— need to be pursued and accelerated to allow us to correct our views if necessary.

With respect to the economic impacts of climate change on the Greek agricultural sector, the present study has attempted to produce a first estimate of a very complex issue requiring multiple data streams. Further research is required, particularly to explore adaptation actions and to determine which options would be more cost-effective at the appropriate spatial level. Timely diagnosis will enable the formulation of a more informed policy in view of climate change, and enable the Greek economy to maximise the benefits and reduce the losses attributable to climate change.

2.5 Impacts of climate change on forest ecosystems in the 21st century*

2.5.1 Introduction

Knowledge of the impacts of climate change on forest ecosystems is essential, given the economic and environmental contribution of these ecosystems to the quality of human life. Forest

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* Sub-chapter 2.5 was co-authored by Anastasios Nastis, Ilias Karmiris, Eftichios Sartzetakis and Stefanos Nastis.

ecosystems occupy 65% of Greece's land surface (forests 25%, rangelands 40%). Having undergone considerable degradation as a result of centuries of disregard and improper use, their present contribution to human welfare is well below potential. Forest ecosystems provide a wide range of wood and non-wood products, including wood biomass, forage, fruits, mushrooms, honey, botanical herbs; affect water quantity and quality; enhance air quality and the sequestration of CO_2; play a valuable role in soil protection and biodiversity conservation by providing habitats and food for a host of living creatures. They also have considerable cultural and aesthetic value and provide opportunities for numerous recreational activities (hiking, camping, hunting, etc.), all essential to human wellbeing. The ability of forest ecosystems to yield products and quality services depends primarily on their stability, a function of their biodiversity, vigorousness and growth dynamic.

Forest production depends primarily on environmental factors, such as temperature, solar radiation, soil water and nutrients, but is also affected by synecological factors, such as inter- and intra- competition, interactions with animals and microorganisms, as well as wildfires (Johnsen et al., 2001). A small rise in temperature and decrease in precipitation was recorded in the course of the 20th century, a trend expected to continue in the 21st century as well (Zerefos, 2009), with precipitation projected to decrease in Greece : Scenario B2 (-35 mm), Scenario A2 (-84 mm).

It has been estimated that the overall decrease in precipitation by 2100 will not be uniform across Greece. Precipitation is expected to decrease in continental Greece (where the country's productive forests are located), but to increase in the islands of the Aegean (except Crete). Forest ecosystems will suffer from the combined effect of reduced precipitation and increased temperatures during the hot and dry period, while facing a higher risk of devastation from wildfires (Giannakopoulos et al., 2009). The question that arises is to what extent forest species will be able to adapt to the rapidly changing environment. Otherwise, forest ecosystems will be at an increased risk of destabilisation and, in extreme cases, extinction. These impacts could be considerably mitigated with the timely implementation of appropriate management strategies – such as special silvicultural treatment (FAO, 2003). Thus, the urgent need to adapt innovative forest policy and strategic management geared towards mitigating and effectively addressing the negative impacts of oncoming climate change. The purpose of the present sub-chapter is to estimate the impacts of climate change on wood and forage production and to explore management options to mitigate the adverse impacts.

2.5.2 Impacts of climate change on forest ecosystems

Assuming that today's forest management strategy remains unchanged and that no mitigation measures are taken, it is estimated that the impacts of climate change on forest ecosystems by 2100 will include (a) a spatial redistribution of the country's forests, and (b) a decrease in total canopy cover. More specifically, temperate coniferous and broadleaf evergreen forests (de Dios et al., 2007) are expected to expand by 2% (Scenario B2) to 4% (Scenario A2), while spruce, fir, beech and black pine forests will shrink by 4% (Scenario B2) to 8% (Scenario A2). Moreover, some coastal forest ecosystems are at risk of deforestation/pastoralisation and desertification (Scenario B2: 1%; A2: 2%) (Le Houérou, 1996). Spatial redistribution and the decrease in productive forest area by 160,000 ha (Scenario B2) to 320,000 ha (Scenario A2) on average would lower yearly wood biomass production by 0.5 m^3/ha or by a total of 80,000 m^3 (Scenario B2) or 160,000 m^3 (Scenario A2).

Based on the projected rise in CO_2 and temperature levels, the growing season will, depending on the scenario, be 10 to 15 days longer (Chmielewski and Rötzer, 2001), with positive repercussions on forest and rangeland production, because of the greater abundance of soil moisture for plant growth during early and late summer. The anticipated higher productivity is likely, however, to be moderated by the decrease in precipitation and the increased frequency and intensity of climate change-induced extreme weather events, such as heat waves, floods, etc. According to the BIOME3 model, it is estimated that forests' carbon assimilation rate under Scenarios B2 and A2 will decline by about 25% and 30%, respectively, by 2050, and by an additional 7% and 15% by 2100.[17] Greece's total wood production is expected to decrease on average by roughly 27% (Scenario B2) to 35% (Scenario A2) by 2100. In other words, the annual production of wood biomass is projected to decrease by an average 529,200 m^3 (Scenario B2) to 686,000 m^3 (Scenario A2) by 2100, based on the average for the last 21 years (1,960,000 m^3, Ministry of Environment, Energy and Climate Change 2010) (Sohngen and Sedjo, 2005). At the same time, rangeland production is projected to decline, mainly as a result of decreased precipitation (Papanastasis, 1982) by 10% under Scenario B2 and by as much 25% under Scenario A2. The decrease in forage production is estimated at 120 kg/ha (Scenario B2) and 300 kg/ha (Scenario A2) by 2100, meaning that Greece, with its current 5.2 million ha of rangeland, would see its total forage production decrease by 312,000 tonnes (Scenario B2) to 780,000 tonnes (Scenario A2) by 2100.

Global warming is expected to affect both the number of summer wildfires and total burned area, while the interval between two successive fires in the same area will decrease (Mouillot et al., 2002). Forests in southern continental Greece and Crete are expected to be most affected (Giannakopoulos et al., 2009; Carvalho et al., 2010). From 2000 to 2010, there were over 100,000 fire occurrences in Greece, consuming an average of 62,000 ha of arable and forest land each year (Gourbatsis, 2010). As estimated, total burned areas and total annual costs of fire fighting/suppression, damage and rehabilitation/reforestation will increase by about 10% (Scenario B2) to 20% (Scenario A2) relative to today's levels (Torn et al., 1999; Flannigan et al., 2000; Moriondo et al., 2006; Giannakopoulos et al., 2009; Carvalho et al., 2010; Schelhaas et al., 2010). The total costs of

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[17] http://aede.osu.edu/people/sohngen.1/forests/GTM/index.htm

fire extinction and damage, estimated today at over €400 million per year, are expected with global warming to increase by €40 million/year (Scenario B2) to €80 million/year (Scenario A2).

As a result of changes in forest structure (such as reduced canopy density) and the increased severity of weather extremes, surface runoff and erosion are expected to increase by 16% (Scenario B2) to 30% (Scenario A2), with adverse repercussions on deep infiltration and underground aquifer recharge. This, combined with the expected higher evapotranspiration, will reduce the amounts of usable water resources (Arora and Boer, 2001) by 25% (Scenario B2) to 40% (Scenario A2), i.e. by 5 billion m^3/year (Scenario B2) to 8 billion m^3/year (Scenario A2). In addition, non-use values and other environmental services are expected to fall by 5% to 10% (de Dios et al., 2007; Founda and Giannakopoulos, 2007).

Sea level rise (SLR) is predicted to accelerate relative to today, reaching 0.25 m (Scenario B2) and as much as 1 m (Scenario A2) by 2100, thereby bringing about changes in the spatial distribution of present coastal area land uses (Nicholls, 2004; Nicholls and Klein, 2005; Bindoff et al., 2007; Rahmstorf, 2007). According to Poulos (2011, personal communication), a SLR of 0.5 m by 2100 would result in the inundation of 15% of Greece's present total coastal wetland area (1,000 km^2). Such a rise is not expected to substantially impact coastal forest production, whereas total rangeland production will decline by 26,000 tonnes (Scenario B2) to 52,000 tonnes (Scenario A2). The coastal wetlands expected to face the greatest impact are the deltas of rivers Evros, Nestos, Axios, Loudias, Aliakmon and Acheloos, the lagoons of Messolonghi and Kyllini, and the Amvrakikos and Pagassitikos gulfs. The islands likely to be most strongly affected include Lemnos, Samos, Rhodes, Crete and Corfu (Nicholls and Klein, 2005).

The above changes will entail negative impacts on tourism and recreation, mainly during July and August, as the average air temperature and heat wave frequency, intensity and duration are set to increase. The earlier start of the tourist season (in May) and its prolongation into September are likely to offset such repercussions. Thus, total tourist traffic is not projected to change significantly by 2100 (Rutty, 2009). The impacts of climate change on tourism are discussed in Sub-chapter 2.7. Although the impacts on human health and the ensuing increase in healthcare and treatment costs are difficult to quantify, the degradation of forest ecosystems is expected to worsen the quality of life in large urban centres and to increase the frequency of illnesses associated with the deterioration of the urban and semi-urban environment (allergies, respiratory diseases, heart diseases, etc.).

2.5.3 Estimating the economic impacts of climate change

The average domestic production of wood products (Table 2.31) during the years 1988-2008 was 1,960,000 m^3. According to data from the 2008 report on Forest Service Activities,[18] 28%

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[18] http://www.ypeka.gr/Default.aspx?tabid=588&language=en-Us

Table 2.31 Average annual timber production, 1988-2008

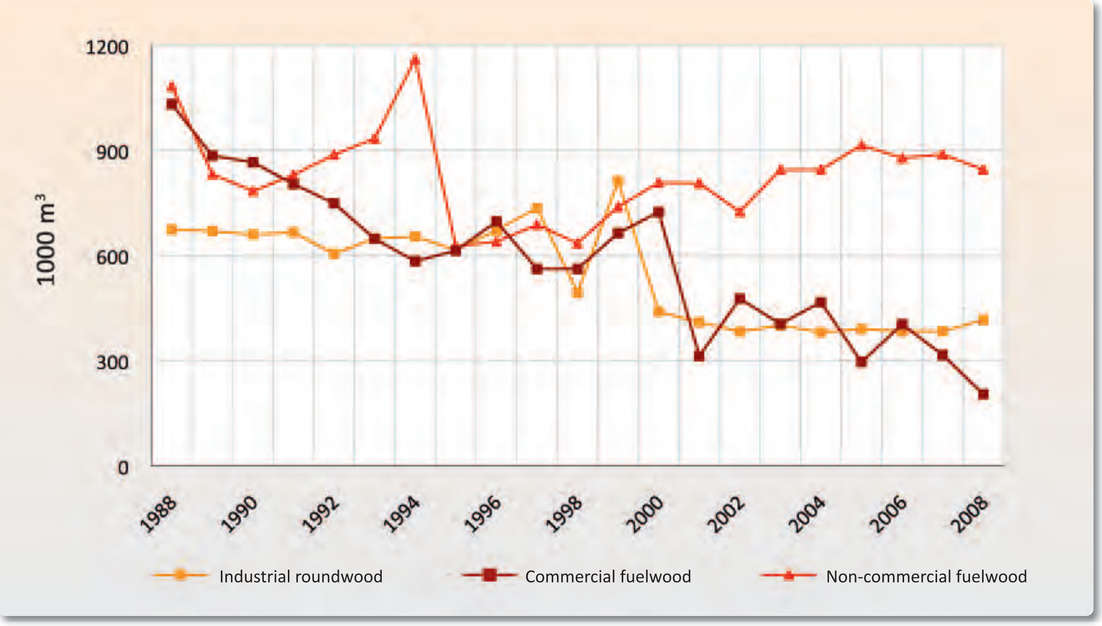
Type of timber	1000 m^3	% of the total
Industrial roundwood	547.43	27.9
Commercial fuelwood	828.33	42.3
Non-commercial fuelwood	584.48	29.8
Total	1,960.24	100.0

Source: Ministry of Environment, Energy and Climate Change (2010).

of the total wood production was industrial roundwood. According to the NSSG (2007), domestic wood production covered only one-third of the national demand for industrial roundwood, but the entire demand for fuelwood.

The production of industrial roundwood (which includes sawn wood, carpentry and joinery wood, windows, doors and their frames, parquet panels, etc.) has decreased, while the production of engineered wood (particle boards, pre-laminated boards, MDF, wooden crates, etc.) has increased. Both categories (industrial roundwood and engineered woods) form part of the wood manufacturing industry. Greece's total wood production in the last 20 years has been considerably below potential, mainly on account of high production costs, cheap wood imports and

Figure 2.9 Annual timber production, 1988-2008 (1000 m^3)



Source: Ministry of Environment, Energy and Climate Change (2010).

forest service mismanagement. The annual production of industrial roundwood (Figure 2.9) peaked in 1999 at 812,000 m^3, which is double the present production.

The sale value of manufactured wood products came to €326 million in 2007, putting the industry on a par with the buoyant yoghurt industry, which has a turnover of €353 million (NSSG, 2007). Non-commercial fuelwood is used exclusively for heating.

Based on data available for Greece, the economic impact multiplier associated with wood manufacturing is 4.65, meaning that each initial €1 of forest wood is converted into an end-value of €4.65. This value of 4.65 is somewhere between the values of 3 and 6.5 reported in the literature for New Zealand (Griffiths, 2002; Thorpe, 1998), but higher than the value of 2.68 found for the UK (Forestry Commission, 2000) and very close to the estimated economic multipliers of 4.89 reported for the forests of California (California Economic Strategy Panel, 2002).

Estimating the economic impacts of climate change on forest ecosystems would normally require a forecasting of future prices. However, since the necessary data are lacking in Greece, we had no other option than to perform our estimates using present prices. It should be noted that until 1987 the prices paid to producers for industrial roundwood and fuelwood were determined by tender procedures by the Forest Service. Since 1987, pursuant to Presidential Decree 126/1986, agro-forest cooperatives and associations have the right to sell the timber they have harvested in public forests on the open market (Tororis, 1994). In 2010, fuelwood sold for €22.3/m^3 and beech roundwood for €60.3/m^3 (Forestry Department of the Pella Prefecture, 2010)[19]. Given that industrial roundwood accounts for 27.9% of total wood production, with fuelwood accounting for the rest, the weighted average price of wood was estimated at: (0.279 x €60.3) + (0.721 x €22.3) = €32.90/m^3. Consequently, the economic impact of forest spatial redistribution by 2050 would amount to €2.6 million/year (Scenario B2) and to €10.6 million/year (Scenario A2), while the impact of the anticipated decrease in wood production by 2100 would amount to €17.4 million (Scenario B2) and €22.6 million (Scenario A2), respectively. Using our economic multiplier of 4.65, the total economic impact by 2100 is estimated at €80.9 million/year to €105.1 million/year.

There are no official prices for forage. Considering, however, that 10 kg of forage are roughly equivalent to 1 kg of usable meat and adopting €5/kg as the present average price of meat, the economic loss from reduced rangeland production is estimated at €156 million/year (Scenario B2) to €390 million/year (Scenario A2) by 2100. Using the same assumptions, the economic loss associated with the loss of wetland area due to SLR would amount to an estimated present value of €13 million/year (Scenario B2) to €26 million/year (Scenario A2) by 2100. The impact of SLR on forest production is estimated to be insignificant.

Although it is impossible to accurately predict the increase in forest fire frequency and intensity attributable to climate change, it is safe to presume the number of wildfires and the devas-

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[19] Beech is one of the main forest sources of industrial roundwood in Greece (Zafeiriou et al., 2007).

tation caused by each one will increase. It is estimated that the yearly burned area of forests will increase by 10% (Scenario B2) to 20% (Scenario A2) by 2100, i.e. by an additional 20,000 ha/year to 40,000 ha/year. Considering that the average timber stock is 61 m^3/ha, the increase in fire occurrences would lead to an additional economic impact of €40 million/year (Scenario B2) to €80 million/year (Scenario A2) by 2100. Assuming that the value per m^3 of water is no less than 25% of the lowest price of irrigation water in Bulgaria (Öko Inc., 2001), i.e. €0.0026/m^3, the anticipated annual loss from the decrease in the usable water capacity of 20 billion m^3 yearly (Soulios, personal communication) would amount to between €13 million (Scenario B2) and €20.8 million (Scenario A2).

To estimate the present value of the economic impacts from climate change, it is necessary to choose a discount rate and to estimate the annual rate of economic impact variation from 2010 to 2100. Choosing the right rate for discounting the economic impact of climate change is an issue that continues to divide economists (Newell and Pizer, 2003; Stern et al., 2006; Dasgupta, 2007; Nordhaus, 2007a, b; Stern and Treasury, 2007; Stern, 2008; Weitzmann, 2007). There is still no clear consensus on which discount rate is socially more acceptable, as this essentially moral issue involves an explicit trade-off between the welfare of the present generation and that of future generations, in this case of those living in 2050 and 2100 (Varian, 2006). In the present study, we chose to use two discount rates in our economic valuation (Nordhaus, 2007a, b): 1% for a long-term horizon, i.e. more than 300 years, and 3% for the first years of climate change.

Figure 2.10 **Assessment of the economic impact of climate change (EUR millions)**

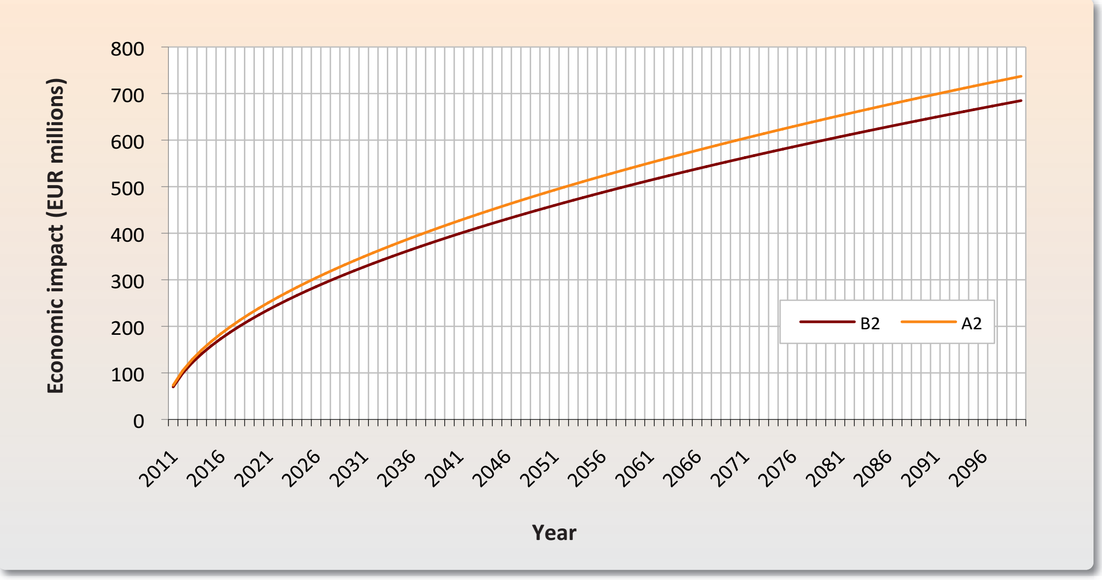

Table 2.32 Estimated present value of the economic impact on forest ecosystems by 2100 (EUR millions)

Discount rate	1%		3%	
	Scenario			
Present value	B2	A2	B2	A2
Redistribution of forests	46.7	94.8	14.9	30.4
Fires	721.2	1,462.1	231.0	470.9
Sea-level rise	116.8	237.4	37.4	76.2
Wood and forage biomass	3,154.2	7,300.9	1,014.0	2,320.2
Usable water	235.4	376.7	75.5	120.9
Total	***4,274.4***	***9,471.9***	***1,372.8***	***3,018.6***

The BIOME3 model, based on which the physical impacts on forest ecosystems were estimated, does not yield forecasts for each year, but only for 2050 and 2100. With the limited data available, the assumption was made in our case that biomass variation follows a simple exponential function. The best-fitting function used with Scenario B2 to estimate the annual economic impacts of climate change was $y=69.91x^{0.507121}$, where y is the biomass variation (10^3 m^3) and x are the years (x=1 for 2011, up to x=90 for 2100). The function best describing Scenario A2 was found to be $y=73{,}423x^{0.512566}$. The estimated economic impact derived from the above two functions for the next 90 years (2011-2100) are presented in Figure 2.10.

As shown in Table 2.32, the present value of the direct economic impact of climate change on forest ecosystems, for the two more likely scenarios B2 and A2 and using two different discount rates, ranges between €1.4 billion (Scenario B2; 3% discount rate) and €9.5 billion (Scenario A2; 1% discount rate). It should be noted that, due to the length of the period examined, the discount rate has a much greater impact than the two climate scenarios used. In any event, due to the score of uncertainties surrounding such forecasts and estimates, the estimated values should be taken as a lower bound of the real economic impacts. This view is also supported by the fact that the estimates are based only on the direct impacts attributable to forest ecosystems and that the indirect impacts, which may be far more important, have not been taken into account.

2.5.4 Adaptive management for impact mitigation

Mitigating adverse climate change impacts on forest ecosystems calls for the timely adoption of specific management measures. Adaptation should be focused on (a) intensifying silvicultural management interventions to reduce competition, erosion and flooding, (b) regulating the water balance through the harnessing of winter precipitation, and (c) preventing desertification of low-altitude areas. Adaptive management aimed at offsetting the adverse impacts of climate change is expected to cost 25% more under Scenario B2 than the total present cost of managing forest ecosystems, and 40% more under Scenario A2 (Bou-Zeid and El-Fadel, 2002), the total present cost having been estimated at €120 million in 2008. Erosion control will require the construction of sediment retention dams (1,000 under Scenario B2; 2,000 under Scenario A2), each costing a total of €0.5 million, including stabilisation interventions. Regulating the water supply will require the construction of (a) winter rainwater harvesting dams (500 under Scenario B2; 1,000 under Scenario A2) each with a storage capacity of 0.5 million m^3 and each costing €3.5 million, and (b) underground dams for aquifer recharge/water conservation purposes (200 under Scenario B2; 400 under Scenario A2) each costing €0.3 million. Minimising the damage caused by the greater frequency of wildfires will require an overhauling of the fire prevention and fire-fighting system, as well as the restoration of burned areas. Preventing the inundation of coastal regions of high ecological and economic value (e.g. river deltas, lagoons, etc.) will require the construction of levees or floodwalls (100 km under Scenario B2; 200 km under Scenario A2) to conserve and stabilise the ecosystems in question (Day et al., 1995). Such actions can be expected to substantially contain the adverse impacts, although the production of use and non-use values and services from silvopastural ecosystems will decrease.

In addition to the above, other necessary actions, mainly of an institutional nature, should include: setting up and up-keeping a forest cadastre, modernising the legal framework governing forest ecosystem study, overhauling the fire prevention and fire-fighting system, and reorganising state forestry services. Successful implementation of such measures would compensate for adverse climate change impacts and help increase forest and rangeland production; increase the carbon sink capacity of forests; reduce erosion and runoff; reduce the number and frequency of wildfires and the total area burned to below today's levels; minimise desertification; and contribute to the more effective protection of vulnerable and rare species populations and biotopes. There are valid indications that the immediate adoption of additional specific institutional measures, together with appropriate legislative regulations and policies, would almost totally offset the negative impacts of climate change. However, research efforts into adaptive management options aimed at preserving and enhancing sustainable ecosystem production need to be pursued and intensified. Reversing the degradation of Greece's forest ecosystems in anticipation of climate change and restoring these ecosystems back to a more productive state is a battle that must be waged and won.

In the case of forest ecosystems, the total costs of climate change adaptation until 2100 can be summarised as follows: (a) forest ecosystem management (silviculture interventions, grazing systems): €30 million/year (Scenario B2) and €50 million/year (Scenario A2); (b) improved forest-fire fighting and prevention: €40 million/year (Scenario B2) and €80 million/year (Scenario A2); (c) construction, maintenance and repair of sediment retention dams: lump-sums of €0.5 billion (Scenario B2) and €1.0 billion (Scenario A2); (d) construction and maintenance of rainwater storage dams: lump-sums of €1.75 billion (Scenario B2) and €3.5 billion (Scenario A2); and (e) construction and maintenance of levees (floodwalls) in low-lying coastal areas: lump sums of €0.1 billion (Scenario B2) and €0.2 billion (Scenario A2). Thus, the total adaptation costs amount to: €70 million/year (Scenario B2) or €130 million/year (Scenario A2), in addition to lump-sums of €2.35 billion (Scenario B2) and €4.7 billion (Scenario A2).

2.5.5 Conclusions

Climate change is, depending on the scenario (B2 or A2), expected to lead to the following:

1. Changes in the spatial distribution of forest land cover (2-4% increase in Mediterranean coniferous and evergreen broadleaf species; 1-2% forest cover loss on account of desertification; 4-8% decrease in boreal species; biodiversity loss). As a result, yearly wood biomass production will decrease by 80,000-160,000 m^3 by 2100.
2. A decrease in the carbon sink capacity of forest ecosystems of 32-45%, relative to present levels, and a decrease in total wood production of 27-35% or 529,200-686,000 m^3 by 2100.
3. A decrease in rangeland forage production of 10-25% (or 312,000-780,000 tonnes) by 2100. An additional decrease of 26,000-52,000 tonnes in rangeland production will result from the loss of coastal wetland area to SLR by 2100.
4. Additional annual costs of €40-80 million for fire extinction and damage by 2100, which highlight the need to overhaul fire prevention and fire-fighting systems, as well as the need for restoration/reforestation of burned areas.
5. A pressing need to intensify silvocultural interventions and implement grazing systems that will reduce competition and maintain productivity and biodiversity. These interventions will improve the water balance and prevent flooding and desertification.
6. A need for construction of winter precipitation retention dams in the mountainous zone and levees in the low-lying coastal zone to avoid inundation from SLR.
7. An imperative need for the immediate implementation of additional institutional measures, such as (a) setting up a forest cadastre as required by the Constitution, as a more effective way (compared to forest maps) of reducing wildfire risk and damage by 50%, and (b) modernising the legal framework governing forest ecosystem study.
8. A need to develop drought-tolerant forest species to ensure adequate production under more arid conditions.
9. Total costs from all sorts of physical impacts by 2100 from €4 billion (Scenario B2) to €9.5 billion (Scenario A2) at a 1% discount rate, and from €1.5 billion (Scenario B2) to €3.3 billion (Scenario A2) at a 3% discount rate.

10. Total adaptation costs of €70 million/year (Scenario B2) to €130 million/year (Scenario A2), plus lump-sums of €2.35 billion (Scenario B2) to €4.70 billion (Scenario A2).

2.6 Biodiversity and ecosystems*

According to the Convention on Biological Diversity (Article 2: Definitions), biodiversity refers to the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which these organisms are part; this includes diversity within species, between species and of ecosystems.

Greece has one of the richest biodiversities in Europe and the Mediterranean on account of combined multiple factors, which include the country's climatic variety, geographical location (at the junction of three continents), complex geologic history, and great topographic diversity (pronounced relief, land discontinuity, large number of caves, gulfs and seas, and until recently only moderate human intervention), all of which have fostered the development and support of a wide variety of plants, animals, ecosystems and landscapes (Dafis et al., 1997). An important characteristic of Greek biodiversity is the high endemism observed in most animal and plant groups. Many endemic species have a very small distribution area (limited e.g. to one islet or one mountain) and are thus vulnerable to disturbance.

Climate change ranks among the top direct causes of biodiversity loss, as well as of changes in ecosystem services globally (Millennium Assessment, 2005). As regards the European environment, according to the fourth assessment by the European Environment Agency (EEA, 2007), climate change is increasingly recognised as a serious threat, particularly to coastal, alpine and arctic species and habitats.

The Intergovernmental Panel on Climate Change (IPCC) concluded in its Fourth Report (Alcamo et al., 2007) that climate change will impact considerably on several individual components of biodiversity: ecosystems, species, genetic diversity within species, as well as ecological interactions.

The effects of climate change on biodiversity are multifaceted. Biodiversity can be affected by a combination of: (a) direct impacts on organisms (e.g. the effects of temperature on survival rates, reproductive success, distribution and behavioural patterns); (b) impacts through biotic interactions (e.g. conferral of competitive advantage); and (c) impacts through changes in abiotic factors (e.g. inundation, shifts in ocean currents).

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* Sub-chapter 2.6 was co-authored by: Eugenia Vella, Euthymia Kyriakopoulou, Vasiliki Tsiaoussi, Charalambos Doulgeris, Dimitra Kemitzoglou, Anastasios Xepapadeas, Dimitrios Papadimos, Miltiadis Seferlis and Vasiliki Chrysopolitou.

However, climate change is not the only pressure on biodiversity and its effects are strongly dependent on interactions with other pressures, such as land-use change and habitat loss (Millennium Assessment, 2005), which reduce the abilities of organisms to adjust their distributions in response to changing climate (Campbell et al., 2009).

Southern Europe is already experiencing extremely dry weather conditions, with precipitation levels having declined by as much as 20% in the course of the 20th century (EEA, 2010). In fact, Mediterranean ecosystems rank among the most vulnerable in Europe (EEA, 2005; Schröter et al., 2005; Berry et al., 2007) and are close to reaching their environmental ‘tipping point’. Greece figures among the most vulnerable regions of Europe on account of rising temperatures and lower precipitation levels in areas already facing water scarcity, and on account of rising sea levels along its long coastal zone (European Commission, 2007).

As regards the effects of climate change on species, differences in response and shifts in spatial distribution are expected for many species across Europe (Harrison et al., 2006). As part of a research project, projections of late 21st century distributions for 1,350 European plants species under seven climate change scenarios were made (Thuiller, 2005). More than half of the species studied could be vulnerable or threatened by 2080. Expected species loss, however, proved to be highly variable across scenarios and across regions. In Southern Europe, particularly in parts of the Iberian Peninsula, Italy and Greece, species abundance is expected to decrease, while species distribution/migration will depend on habitat suitability.

The plant and vertebrate species endemic to the Mediterranean region seem to be particularly vulnerable to climate change (Malcolm et al., 2006). Under the assumption of no migration, most amphibians and reptiles in SW Europe are expected to face a significant loss of their distribution range (Araújo et al., 2006).

In order to estimate climate change impacts on biodiversity, Harrison et al. (2006) used the SPECIES neural network model to simulate the possible ‘climate space’ of 47 species throughout Europe. An object of study in Greece was the *Sarcopoterium spinosum* shrubland and the species that use this habitat. Among these species, the red fox (*Vulpes vulpes*) shows no change in climate space under the different climate change scenarios, while two plant species, the *Genista acanthoclada* and the *Sarcopoterium spinosum*, show large increases in climate space (as high as 386% and 198% under one scenario), spreading from the SW through Central and Northern Europe, and across Western France and Spain. For the *Sarcopoterium spinosum* in particular, the simulation showed a distribution as far as in Scandinavia. One Mediterranean oak species, the *Quercus macrolepis*, displays a similar distribution shift pattern, mainly through the Balkans and France, while the woodpecker *Dendrocops medius* shows a decrease in spatial distribution in the climate space of Central European, together with a noteworthy northward expansion towards Scandinavia under one climate change scenario. Of all the olive tree species, the *Olea europea* gains the most ground, expanding west and northwest of its distribution area. The plant species *Matricaria chamomilla* and the mammal species *Sciurus anomalus* lose ground in the west and southwest, but the *Matricaria chamomilla* gains ground farther north, towards Scandinavia. In summary, three species —the *Matricaria chamomilla*, the *Sciurus anomalus* and the *Quercus macrolepis*— face a significant decrease in their forecast climate space within Greece, with losses of 88%, 98% and 56%, respectively, under one climate change scenario.

According to Schwartz et al. (2006), the largest decreases in species abundance are expected to occur in Southern Europe, in regions of the Iberian Peninsula, Italy and Greece, with many Mediterranean islands projected, under specific conditions, to lose up to 100% of their current species abundance. With respect to certain mammals in Greece, according to Levinsky et al. (2007), the spiny mouse (*Acomys minous*)[20] and the endemic Cretan white-toothed shrew (*Crocidura zimmermanni*) are predicted to become extinct under both severe and mild climatic scenarios, under the assumption of no migration. The same also holds for the mouse-tailed dormouse (*Myomimus roachi*) and the Caucasian squirrel (*Sciurus anomalus*). The endemic species, represented in the model with all of their climate locations, appear more vulnerable to climate change (based on the assumption of no migration) than other species, mainly due to their more limited distribution (Schwartz et al., 2006).

As regards flora, Kazakis et al. (2007) correlated the vascular plants of Crete's White Mountains (Lefka Ori) with climate data. Under a scenario of temperature increase, southern exposures are likely to be invaded first by thermophilous species, while northern exposures are likely to be more resistant to changes. Species distribution shifts will also depend on habitat availability. Many, already threatened, narrow-niche endemic species will be affected first.

With respect to inland water fish and according to the Red Data List of the International Union for Conservation of Nature (IUCN), 60 of the 127 species native to Greece (~47%) are threatened by climate change (Economidis, 2009). Of these 60 species, 31 are endemic and 35 —according to the IUCN criteria— have been classified in risk categories 10 (Crucially Endangered), 11 (Endangered) or 14 (Vulnerable) (Economidis, 2009).

As regards Greece's forest ecosystems, three changes could be attributed to or associated with climate change (Dafis, personal communication 2009): the dieback of the Greek fir, the invasion of conifers into deciduous broadleaved forests, and the dieback of the Scots pine. In more detail:

- The first massive dieback of Greek fir in areas of the Peloponnese, but elsewhere in Greece as well, occurred in 1989, after two dry and extremely hot summers (1987, 1988) and was initially attributed to a bark beetle epidemic. However, bark-eating beetles are known to act secondarily and to attack already weakened trees. This dieback is still ongoing, possibly at lower intensity.

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[20] The *Acomys minous* is no longer considered different from the North-African species *Acomys cahirinus*.

- Conifers, particularly the hybrid Greek fir (*Abies borisii regis*) and the Black pine (*Pinus nigra*), have begun to invade broadleaved forests, mostly forests of broadleaved oak (*Quercus frainetto*), Turkey oak (*Quercus cerris*), chestnut tree (*Castanea sativa*) and, to a lesser extent, beech.
- The dieback of the Scots pine in the Pieria mountain range (Thessaly) has been attributed to an attack by fungi and insects, which could however be secondary.

Turning to wetland systems, many ephemeral wetlands are expected to disappear, while other permanent ones will shrink (Alvarez Cobelas et al., 2005). Mediterranean coastal wetlands seem in many areas to be particularly at risk of decline or considerable variation in sediment deposition, as their location makes them vulnerable to rising sea levels. However, their ability to dynamically respond to such changes needs to be carefully investigated (French et al., 1995, from Nicholls and Hoozemans, 1996). According to regional models, climate change may considerably affect Mediterranean lakes in terms of water availability and quality (Dimitriou and Moussoulis, 2010). Any significant loss of wetland area is expected to affect avian migratory routes, largely determined by the suitability of wintering and resting grounds on the southbound journey. With respect to wetlands in Greece, based on unpublished data from the Greek Biotope/Wetland Centre (see Doulgeris and Papadimos, 2010) and on water balance simulations for Lakes Chimaditis and Kerkini using historical climate data and the Scenario A1B for the period 2020-2050 and Scenarios A1B and A2 for the period 2070-2100, Lake Chimaditis is expected to decrease in area by 20% to 37% and Lake Kerkini by 5% to 14%. Meanwhile, Lake Trichonis, Greece's largest, is expected to see its water level decrease and its total nitrogen concentrations increase (Dimitriou and Moussoulis, 2010).

The seagrass meadows of endemic Mediterranean marine angiosperm *Posidonia oceanica* seem to be highly vulnerable to the physical and chemical changes induced by extreme weather events (e.g. storms and floods; Orr et al., 1992; Bombace, 2001), as such events lead to the increased discharge of suspended solids and pollutants into the marine environment. Given that these meadows provide spawning and nursery sites for numerous marine species and play an important ecological role, their degradation or disappearance would have serious consequences for coastal ecosystems (Francour, 1997, from Gambaiani et al., 2009).

Marine ecosystems have been studied much less than their terrestrial counterparts and data time-series, when available, are short (Roberts and Hawkins, 1999, from Bianchi and Morri, 2000). The Mediterranean Sea is projected to see an increase in temperature and a decrease in run-off (see Joint EEA-JRC-WHO report, 2008). Changes in the biochemical and physical seawater properties resulting from global warming are likely to alter marine biodiversity and productivity, trigger trophic web mismatches, and favour disease outbreaks, toxic algal bloom and the proliferation of warmer-temperature tolerant species (see Gambaiani et al., 2009). Marine invasive alien species are a source of biodiversity loss, as they drive native species out, and can significantly alter the structure and functions of marine ecosystems, while also threatening marine industries (fishing, tourism, etc.) and human health. This is particularly the case when the species in question invade an ecosystem already vulnerable on account of other pressures (EEA, 2010). The gradual rise in sea surface temperature (SST) in the Mediterranean (Salat and Pasqual, 2002) has facilitated the entry, acclimatisation and settlement of tropical marine microalgae and other organisms (macroalgae, molluscs, fish; Occhipinti-Ambrogi, 2007). An interannual analysis based on a recent inventory showed that the number of alien species in the Greek seas has increased in recent years (Pancucci-Papadopoulou et al., 2005). The increased rate of invasions could be the result of a synergy of causes, including global warming, which favours the introduction and/or proliferation of alien species, particularly of certain thermophilic Lessepsian migrants.

Apart from the physical impacts on biodiversity and ecosystems, an effort was also made in the present study to estimate the economic impacts of climate change. As mentioned earlier, biodiversity loss entails a degradation of ecosystem services. We therefore performed a valuation of the impacts of biodiversity loss using an ecosystem service approach. A major initiative in the field of ecosystem service valuation and the development of ‘toolkits’ for policy makers was “*The Economics of Ecosystems and Biodiversity*” (TEEB), supported inter alia by the European Commission. This global study involved the creation of a valuation database for various ecosystem services, including provisioning services, regulating services, habitat or supporting services and cultural services.

Using TEEB data, we proceeded to estimate the economic costs of ecosystem service loss for forests and Lakes Chimaditis and Kerkini, under Scenarios A2, A1B and B2, as envisaged for Greece for the period 2011-2100. According to Brenner-Guillermo (2007), the total economic value of ecosystem services provided by forests comes to \$3,789/ha/year (base year: 2004). This value is the aggregate of the following components: water supply, genetic resource conservation, climate regulation, waste management/water purification, erosion prevention, nutrient cycling and soil fertility, pollination, biological control, ‘gene pool’ protection, recreation and tourism opportunities and various cultural services. At roughly the same time, Croitoru and Merlo (2005) estimated the total economic value of Mediterranean forests at \$96/ha/year. The reason why this second estimate is so much lower is that it only covers the following components: wood and non-wood forest products, grazing, recreation, hunting, watershed protection and carbon sequestration, as well as non-use values (existence values and bequest values for future generations).

Based on the methodology used, the present value (PV) of the loss of ecosystem services was calculated as follows:

$$\mathrm{PV} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$

where C_t is the monetary cost of losing ecosystem services in time period t; T is the total number of periods examined; and r is a the discount rate that reflects the cost of capital and the relative weight between current and future benefits. The higher the discount rate, the lower the present generation's concern for future generations. Our choice of two relatively low discount rates (1% and 3%) therefore underlines the importance of ecosystem services and of their preservation for future generations.

As can be seen from Table 2.33, we calculated the present values of forest ecosystem service loss using each of the two 'total economic value' estimates mentioned above for Scenarios A2 and B2. These results can be used to assess and prioritise measures geared toward containing forest area loss. For instance, if the installation of better fire-fighting systems can reduce the expected burned areas and if the cost of such an installation is lower than the benefit that would be lost as a result of forest fire, then such an investment is cost-effective from an economic standpoint. In algebraic terms, the present value of the cost can be represented as:

$$I+\sum_{t=0}^{T}\frac{O_t}{(1+r)^t}$$

where I is the cost of installing the fire-fighting systems, and O_t is the cost of operating them in time period t.

The investment can then be considered cost-effective if:

$$I+\sum_{t=0}^{T}\frac{O_t}{(1+r)^t}<\sum_{t=0}^{T}\frac{C_t^*}{(1+r)^t}$$

where C_t^* is the cost of forest ecosystem loss due to fires in time period t, while the right-hand side of the inequality represents the benefit, in present value terms, from reduced burned areas. If the discounted benefit from preventing fires and forest area loss exceeds the cost of the fire-extinction systems, the investment can be considered worth making.

Table 2.33 **Discounted cost of forest ecosystem service loss, 2011-2100**

	Scenario A2	Scenario B2	Scenario A2	Scenario B2
Economic value of services ($/ha)	3,789		96	
Present value of cost (1%) (million $)	351,618	176,227	8,909	4,465
Present value of cost (3%) (million $)	130,790	65,614	3,314	1,663

Table 2.34 **Discounted cost of forest ecosystem service loss for lakes Chimaditis and Kerkini, 2011-2100**

	Scenario A1B	Scenario A2	Scenario A1B	Scenario A2
Economic value of services ($/ha)	3,789		96	
	Lake Chimaditis			
Present value of cost (1%) (million $)	20,292	17,114	91,238	76,949
Present value of cost (3%) (million $)	8,540	6,868	38,397	30,881
	Lake Kerkini			
Present value of cost (1%) (million $)	35,593	39,592	160,034	178,016
Present value of cost (3%) (million $)	13,873	15,889	62,375	71,440

Table 2.34 presents the discounted cost of ecosystem service loss associated with the physical impacts of climate change for Lakes Chimaditis and Kerkini, using two different economic values per hectare and per year for the services provided by open freshwater ecosystems: the first value (per year) is the one estimated by Brenner-Guillermo (2007) at $1,890/ha (base year: 2004), as the aggregate of two main services: water supply ($1,011/ha) and recreation/aesthetic value ($880/ha). The second value is the one calculated by Costanza et al. (1997) at $8,498/ha, comprising such services as water regulation, water supply, waste treatment, food production, and recreation.

As with forest ecosystems, estimating the present value of lake area loss and of lake ecosystem service loss can serve to assess potential mitigation or prevention measures. Measures entailing a smaller cost to implement than the potential benefits from preventing ecosystem service loss (the cost of which is estimated in the present study) are considered cost-effective and worth implementing. The cost figures obtained will obviously differ considerably depending on the assumptions and scenarios adopted, and therefore need to be interpreted with caution. In general, however, measures to limit ecosystem service loss are worth implementing when they cost less than the estimated cost of losing such services due to inaction. The present methodology and the estimates obtained for Greek forests and the two lakes chosen in the study can provide a basis for assessing different action measures to contain the impacts of climate change.

By the end of the century, climate change and its impacts may be the dominant direct drivers of biodiversity loss and the change in ecosystem service globally (MEA, 2005; Thomas et al., 2004). Currently, terrestrial and marine ecosystems play a crucial role in climate regulation, absorbing roughly half of the CO_2 emissions humanity generates. Among the measures to reduce greenhouse gas emissions are priority ‘low cost co-benefit options’ that simultaneously

Table 2.35 **Measures to address the impact of climate change at ecosystem level**

Climate impact	Ecosystem-based adaptation
Increased droughts	Use appropriate agricultural and forestry practices to increase the water retention capacity and mitigate droughts
Heat extremes	Increase green spaces in cities to improve the microclimate and air quality
River flooding	Maintain and restore wetlands and riverbeds which will act as natural buffers against floods
Increased fire risk	Cultivate diverse forests, which are more robust against pest attacks and present a lower fire risk

Source: European Commission (2009).

contribute to conservation and sustainable use of biodiversity. Some of these measures are listed in Table 2.35.

Inaction or even delayed action could result in ecosystem degradation and even loss, which would reduce the overall carbon storage and sequestration capacity of ecosystems. The climate system has ‘tipping’ points, beyond which the response of ecosystems can become unpredictable. Under such conditions, carbon sinks could become carbon sources.

Failure on the biodiversity targets may seriously compromise our efforts to reduce global warming, whereas stepping up our nature conservation efforts and reducing the environmental pressures on biodiversity and ecosystems helps to combat climate change and provides multiple benefits.

2.7 Economic and physical impacts of climate change on tourism*

Summary

The present study examines the impacts of climate change on Greek tourism, in physical and economic terms. It focuses on an analysis of the direct impacts and, using a modified version of Mieczkowski’s Tourism Climatic Index (TCI), explores the impact of projected climate change on tourist demand. The analysis of climate projections reveals that the use of aggregate national and annual data masks significant regional and seasonal differences in climate characteristics and tourist demand. We focused our analysis on two leading destinations in Greece’s tourism industry (Crete and the Dodecanese) —for which reliable economic and climate data were available— thus enabling two regional estimates of the economic impact of climate change. The results of the analysis make it particularly clear that any strategy plan for Greek

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* Sub-chapter 2.7 was co-authored by: Eftichios Sartzetakis and Benjamin Karatzoglou.

tourism must necessarily: expand the tourist season, and ensure the geographic diversification of the tourism product. Achieving these objectives will crucially depend on the ability to: (a) market Greece's many, still unexploited, natural attractions; (b) develop and promote alternative eco-friendly forms of tourism; (c) attract new tourist target groups; and (d) enforce measures to reduce the industry's environmental footprint. Lastly, we were able to estimate that the operating costs of accommodation establishments would, depending on the adaptation scenario, increase by an annual 5-7%. An increase of such magnitude, combined with the forecast decrease in international arrivals during the summer peak would have serious repercussions on the net financial results of many tourism establishments, especially in tourism-intensive regions. Given the weight of the tourism industry in the Greek economy, the results of the study underscore the urgent need for a long-term strategy plan for Greek tourism, geared toward achieving the two primary objectives (i.e. extension of the tourist season; geographic diversification of the tourism product) and involving all stakeholders and drawing on collaboration between State authorities, at all levels, and the tourism industry.

2.7.1 Introduction

The aim of the present study is to provide estimates of the economic impact of climate change on Greece's tourism industry, based on projections of the physical impacts. Tourism is one of Greece's leading industries, in terms of GDP, employment, and the current account balance, considering that tourism receipts substantially reduce the current account deficit.[21] Despite its increasing weight in the Greek economy, Greek tourism faces important structural problems, such as strong seasonality, regional concentration and difficulties in coping with new trends in demand and increasing regional competition. The main characteristics and performances of the Greek tourism industry are presented in Table 2.36.[22]

Climate is a principal resource for tourism, as it co-determines the suitability of locations for a wide range of tourist activities, and, as such, makes tourism vulnerable to climate change. High temperature and other weather extremes, together with water shortages, are just some of the impacts that climate change is expected to have on the tourism industry. Two leading studies, one by Germany's Deutsche Bank (Deutsche Bank Research, 2008)[23] and another by the World Tourism Organisation (WTO, Climate change and Tourism: Responding to Global Challenges, 2008)[24] forecast a redistribution of tourist arrivals from Southern Europe to countries

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[21] According to the Bank of Greece, tourism receipts in 2011 reduced the current account deficit by 27%.

[22] The figures of Table 2.36 were taken from the full version of the study on Greek tourism available (in Greek) from the webpage of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr).

[23] Deutsche Bank Report (2008) Climate Change and Tourism: Where will the change lead? Deutsche Bank Research, Frankfurt am Main, Germany. Available at: http://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000222943.pdf

[24] World Tourism Organization, UNWTO Annual Report A year of recovery (2010), Madrid, Spain. Available at: http://dtxtq4w60xqpw.cloudfront.net/sites/all/files/pdf/final_annual_report_pdf_3.pdf

Table 2.36 **Greek tourism: Key figures and performance ranking relative to main competitors (2007)**

Key figures for Greek tourism, 2007	
Contribution to GDP	17.2% (World Travel and Tourism Council)
Contribution to employment	20.8% of total employment (World Travel and Tourism Council)
Employment (direct and indirect)	939,820 persons (World Travel and Tourism Council)
Receipts	€11.3 billion (Bank of Greece)
International tourist arrivals	15.2 million
Average spending per person	€743
Market share	1.68% (global), 3.13% (Europe)
Seasonality	47.7% of international tourist arrivals occur from July to September
Supply concentration	52% of hotel beds are concentrated in 3 regions (Hellenic Chamber of Hotels)
Hotel capacity	9,207 hotels/700,933 beds (Hellenic Chamber of Hotels)
Top 5 markets	United Kingdom (2,618,542 visitors), Germany (2,264,332), Italy (1,157,081), Netherlands (828,185), France (756,105) [NSSG]

Performance indicators for Greece and its main competitors (2007)

Performance indicators, 2007	Greece	Spain	Cyprus	Turkey	Egypt	Croatia
Rank in international tourist arrivals	16th	2nd	below 50th	9th	22nd	24th
Rank in tourism receipts	12th	2nd	below 50th	10th	25th	26th
International tourist arrivals, 2007 (million)	15.2	58.7	2.4	22.2	10.6	9.3
% change in arrivals, 2000 - 2007	22.6	26.5	-11.1	131.3	107.8	60.3
Receipts, $ billion 2007	15.5	57.6	2.7	18.5	9.3	9.3
% change in receipts, 2000-2007	68.5	92.0	42.1	143.4	116.3	232.1
Average spending per person per trip in $	1,019.7	971.4	1,125.0	829.6	877.4	1,000.0
Market share – world arrivals (%)	1.68	6.49	0.27	2.46	1.17	1.03
Market share – world receipts (%)	1.81	6.72	0.32	2.16	1.09	1.09

Source: Own calculations based on data from multiple sources.

with lower average summer temperatures in Middle-Northern Europe (Baltic Sea region, Benelux and Scandinavia).

Both studies are solid examples of the recent and rapidly expanding literature on the impacts of climate change on the economy as a whole and tourism in particular. The main physical and economic impacts of climate change on the tourism industry, compiled from a review of the literature, are listed in Tables 2.37 and 2.38.[25]

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[25] See footnote 22.

Table 2.37 **Physical impacts of climate change on tourism**

Direct impacts	Indirect impacts
• Temperature increase	• Damage to coastal tourism infrastructure
• Sea-level rise	• Depreciation of tourism infrastructure due to inadequate natural conditions (e.g. lack of snow in ski resorts)
• Changes in air humidity and quality	
• Increased drought	• Intrusion of sea water in aquifers and salinisation of drinking water
• Increased pollution	
• Increase in discomfort index	• Decreased water availability due to decreased rainfall
• Decreased rainfall and snowfall	
• More frequent appearance of photochemical smog	• Decrease and/or loss of ecotourism infrastructure and activities
• Increased extreme events (storms, floods, hurricanes)	
• Increased fires and diseases	
• Destruction of sensitive ecosystems	

Source: Table compiled by the research team.

Table 2.38 **Economic impacts of climate change on tourism**

• Possible decline in the number of tourist arrivals
• Possible decline in average tourist length of stay
• Reduced seasonality
• Global fall in disposable income for tourism due to drop in GDP as a result of climate change
• Increase in average cost of services provided to tourists
• Cost of forced discontinuation of provided tourism services due to extreme natural events (opportunity cost or loss of revenue)
• Works to reduce pollution and gas emissions
• Works (incl. engineering) to address the physical impacts of climate change and extreme events (dams, water recycling systems)
• Need to develop novel bioclimatic infrastructures
• Increased maintenance cost for older infrastructures
• Works to substitute natural capital with man-made capital in order to preserve the attraction of an area (e.g. substituting a forest with a thematic park, mountain bike activities with a kart circuit, addressing the lack of snow by creating a climbing wall)
• Downgrade of cultural and historic monuments (UNESCO study, 2007) and possible destruction of archaeological monuments
• Cost of staff training and adaptation to new operations and working procedures
• Repositioning of the tourism product in the global market

Source: Table compiled by the research team.

Building on these studies and fully aware of the methodological problems and the limitations of any effort to estimate climate change impacts, we have attempted in the present study to offer the most reliable estimates possible, at a national and regional level. To the best of our knowledge, this is the first attempt to compare results using climatological estimates at the aggregate (national) and disaggregate (regional) level. It should also be stressed that the present study deals only with the cost of adaptation, and not mitigation, due to the generally small size of tourism establishments in Greece and of the country as a whole.

Tourism-supporting activities —e.g. restaurant, transport and recreational services— were not taken into account either because (a) they are addressed in other sectoral studies, (b) they are in demand by both local residents and non-residents (tourists), or (c) they have a limited economic weight.

The focus of the present study will therefore be the direct impacts of climate change on tourism establishments, distinguishing between:

- *demand-side* implications, affecting the *revenue* of tourism businesses and its annual distribution; and
- *supply-side* implications, affecting the *operating cost* structure of tourism establishments either directly (operating costs, infrastructure maintenance costs), indirectly (need for new infrastructure, higher financing costs, cost of repositioning the tourism product in the national and international markets) or potentially due to extreme climate change-related events (indemnifications, opportunity cost, higher insurance costs).

The magnitude and extent of these impacts vary in function of:

- the characteristics of the specific tourism business and the services it offers (category, type of clientele, credit policy, customer loyalty rate, dependence on tour operators);
- the specifics of each accommodation establishment (size, age, features and maintenance); and finally,
- the accommodation establishment’s geographical location.

In summary, the objectives of our study are to record and present the country’s natural, tourism and hotel product; to estimate and analyse the financial performance of tourism businesses; to estimate the impacts of climate change on performance; and, based on the results, to draw conclusions and formulate policy recommendations for the efficient adaptation of the Greek tourism industry to climate change.

2.7.2 Methodology and data

The present study adopts the methodology used by leading studies in the field, such as the Garnaut,[26] Metroeconomica[27] and PESETA[28] studies, making the necessary modifications to

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[26] Garnaut, R. (2008), Garnaut Climate Change Review: final report, Garnaut Climate Change Review.

[27] Climate Change Impacts and Adaptation Cross-regional Research Programme: Project E – Quantifying the cost of impacts and adaptation, Defra Metroeconomica Ltd, UK (2005-2006).

[28] Ciscar, J.C. (2009) (ed.), *Climate change impacts in Europe*, Final report of the PESETA research project, European Commission, JRC, IPTS and IES.

Table 2.39 **Attributes of study scenarios (2050)**

	SRES A2		SRES B2	
Attributes	**2050**	**2100**	**2050**	**2100**
Rise in mean global temperature (°C)	1.6	3.5	1.6	2.5
Rise in mean temperature in Greece (°C)	2.0	4.5	2.0	3.1
Global population (in billion)	11.3	15.1	9.3	10.4
Global GDP (in billion USD)	82	243	110	235
CO_2 (parts per million)	532	856	478	621
Sea-level rise (cm)	12.0-16.0	23.0-51.0	12.0-16.0	20.0-43.0
Change in rainfall in SE Europe (%)	-7	-13	-5	-7

Source: IPCC, 2007, Chapter 1 of present study and Ciscar (2009).

incorporate regional characteristics and to conform with data availability (in terms of quantity and quality). The scenarios taken into consideration in the present analysis were based initially on the IPCC study. Initial estimates using the HadCM2 climate change model under the old GCM-IS92a scenario indicated that the number of warmer days (i.e. days with an average temperature above certain critical thresholds) will increase. This increase has been found to have an important influence on the tourist index used in the present study to estimate demand for the Greek tourism product.

To analyse Greece's tourism product, it was necessary to perform simulations using regional climate models (RCMs) with a high spatial resolution. The results of these models for Greece as a whole, as well as for the 12 climate regions into which Greece was divided, were provided by the research team of the Research Centre for Atmospheric Physics and Climatology (RCAPC) of the Academy of Athens. For the purposes of the present study, the simulation results were limited to Scenarios A2 and B2 (detailed in section 1.15.2, Chapter 1), which essentially represent the two extreme estimates of anthropogenic greenhouse gas emissions in forthcoming decades. For both scenarios, the calculations were made using the average of a set of simulations of RCMs, as described in Chapter 1.

Table 2.39 presents the two scenarios' basic attributes/assumptions. Differences in climate parameters were calculated based on the baseline period 1960-1990.

2.7.3 State of play of Greece's tourism infrastructure at the national and regional level[29]

Over the last few years there has been a considerable expansion in hotel capacity at the aggregate national level, as well as an increase in higher-rated hotels (4-star and 5-star), in both

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[29] See footnote 22.

absolute and percentage terms. However, Greece still trails its main competitors in average number of bed spaces per establishment and in the share of upper-category (luxury) beds in total number of beds. The Greek tourism industry thus consists mostly of small, lower-category establishments, unable to provide the high-quality services needed to attract high-income tourists in large numbers.

As regards camping/caravan establishments, their contribution to the economy is very small (0.1% of total tourism receipts) and half of the demand for camping/caravanning services comes from domestic tourists. Most camping establishments are small, family-run, unincorporated businesses. They will therefore be omitted from our study, which will focus on hotel accommodation.

In terms of regional breakdown, Greece's bed capacity highly concentrated in specific regions (Crete: 21%, Dodecanese: 17%, Macedonia: 14%, Central Greece: 13%, Ionian Islands: 11%). Upper-rated hotels are also highly concentrated in a small number of regions. In addition, the capacity utilisation rate in most regions is low (except urban centres, the Dodecanese and Crete), indicating the existence of an underutilised tourism stock, as a result of overinvestment and/or insufficient advertising and regional promotion.

Another problem is high seasonality, which results in full capacity remaining idle for extensive periods each year (often for six months or more). Indicatively, the annual accommodation capacity of Greek hotels is 182 million overnight stays, while actual overnight stays in 2007 —a representative year for Greek tourism— amounted to 64 million. Greece's Research Institute for Tourism has estimated that Greece as a whole has an over-capacity of 184.2% and that the current hotel capacity could, depending on the scenario, cover future increases in demand over the next 14 to 35 years.

Finally, significant differences are observed across regions in the average length of time during which hotels remain open each year. Attica and Western Macedonia are the only two regions with high percentages of year-round accommodation capacity, whereas regions with a high accommodation capacity remain open only seasonally (Crete: 82%, Ionian Islands: 84%, the Dodecanese: 90%).

2.7.4 Economic data[30]

As mentioned in the introduction, Greek tourism makes a substantial contribution to the national economy. According to the WTO estimates for 2010, the tourism industry generated 15.5% of GDP and 10% of total employment. Tourism investment almost tripled in the period 2002-2007 and is still rising. According to ELSTAT estimates, the above figures increase twofold, when supporting tourism services, such as bars, restaurants, refreshment stands, catering

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[30] See footnote 22.

services, etc., are taken into account. However, neither ELSTAT nor the WTO provide a methodology for distinguishing between resident and non-resident (tourist) consumption of such services. Due to the lack of specific methodology and data for determining the industry's indirect contribution, the focus of our sectoral study will be accommodation establishments.

Changes in the number of arrivals, average length of stay and average daily spending are expected to have a significant impact on tourism receipts and the net revenue of accommodation establishments. According to available data, although tourist spending levels differ according to the country of origin, total spending per person per trip has steadily decreased over the last few years.

Accommodation establishment operating costs differ considerably in function of establishment size, category and target market, the region's physical and climate characteristics, seasonality, etc. Table 2.40 provides an indicative operating cost structure for an average-size hotel, based on various estimates, and presents primary data for various cost categories as a percentage of total turnover, collected directly from a sample of 55 hotels, as well as data from three other studies.

Finally, according to a US study, the total energy consumption of a medium-size hotel can be broken down as follows: 33% for water heating, 24% for lighting, 22% for space heating,

Table 2.40 **Indicative operating cost structure of a representative average-size hotel (In percentages)**

	Primary research (n=55)	JBR research 2002	Hotel on line USA Research	ICAP research 2009 (for B class hotels)
Turnover	100.00	100.00	100	100
Cost of goods sold and services provided	71.01	56.40		68.23
Depreciation	15.60	17.40		16.84
Salaries and contributions	32.00	39.40	43.70	33.12 (NSSG)
Gross profit	28.99	44.60		31.77
Other operating expenses (excluding financial expenses)	18.66			
Energy	5.00	3.60	6.00	
Promotion/advertisement expenses	1.00	2.80	3,00	
Maintenance expenses	3.00	2.60	3.10	
Overheads	4.00	8.00		
Financial expenses	3.84	Included in 'Other Oper. exp.'		6.18
Pre-income tax profit	4.69	26.70	27.50	-2.06
Net disposable income	2.59			

n: number of hotels in the sample.
Source: Primary research and synthesis of information from various sources.

5% for space cooling, 3% for ventilation, 3% for meal preparation, and the remaining 10% for other uses.

2.7.5 The economic impacts of climate change on tourism in Greece

As mentioned above, we consider two sources of economic impacts of climate change on tourist activity: the change in revenue and the increase in operating expenses of tourism enterprises. The economic impacts on revenue are far more important than those on operating costs. To estimate the change in revenue, at the regional and seasonal level, we used the Tourism Climatic Index (TCI, Mieczkowski, 1985).

The TCI combines different climate variables —either recorded or estimated by meteorological studies— into a single index, designed to evaluate the climatic suitability of a region to support outdoor tourism activities. The TCI has been widely used in relevant studies, and a number of authors have even suggested adding or modifying the variables and weights used in the index (see, for instance, Morgan, 2000; Amelung and Viner, 2006; de Freitas et al., 2008). Despite its drawbacks, the TCI has the advantage of being easy to calculate and easy to comprehend and thus remains widely used.

The parameters that go into the final TCI are temperature, rainfall, sunshine, and wind speed and chill. The formula used to calculate the TCI is:

$TCI = 8CID + 2CIA + 4P + 4S + 2W$,

where:

CID is the maximum daily temperature in combination with the minimum possible humidity;

CIA is the average 24-hour temperature;

P is the average rainfall (in mm/month);

S are the total hours of sunlight per day; and

W is the average wind speed (in km/h).

The values of these parameters are not incorporated into the index as such: first, the continuous variables are converted into a scale of discrete values ranging from a perfect 5 (denoting optimal conditions for tourism activity) to a minimum value of -3. In the case of Greece, none of the TCI parameters take a negative value in any of the periods examined.

The climate data used to compile the index were calculated by the research team of the RCAPC and refer to climate data by decade for the period 2010-2100, broken down by season at the national level and for each of the 12 geographical districts described in Chapter 1. These data were fed into a specially designed spreadsheet, once the available data were converted into values ranging from 5 to -3.

The calculation of the TCI for the period 2070-2100 was based on Scenarios A2 and B2. The TCI calculations for the period 2010-2070 were based on the results of Scenario A1B for

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2)

		TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
Climate zone	Time period	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Greece	1961-1990	61	61	0	0	44	44	0	0	58	58	0	0	89	89	0	0	61	61	0	0
	2011-2020	60		-1		44		0		58		0		89		0		66		5	
	2021-2030	60		-1		44		0		58		0		89		0		65		4	
	2031-2040	61		0		44		0		58		0		89		0		71		10	
	2041-2050	66		5		49		5		63		5		89		0		71		10	
	2051-2060	66		5		49		5		63		5		89		0		71		10	
	2061-2070	71		10		49		5		63		5		89		0		76		15	
	2071-2080	71	71	10	10	52	49	8	5	63	63	5	5	84	83	-5	-6	81	76	20	15
	2081-2090	76	71	15	10	52	49	8	5	63	63	5	5	84	83	-5	-6	83	76	22	15
	2091-2100	76	71	15	10	52	49	8	5	68	63	10	5	79	83	-10	-6	81	76	20	15

TCI rating categories and corresponding colours in the table	
80≤TCI≤100 ideal,	🟩
60≤TCI≤79 excellent,	🟩
50≤TCI≤59 very good,	🟩
40≤TCI≤49 acceptable,	
TCI≤39 unacceptable	

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Western & Central Macedonia	1961-1990	55	54	0	0	41	40	0	0	,57	57	0	0	88	88	0	0	55	55	0	0
	2011-2020	53		-2		39		-2		56		-1		88		0		55		0	
	2021-2030	53		-2		39		-2		56		-1		88		0		55		0	
	2031-2040	54		-1		39		-2		56		-1		88		0		55		0	
	2041-2050	54		-1		44		3		56		-1		88		0		55		0	
	2051-2060	54		-1		45		4		58		1		88		0		55		0	
	2061-2070	59		4		44		3		58		1		88		0		60		5	
	2071-2080	60	60	5	6	46	45	5	5	57	57	0	0	83	88	-5	0	60	60	5	5
	2081-2090	60	60	5	6	46	45	5	5	59	57	2	0	80	88	-8	0	65	60	10	5
	2091-2100	65	59	10	5	46	45	5	5	64	57	7	0	75	88	-13	0	65	60	10	5
Eastern Macedonia/ Thrace	1961-1990	54	53	0	0	41	41	0	0	56	55	0	0	88	88	0	0	57	57	0	0
	2011-2020	53		-1		46		5		56		0		87		-1		56		-1	
	2021-2030	53		-1		46		5		56		0		87		-1		55		-2	
	2031-2040	53		-1		46		5		56		0		87		-1		56		-1	
	2041-2050	53		-1		46		5		56		0		87		-1		61		4	
	2051-2060	58		4		46		5		56		0		87		-1		61		4	
	2061-2070	58		4		46		5		56		0		87		-1		61		4	
	2071-2080	60	58	6	5	47	46	6	5	57	55	1	0	85	90	-3	2	67	61	10	4
	2081-2090	65	58	11	5	47	46	6	5	62	55	6	0	80	84	-8	-4	67	61	10	4
	2091-2100	70	58	16	5	47	46	6	5	62	55	6	0	75	90	-13	2	71	61	14	4

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Northern Aegean	1961-1990	61	61	0	0	43	43	0	0	58	58	0	0	89	89	0	0	65	65	0	0
	2011-2020	60		-1		48		5		57		-1		88		-1		70		5	
	2021-2030	60		-1		48		5		57		-1		89		0		70		5	
	2031-2040	65		4		48		5		57		-1		88		-1		70		5	
	2041-2050	65		4		48		5		62		4		88		-1		75		10	
	2051-2060	70		9		48		5		62		4		88		-1		75		10	
	2061-2070	70		9		48		5		62		4		88		-1		80		15	
	2071-2080	76	71	15	10	48	48	5	5	63	63	5	5	89	89	0	0	80	80	15	15
	2081-2090	76	71	15	10	49	48	6	5	63	63	5	5	84	89	-5	0	80	80	15	15
	2091-2100	81	71	20	10	48	48	5	5	63	63	5	5	84	89	-5	0	80	80	15	15
Cyclades	1961-1990	65	65	0	0	50	50	0	0	64	64	0	0	88	88	0	0	77	77	0	0
	2011-2020	72		7		50		0		64		0		88		0		82		5	
	2021-2030	72		7		50		0		64		0		88		0		82		5	
	2031-2040	72		7		50		0		64		0		88		0		82		5	
	2041-2050	77		12		50		0		64		0		88		0		82		5	
	2051-2060	77		12		51		1		69		5		88		0		82		5	
	2061-2070	82		17		56		6		69		5		88		0		82		5	
	2071-2080	83	82	18	17	56	55	6	5	69	69	5	5	88	88	0	0	82	82	5	5
	2081-2090	83	82	18	17	56	55	6	5	69	69	5	5	88	88	0	0	82	82	5	5
	2091-2100	82	82	17	17	56	55	6	5	74	69	10	5	83	88	-5	0	82	82	5	5

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Eastern Aegean	1961-1990	60	60	0	0	48	48	0	0	58	58	0	0	89	89	0	0	73	73	0	0
	2011-2020	64		4		48		0		63		5		88		-1		78		5	
	2021-2030	65		5		48		0		63		5		89		0		75		2	
	2031-2040	71		11		48		0		63		5		88		-1		78		5	
	2041-2050	69		9		48		0		63		5		88		-1		83		10	
	2051-2060	70		10		48		0		63		5		88		-1		83		10	
	2061-2070	75		15		48		0		63		5		88		-1		82		9	
	2071-2080	81	76	21	16	49	48	1	0	68	63	10	5	83	82	-6	-7	83	83	10	10
	2081-2090	81	75	21	15	51	48	3	0	68	63	10	5	83	82	-6	-7	82	83	9	10
	2091-2100	81	74	21	14	51	48	3	0	73	68	15	10	78	77	-11	-12	82	82	9	9
Dodecanese	1961-1990	72	72	0	0	50	50	0	0	64	64	0	0	88	88	0	0	83	83	0	0
	2011-2020	77		5		50		0		64		0		88		0		83		0	
	2021-2030	77		5		50		0		65		1		88		0		83		0	
	2031-2040	77		5		50		0		64		0		88		0		83		0	
	2041-2050	77		5		50		0		69		5		88		0		83		0	
	2051-2060	82		10		55		5		69		5		88		0		83		0	
	2061-2070	82		10		55		5		70		6		88		0		83		0	
	2071-2080	82	82	10	10	55	55	5	5	74	69	10	5	83	84	-5	-4	83	83	0	0
	2081-2090	83	82	11	10	56	55	6	5	74	69	10	5	83	84	-5	-4	85	83	2	0
	2091-2100	82	82	10	10	62	55	12	5	79	74	15	10	78	79	-10	-9	83	83	0	0

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

		TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
Climate zone	Time period	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Crete	1961-1990	62	62	0	0	52	52	0	0	58	58	0	0	89	89	0	0	68	68	0	0
	2011-2020	66		4		51		-1		60		2		89		0		73		5	
	2021-2030	66		4		51		-1		65		7		89		0		73		5	
	2031-2040	68		6		51		-1		65		7		89		0		73		5	
	2041-2050	73		11		51		-1		65		7		89		0		78		10	
	2051-2060	73		11		51		-1		65		7		89		0		78		10	
	2061-2070	73		11		51		-1		65		7		89		0		83		15	
	2071-2080	79	74	17	12	52	52	0	0	70	65	12	7	84	85	-5	-4	83	83	15	15
	2081-2090	79	74	17	12	52	52	0	0	70	65	12	7	84	85	-5	-4	83	83	15	15
	2091-2100	84	77	22	15	52	52	0	0	75	65	17	7	79	83	-10	-6	83	83	15	15
Central & Eastern Greece	1961-1990	56	56	0	0	47	47	0	0	58	58	0	0	89	89	0	0	63	63	0	0
	2011-2020	61		5		47		0		58		0		89		0		63		0	
	2021-2030	61		5		47		0		58		0		89		0		63		0	
	2031-2040	61		5		47		0		58		0		89		0		63		0	
	2041-2050	61		5		47		0		58		0		89		0		63		0	
	2051-2060	61		5		47		0		58		0		89		0		68		5	
	2061-2070	66		10		47		0		63		5		84		-5		68		5	
	2071-2080	71	66	15	10	52	47	5	0	63	63	5	5	79	78	-10	-11	78	68	15	5
	2081-2090	71	66	15	10	52	47	5	0	63	63	5	5	79	78	-10	-11	78	73	15	10
	2091-2100	76	66	20	10	52	47	5	0	68	63	10	5	74	78	-15	-11	83	73	20	10

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

Climate zone	Time period	TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
		Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Eastern Peloponnese	1961-1990	61	61	0	0	45	44	0	0	58	58	0	0	89	89	0	0	61	63	0	0
	2011-2020	61		0		44		-1		58		0		89		0		66		5	
	2021-2030	61		0		46		1		58		0		89		0		66		5	
	2031-2040	66		5		44		-1		58		0		89		0		71		10	
	2041-2050	66		5		52		7		63		5		89		0		71		10	
	2051-2060	66		5		52		7		63		5		89		0		73		12	
	2061-2070	71		10		52		7		63		5		84		-5		78		17	
	2071-2080	76	71	15	10	52	52	7	8	63	63	5	5	79	78	-10	-11	83	78	22	15
	2081-2090	77	71	16	10	52	52	7	8	68	63	10	5	74	78	-15	-11	83	78	22	15
	2091-2100	81	71	20	10	52	52	7	8	73	63	15	5	74	78	-15	-11	83	76	22	13
Western Greece	1961-1990	55	55	0	0	40	40	0	0	56	56	0	0	88	88	0	0	54	54	0	0
	2011-2020	50		-5		43		3		55		-1		88		0		53		-1	
	2021-2030	50		-5		43		3		55		-1		88		0		53		-1	
	2031-2040	51		-4		43		3		55		-1		88		0		53		-1	
	2041-2050	51		-4		43		3		55		-1		88		0		53		-1	
	2051-2060	51		-4		43		3		55		-1		88		0		58		4	
	2061-2070	56		1		43		3		55		-1		88		0		58		4	
	2071-2080	58	58	3	3	45	45	5	5	56	56	0	0	90	82	2	-6	64	59	10	5
	2081-2090	59	58	4	3	45	45	5	5	56	56	0	0	85	82	-3	-6	67	61	13	7
	2091-2100	64	58	9	3	45	45	5	5	62	56	6	0	80	82	-8	-6	71	59	17	5

Table 2.41 Estimate of the TCI index for Greece as a whole and for the respective climate regions, on an annual basis and by season (2011-2070 for Scenario A2 and 2071-2100 for Scenarios A2 and B2) *(continued)*

		TCI annual				TCI winter				TCI spring				TCI summer				TCI autumn			
		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index		TCI index		Δ TCI index	
Climate zone	Time period	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2	Scen. A2	Scen. B2
Ionian Sea	1961-1990	64	64	0	0	51	51	0	0	58	58	0	0	89	89	0	0	75	75	0	0
	2011-2020	69		5		50		-1		63		5		89		0		80		5	
	2021-2030	69		5		50		-1		63		5		89		0		80		5	
	2031-2040	70		6		50		-1		63		5		89		0		80		5	
	2041-2050	69		5		50		-1		63		5		89		0		80		5	
	2051-2060	75		11		50		-1		63		5		89		0		80		5	
	2061-2070	75		11		50		-1		63		5		89		0		80		5	
	2071-2080	79	74	15	10	51	51	0	0	63	63	5	5	89	83	0	-6	80	80	5	5
	2081-2090	80	75	16	11	56	51	5	0	68	63	10	5	84	83	-5	-6	80	80	5	5
	2091-2100	80	79	16	15	56	51	5	0	73	68	15	10	79	78	-10	-11	80	80	5	5
Western Peloponnese	1961-1990	55	55	0	0	44	44	0	0	56	56	0	0	89	89	0	0	60	60	0	0
	2011-2020	57		2		44		0		58		2		89		0		60		0	
	2021-2030	57		2		43		-1		58		2		89		0		60		0	
	2031-2040	59		4		44		0		58		2		89		0		60		0	
	2041-2050	59		4		46		2		58		2		89		0		65		5	
	2051-2060	60		5		46		2		58		2		89		0		66		6	
	2061-2070	65		10		46		2		58		2		89		0		70		10	
	2071-2080	71	65	16	10	51	46	7	2	63	58	7	2	84	83	-5	-6	76	71	16	11
	2081-2090	71	65	16	10	52	46	8	2	63	58	7	2	84	83	-5	-6	76	71	16	11
	2091-2100	76	65	21	10	51	51	7	7	63	63	7	7	79	83	-10	-6	81	70	21	10

rainfall, cloud cover and wind speed, and on the results of Scenario A2 for temperature. The use of results from two different scenarios is not expected to affect TCI values considerably, due to the very small differences in the results of Scenarios A1B and A2 (until 2070) and to the insignificance, in most cases, of these differences, once the continuous values are converted into the discrete values scale.

Owing to lack of data on maximum daily temperature in combination with minimum possible humidity (CID) and the average 24-hour temperature (CIA), these two temperature variables were merged into one and given a weighting coefficient of 50% in the final index. Table 2.41 presents the TCI and its variations relative to the baseline period (1961-1990) for Greece as a whole and for each of the 12 regions, by decade and by season, for 2011-2070 (Scenarios A2) and for 2071-2100 (Scenarios A2 and B2). These results are, of course, not definitive, as further research is needed to reach detailed estimates calibrated for all scenarios and all cases.

As can be observed from Table 2.41:

- At the countrywide level and on an annual basis, the TCI decreases slightly over the first two decades, but improves markedly towards the end of the century.
- At the countrywide level but on a seasonal basis, the TCI remains unchanged roughly till mid-century, but in the second half of the century improves (increases) in winter and in spring, and improves considerably in autumn. In contrast, it deteriorates (declines) considerably in summer.
- At the regional level, the overall picture drawn for Greece as a whole holds, but with important differences across regions. In other words, there are no significant changes roughly up to mid-century, but in the second half of the century the TCI in some regions improves in winter and spring, improves quite significantly in autumn and decreases considerably in summer.

It should be noted that the changes in the index by season and time period exhibit considerable differences at the regional and countrywide levels. This is because the TCI for Greece as a whole is calculated based on independent climate data of lower geographical resolution and not as a weighted average of the regional TCI values.

Impacts on arrivals, overnight stays and revenue

The assumption commonly made in the international literature is that TCI fluctuations exhibit, ceteris paribus, a linear correlation with the number of arrivals, the number of overnight stays and, by extension, regional tourism receipts Scott and Coyle, 2003; de Freitas et al., 2008) and can be used in tourist demand forecasting and management models (de Freitas et al., 2008). The authors of the present study express reservations as to whether the index at issue suffices on its own to forecast and describe a process as complex as tourist flows, without the appropriate spatial and qualitative adjustments, but share the view that it can make a positive contribution to relevant estimates.

The impact of climate change on Greek hotel revenue, used in this study as a surrogate of Greek tourism, obviously cannot be broken down at a seasonal or regional level, as this would require greater data availability. A thoroughly detailed analysis of the climate change impacts on Greek tourism could be carried out in the future, under greater time and data allowances.

Table 2.42, Panel A presents estimated arrivals, overnight stays and revenue till 2100, without taking climate change impacts into consideration. The estimates were made assuming increases of 3.5% in 2010-2020 (WTTC forecast for Greece,) and progressively decelerating increases every two decades of 3%, 2.5%, 2%, 1.5% and finally 1% in 2090-2100. We opted for partly decelerating increase rates because Greece is already a well-established tourist destination in the international market and because climate conditions in the countries feeding Greek tourism are expected to improve during the same periods. A discount rate of 1.4% (similar the one used in the Stern report) was used in order to derive present values of future streams. It should be stressed that the data in each row refer to the entire corresponding decade and not to a single year.

In Table 2.42, Panel B, we applied the annual TCI to the figures of Panel A, in order to obtain a first overall estimate of climate change impact on physical and economic figures. Panel C presents the differences in figures between Panels A and B. As was expected from the TCI estimates (Table 2.41) on an annual basis and at countrywide level, Greek tourism seems to benefit from climate change. The impacts are negative or neutral for the period 2010-2040, but turn significantly positive in the period 2061-2100. It should be emphasised that, due to space limitations, the data presented refer only to Scenario A1B.

For example, in decade 2091-2100, without taking climate changes into consideration, 41.6 million tourist arrivals are expected on average each year, a number which increases by an additional 10.2 million —or close to +25%— when taking climate changes into account. Similarly significant increases are also observed in the respective figures for overnight stays and tourism receipts.

However, the picture changes considerably when we proceed to a seasonal breakdown of the data. Table 2.42, Panel D presents estimates of the physical and economic figures once the TCI seasonal changes are taken into account. First, we converted the physical and financial figures of base year 2007 into seasonal ones, using seasonality coefficients calculated based on the monthly actual distribution of receipts in the same year. Specifically, the outcome of our computations provided the following coefficients: 4.56% for winter, 14.16% for spring, 56.11% for summer, and 25.17% for autumn. Finally, having obtained the seasonal breakdown of the physical and economic figures, we applied the respective seasonal TCIs.

As Table 2.42, Panel D clearly shows, although climate change continues to have a positive effect on all figures, the increases are much lower than the ones of Panel C. For instance, the increase in arrivals due to climate change in 2091-2100 falls on an annual basis from 25%, as

Table 2.42

Forecast arrivals, overnight stays and revenue (For the whole Greek territory discounted and non-discounted to present value, on an annual basis, as well as adjustment of all forecasts taking into account the impact of TCI both on an annual and a seasonal basis)

		Panel A. Changes assuming decelerating increases from 3.5% to 1% and i=1.4% Without taking into account TCI changes				Panel B. Taking into account TCI changes on an annual basis			
Climate zone	Time period	Arrivals	Overnight stays	Receipts (in thousand euro)	Receipts discounted to present value (in thousand euro)	Arrivals	Overnight stays	Receipts (in thousand euro)	Receipts discounted to present value (in thousand euro)
Greece	2007	16,037,592	65,420,236	11,319,200	11,319,200	16,037,592	65,420,236	11,319,200	11,319,200
	2011-2020	188,143,297	767,470,509	132,789,985	121,412,900	185,058,981	754,889,025	130,613,100	119,422,525
	2021-2030	215,685,205	879,818,929	152,228,837	137,264,579	212,149,382	865,395,668	149,733,282	135,014,340
	2031-2040	247,258,916	1,008,613,802	174,513,301	155,185,855	247,258,916	1,008,613,802	174,513,301	155,185,855
	2041-2050	277,013,603	1,129,988,548	195,513,914	171,460,195	299,719,636	1,222,610,560	211,539,644	185,514,310
	2051-2060	310,348,915	1,265,969,310	219,041,702	189,441,225	335,787,351	1,369,737,286	236,995,939	204,969,195
	2061-2070	339,823,403	1,386,201,074	239,844,552	204,568,892	395,532,158	1,613,447,151	279,163,331	238,104,776
	2071-2080	372,097,146	1,517,851,501	262,623,093	220,904,565	433,096,678	1,766,679,615	305,676,059	257,118,428
	2081-2090	398,245,218	1,624,514,214	281,078,187	233,163,716	496,174,370	2,023,984,923	350,195,773	290,499,056
	2091-2100	416,652,612	1,699,601,299	294,069,973	240,572,816	519,108,172	2,117,536,044	366,382,261	299,730,065
,		Panel D. Taking into account TCI changes on a seasonal basis				Panel C. Differences between forecasts not taking/taking into account TCI changes on an annual basis			
	2007	16,037,592	65,420,236		11,319,200	0	0	0	0
	2011-2020	192,024,909	783,304,306		123,917,788	-3,084,316	-12,581,484	-2,176,885	-1,990,375
	2021-2030	219,245,072	894,340,269		139,530,120	-3,535,823	-14,423,261	-2,495,555	-2,250,239
	2031-2040	257,461,386	1,050,231,522		161,589,180	0	0	0	0
	2041-2050	293,260,731	1,196,263,518		181,516,509	22,706,033	92,622,012	16,025,731	14,054,114
	2051-2060	328,551,192	1,340,219,688		200,552,145	25,438,436	103,767,976	17,954,238	15,527,969
	2061-2070	366,765,336	1,496,102,085		220,787,555	55,708,755	227,246,078	39,318,779	33,535,884
	2071-2080	398,702,063	1,626,377,767		236,699,225	60,999,532	248,828,115	43,052,966	36,213,863
	2081-2090	430,006,223	1,754,073,094		251,759,078	97,929,152	399,470,708	69,117,587	57,335,340
	2091-2100	438,395,357	1,788,293,885		253,126,951	102,455,560	417,934,746	72,312,288	59,157,250

mentioned above, to 5.2%. Aggregation on a seasonal basis sizeably lessens the climate change impacts, which however remain positive at countrywide level.

This marked deceleration should not come as a surprise, considering the data of Table 2.41, which showed the improvement on an annual basis to be clearly the result of the index's impressive rise in autumn by 20 points or more (Scenario A2) in the period 2070-2100, and its significant rise by 5 points during winter and spring. In contrast, the index falls considerably in summer by 5 points (Scenario A2) and by as much as 10 points (Scenario B2). These seasonal differences as to the index variation are of immense importance, since the summer months contribute on average 55-60% of annual tourism receipts.

All the economic figures of Table 2.42 were calculated using a discount rate of 1.4%, as in the Stern report. For a more comprehensive analysis and to demonstrate the role of the discount rate, Table 2.42(a) gives the present value of receipts, taking into account TCI changes on an annual basis, calculated using discount rates of 0%, 1%, and 3%. To facilitate comparison, the present value of receipts calculated using the 1.4% rate discount —i.e. the data in the last column of Panel B/Table 2.42— have also been reproduced. As was expected, a higher discount rate leads to a considerable decrease in the present value of receipts.

Although the above estimates show an overall positive impact of climate change on the physical and economic fundamentals of tourism, it should be stressed that the data calculated

Table 2.42(a)

Impact of discount rate on receipts discounted to present value, taking into account TCI changes on an annual basis (EUR thousands)

Climate zone	Time period	Discount rate i=0%	Discount rate i=1%	Discount rate i=1.4%	Discount rate i=3%
Greece	2007	11,319,200	11,319,200	11,319,200	11,319,200
	2011-2020	130,613,100	122,482,817	119,422,525	108,170,509
	2021-2030	149,733,282	139,022,597	135,014,340	120,393,559
	2031-2040	174,513,301	160,425,800	155,185,855	136,231,086
	2041-2050	211,539,644	192,537,831	185,514,310	160,325,362
	2051-2060	236,995,939	213,571,765	204,969,195	174,387,013
	2061-2070	279,163,331	249,080,615	238,104,776	199,431,787
	2071-2080	305,676,059	270,035,965	257,118,428	212,011,886
	2081-2090	350,195,773	306,301,914	290,499,056	235,815,561
	2091-2100	366,382,261	317,286,706	299,730,065	239,529,371

at the national level are for the most part misleading, at least for certain important regions. Unfortunately, as mentioned above, analysis at the regional level exceeds the scope of the present study due to the absence of available data. However, as it was deemed of great importance to at least indicate the differences emerging when ones moves to a regional breakdown, we have chosen to present the effect of climate change on a seasonal basis for two leading tourism regions, the Dodecanese islands and Crete, which account for roughly 40% of the country's total tourism output.

To point out the major differences, we focused on economic figures. We initially calculated the seasonality coefficients based on the monthly distribution of receipts for the year 2007 (NSSG data). More specifically, we used the following coefficients for Crete: 0.85% for winter, 15.96% for spring, 58.44% for summer, and 24.75% for autumn. For the Dodecanese, the corresponding coefficients were: 0.58%, 13.40%, 61.71% and 24.31%. Having aggregated the receipts on a seasonal basis we estimated the effect of TCI changes. Table 2.43 presents the results of this analysis in terms of differences.

As regards the region of Crete, quite significant reductions of receipts are observed in the summer months, a season during which more than 50% of revenues are raised, and during which the TCI falls. On an annual basis, however, and assuming full time elasticity of tourist arrivals, receipts for the region of Crete increase, mainly because of the extremely significant improvement of the TCI during autumn and spring, when approximately 40% of receipts are collected. But in the case of the region of the Dodecanese islands, the considerable decrease in receipts in the summer months is not offset by the increases in the spring and autumn months. This is due to the fact that approximately 60% of total tourism receipts are collected in the summer months.

The above analysis, despite the embedded simplifications and generalisations, proves that conclusions based on data regarding the entire territory on an annual basis can be misleading. Drawing useful conclusions requires taking into consideration both the seasonal and the regional dimensions of climate change impacts.

As there was no regional seasonality data available so for an estimation of the impacts on revenues on a seasonal basis for all regions, it was not possible to estimate the total impacts of climate change on the physical and economic figures for all of Greece. It should be recalled that, to be complete, such an effort would require data with greater geographical detail and a shorter-term basis for recording climatological variables, so as to support the design of a sound long-term tourism strategy for Greece. Still, in general terms and based on the TCI estimates of Table 2.41, climate change impacts on tourism figures are expected to be quite small and perhaps marginally negative for Greece as a whole.

Therefore, Greece would be able to benefit from climate change in economic terms so long as it can overcome the institutional factors that limit the tourist arrival period mainly to the sum-

Table 2.43 Differences in receipts between forecasts taking/not taking into account seasonal TCI

Climate zone	Time period	Winter	Spring	Summer	Autumn	Totals on an annual basis
Crete	2007	0	0	0	0	0
	2011-2020	-4,649	156,526	0	517,592	669,469
	2021-2030	-5,256	619,367	0	585,169	1,199,280
	2031-2040	-5,942	700,231	0	661,569	1,355,858
	2041-2050	-6,565	773,665	0	1,461,895	2,228,994
	2051-2060	-7,254	854,799	0	1,615,204	2,462,749
	2061-2070	-7,833	923,058	0	2,616,277	3,531,502
	2071-2080	0	1,708,746	-1,698,953	2,825,197	2,834,990
	2081-2090	0	1,803,573	-1,793,237	2,981,982	2,992,318
	2091-2100	0	2,636,252	-3,700,440	3,076,739	2,012,552
Dodecanese	2007	0	0	0	0	0
	2011-2020	0	0	0	0	0
	2021-2030	0	48,753	0	0	48,753
	2031-2040	0	0	0	0	0
	2041-2050	0	304,495	0	0	304,495
	2051-2060	18,639	336,427	0	0	355,066
	2061-2070	20,127	435,951	0	0	456,078
	2071-2080	21,735	784,606	-1,313,922	0	-507,581
	2081-2090	27,529	828,148	-1,386,838	231,697	-299,465
	2091-2100	56,808	1,281,695	-2,861,814	0	-1,523,311

mer months (school vacations, workers' holidays), and co-shape, together with the suitable climate, arrivals' figures and seasonality. This solution presupposes identifying new target tourist markets not bound by the above limitations (pensioners, weekend breaks, professional and conference tourism) and increasing the appeal of Greece's tourism product to prospective tourists and, more importantly, international tour operators.

Returning to the data of Table 2.43, we attempt to provide a sense of the magnitude of the economic impacts of climate change. It can be observed that in the last three decades of the 21st century summer receipts for Crete and the Dodecanese islands will decrease by €7 billion and €5.5 billion, respectively. Should these destinations fail to counterbalance the losses at issue by proportionally increasing arrivals in other seasons of the year during which the TCI improves, the losses entailed for tourism receipts on an annual basis will stand at roughly €240 million and €185 million, respectively. These amounts are relatively small when expressed as a percentage of the country's estimated annual tourism receipts for the base year 2007 (close to 5%). However, their level can prove to be devastating for the long-term survival and profitability of Greek hotel enterprises when expressed as a percentage of these enterprises' profits. Indicatively, for the year 2007, the turnover of all Greek hotels came to €9.93 billion, with a gross profit margin of 33.8%, a margin of earnings before interest, taxes, depreciation and amortisation (EBITDA) of 24.5%, and a net profit margin of 0.98%.[31] The translation of these percentages into figures practically means that gross annual income for the year 2008 stood at €3.35 billion, net income before interest, taxes, depreciation and amortisation at €2.43 billion, and net (distributable) profits at €973 million. Therefore, a reduction of arrivals due to climate change based on the scenarios' forecasts, and consequently a reduction of revenue by about €430 million for only two regions, would suffice to cut annual net results of hotel enterprises at national level by almost one third.

The strong negative impact of the limited reduction of receipts on annual net results stems from the fact that the hotel units' operating leverage is very high. According to the data presented above, this leverage borders on 80%, leading to a high break-even point, a limited margin of safety and strong transformation of fluctuations in tourism receipts and expenses into analogous fluctuations in annual results.

At this point it should be emphasised that the multiplier for the tourism industry is quite high, and so changes in the industry's profitability have further considerable economic impacts on other, cooperating or even —more often than not— dependent industries. Moreover, the fact that tourism is a services-providing industry translates into increased employment for a considerable number of (mostly seasonal) workers and, conversely, into a loss of a proportionately large number of jobs when tourist arrivals or average spending per visitor decrease.

These observations yield a rather optimistic view of reality, as they take no account of the parallel improvement of the same climatic parameters in the countries of origin of the tourists visiting Greece. If climate conditions in these countries change in a way that improves the local TCI, then the above estimates would probably be far more negative. For example, the final PESETA report forecasts TCI improvement in Central and Northern Europe during spring, summer and autumn, and based on these estimates concludes that there will be a shift in tourist demand from Southern to Central and Northern Europe.

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[31] See footnote 22.

In addition to the seasonal variation of TCI changes, equally essential is the variation across regions, which, as was demonstrated earlier, can have very serious economic impacts. It should be emphasised that the analysis carried out above for the regions of Crete and the Dodecanese was based on a seasonal breakdown of overnight stays. But it did not take into consideration the seasonality of operation of these beds, which however stands at 88.91% for the Dodecanese islands and at 81.85% for Crete. These observations highlight the huge negative economic impacts that climate change (through a deteriorating local TCI alone) can have on the revenue and profitability of Greek hotel enterprises. These impacts are masked by non-deterioration or improvement of the TCI in other seasons (during which most tourist beds remain idle) and in other regions of the country, which however account for a limited share in tourism receipts.

Cost of adaptation for tourism establishments

From the point of view of the expenses required to cope with climate change and mitigate its impacts, the economic impacts are assessed as moderate.

These impacts are limited to a possible increase in energy consumption, mainly for ventilation and cooling during the summer months. Given that energy accounts for 5% of the operating costs of accommodation establishments (Table 2.40) and only 10% thereof involves ventilation and cooling, the anticipated increase in energy costs will not exceed 0.5% of operating costs in the event that energy consumption should double.

A more serious impact will be the increase in depreciation related to the acquisition of new systems for expanding/improving existing infrastructure (renewable fuel-fired systems, innovative heat insulation materials, double-pane windows, water recycling systems, solid waste collection and recycling systems, etc.). As depreciations represent 18.6% of hotels' total operating costs, it is estimated that an organised effort to increase energy efficiency and eco-friendly operation could increase this item by 10-20%, burdening hotels' operating costs by an additional 2-4%.

Standardising these efforts by acquiring a relevant certificate (such as ISO or EMAS) or a tourism ecol-label could add an additional 0.2-0.3% to operating costs. One should also factor in the higher maintenance costs for newly acquired equipment, the costs of training personnel in the operation of such equipment and, of course, the costs of acquisition (in cases where acquisitions are made with external capital). All of the above could result in an additional increase in costs in the order of 1%.

International experience has brought to the fore the gradual increase of insurance premia paid by accommodation establishments for coverage against extraordinary events that could compromise their ability to operate at a given time. Indicatively, insurance premia for hotels in the US tripled from 2000 to 2010. Admittedly, extreme weather events such as the ones that led to such an increase (e.g. hurricanes and tornados in the southern US), have yet to occur in Greece, at least not at such severity and frequency. However, the effects of forest fires in the last few years could be taken into account in the estimations as —at least partly— a result of climate change. A potential deterioration of weather conditions and of their consequences, such as wildfires, would undoubtedly lead the Greek insurance market to rapidly adjust its rates accordingly.

Finally, one should not underestimate the cost of repositioning the Greek tourism product in the international tourism ‘arena’. This is a long-term and difficult process that requires careful and comprehensive elaboration at the central (strategic) level, but tailored to the regional and climatic characteristics of each destination. The Hellenic Chamber of Hotels, the Research Institute for Tourism, and the Association of Greek Tourism Enterprises, as well as the local unions of hotel owners, should play a key role in the planning, adaptation and implementation of this effort, contributing their experience and some of their resources, but in the authors’ opinion the additional economic cost per accommodation establishment would be very small.

The negative impression that the above observations may have created can be considerably counterbalanced by the following encouraging considerations:

- many of the sector’s enterprises have already taken initiatives, such as the ones described above, either as part of an upgrading plan or in response to customer demand;
- many of the investments described are rapidly recouped (in 6 months to 3 years), thus allowing additional economic benefit thereafter;
- establishments in close proximity to each other can undertake such initiatives as a group and split certain costs between them (personnel training, waste collection and recycling systems, etc.); and
- under development laws, accommodation establishments can often qualify for special financing (e.g. substantial incentives are often provided under ‘green tourism’ initiatives in the form of grants, accelerated depreciations, labour cost subsidies, etc.).

2.7.6 Conclusions and limitations of the study

Conclusions

The present study found the potential impacts of climate change on Greek tourism to be considerable, despite the fact that we only examined the effect of the TCI on revenue, overlooking the impacts of other major factors, such as SLR, increase in extreme weather events (storms, floods, hurricanes, etc.), greater frequency of fires and diseases, and devastation of sensitive ecosystems.

Considering that climate variables, such as temperature, sunshine, wind and rainfall are known to significantly influence tourists’ choice of holiday destination and vacation timing, a seasonal and regional redistribution of arrivals, and hence of revenue, is to be expected. However, although the TCI index shows Greece to benefit from climate change at the countrywide level and on an annual basis, the seasonal and regional breakdown of the TCI index points to a significant deterioration of the climatic parameters that affect tourist flows to major (thus, crucial) tourist destinations, and more precisely at the peak of the demand for Greece's tourism product.

Given these results, it is important for the tourism industry, in coordination with State authorities at all levels, to adopt a series of initiatives geared toward reducing the seasonality and enhancing the geographic diversification of Greece's tourism product. These objectives can be achieved by marketing Greece's many currently unexploited natural attractions; by developing and promoting alternative eco-friendly forms of tourism; by attracting new tourist target groups; and by taking measures to reduce the industry's environmental footprint.

The decrease in arrivals and in associated revenue, together with the increase in accommodation establishments' operating costs as a result of climate change adaptation measures, will have a profound impact on net results and the financial situation of many tourism businesses. Our analysis of the Crete and Dodecanese regions showed that the €430 million decrease in hotel revenue and the €70-90 million (5-7%) increase in hotel operating costs[32] would be enough to wipe out any annual profit in an industry that as a whole has been increasingly raking up losses since 2008, even before the negative impacts of climate change are factoring in.

The results of the study indicate that reliable detailed estimates of the economic impacts of climate change can (and should) be pursued only at the local level and on an ad hoc basis. Such estimates should apply the most reliable scenario to a small-scale area, taking all of the location's other crucial features into account (e.g. altitude, windward/leeward position). Coupling this information with an analysis of the area's tourism establishments (age, size, infrastructure, etc.) would make it possible to tailor the measures needed to mitigate and manage the physical and economic impacts of climate change to the specific location.

Limitations of the study

Future studies of climate change impacts on tourism should place greater emphasis on regional analysis and use higher resolution data. This would require more comprehensive and accurate climate data series used in the TCI. Furthermore, there is a need to replace seasonal (quarterly) data with data adjusted to the average vacation time foreign visitors spend in Greece. Similarly, data for smaller geographical areas are needed (indicatively, in the order of 15x15 km, available today), and the emphasis of the analysis should be shifted to geographical areas that already have major tourism activities or a potential to develop new sustainable and profitable activities. Empirical studies of the specific climate factors affecting international

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[32] Operating costs in 2007 came to €1.4 billion. See footnote 22.

tourist arrivals (and of the weighting of these factors) are needed to adjust and improve the tourism product and ensure that it meets the desired specifications. Alternative indicators of thermal discomfort, such as the ASHRAE and PET indexes, can be used in lieu of Mieczkowski's arbitrary heat scale. Finally, it would be important to take into consideration the results of similar studies on the countries of origin of foreign visitors to Greece, as well as on Greece's major competitor destinations.

2.8 Risks and impacts of climate change on the built environment*

2.8.1 Introduction and review

The them 'built environment' encompasses any construction resulting from human intervention and, in a broader sense, denotes not only the natural or artificial environment in which people live, but also the effects that human action can have on the surrounding infrastructure.

Based on the classification used in the Garnaut Climate Change Review (Garnaut, 2008), the elements of the built environment can be grouped into seven general categories:

- Buildings: for residential, commercial and industrial use;
- Supply networks: power and water processing and management infrastructure;
- Public transport: transport systems and means (roads, railways, ports, airports, urban railways, etc.);
- Telecommunications: fixed-line networks and towers for electricity and telecommunications;
- Public spaces: recreation areas, parks, and all outdoor areas that combine natural and built environments;
- World heritage properties: national heritage buildings and monuments;
- Other buildings: various types of infrastructure.

In this sectoral study, the authors present a broad review of the impacts of climate change on the built environment, before focusing on the impacts on Greece's building sector. The energy-related, economic and social implications of climate change are examined with a view to estimating the change in the energy consumption of buildings and the implications of such a change for thermal comfort and overall quality of life. In closing, the study explores and proposes policies for offsetting the climate change impacts, and estimates the cost of their implementation.

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* Sub-chapter 2.8 was co-authored by: Dimosthenis Asimakopoulos, Matheos Santamouris, Andreas Papandreou, Ifigenia Farrou, Marina Laskari, Maria Saliari, George Zannis, Costas Tiggas, George Giannakidis, Theodora Antonakaki, Konstantinos Vrettos, Stelios Zerefos and John Kapsomenakis.

Table 2.44 **Overview of the direct and indirect impacts of climate change on the built environment**

Climate factors	Direct impacts	Studies	Indirect impacts	Studies
Rise in mean temperature	Increase in summer energy demand (cooling) (M)	Franco and Sanstad (2008), Garnaut (2008), Miller et al. (2008), Giannakopoulos and Psiloglou (2006), Metroeconomica (2006), Hadley et al. (2006), Plessis et al. (2003), LCCP (2002)	Lower worker performance and productivity due to hotter temperatures (M)	WWF (2008)
			Excess summer demand can cause network congestion and general service disruption, resulting in general production losses (M)	Garnaut (2008), Hanemann (2008)
	Urban Heat Island (M)	Souch and Grimmond (2006), Arnfield (2003), Shimoda (2003), Livada et al.(2002), Hassid et al. (2000), Katsoulis and Theoharatos (1985), Oke (1982)		
	Decrease in winter energy demand (heating) (M)	Garnaut (2008), Metroeconomica (2006), Plessis et al. (2003), LCCP (2002)		
Increase in heat wave frequency	Increased energy demand for air-conditioning (M)	Psiloglou et al. (2009), Franco and Sanstad (2008), Miller (2008), Giannakopoulos and Psiloglou (2006), Plessis et al. (2003), LCCP (2002), Cartalis et al. (2001)	Decrease in labour productivity due to poorer health and living factors (M)	WWF (2008)
	Decreased thermal comfort in urban areas and indoors (NM)	Garnaut (2008), Younger et al. (2008), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003), LCCP (2002)	General economic losses from specific service disruption (e.g. water supply, communications, power supply, etc.) due to network congestion (M)	Garnaut (2008), Franco and Sanstad (2008), Hanemann (2008), WWF (2008), Jollands et al. (2007a,b), Sailor and Pavlova (2003)
			Impacts on human health from deterioration in indoor thermal comfort (e.g. cardiovascular disease, asthma, etc.). Increase in emergency hospital admissions (M)	Garnaut (2008), Younger et al., (2008), Vandentorren (2004), LCCP (2002)
Sea-level rise	Increased damage to buildings and other infrastructure in coastal areas (M)	Hunt and Watkiss (2011), PESETA (2009), Garnaut (2008), EEA (2007), IPCC (2007), Kirshen et al. (2007), Metroeconomica (2006), Kirshen et al. (2004), LCCP (2002)	Increase in expenditure for repair and maintenance of natural capital affected by sea level rise (M)	PESETA (2009), Garnaut (2008), IPCC (2007), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003), LCCP (2002)
	Increased flood events (M)	PESETA (2009), Garnaut (2008), EEA (2007), IPCC (2007), Kirshen et al. (2007), Metroeconomica (2006), Kirshen et al. (2004), LCCP (2002)		
	Increased risks to human safety (M)	Garnaut (2008), IPCC (2007)	Immigration flows due to environmental reasons (NM)	IPCC (2007)

M=Market, NM=Non-market.

Table 2.44 **Overview of the direct and indirect impacts of climate change on the built environment *(continued)***

Climate factors	Direct impacts	Studies	Indirect impacts	Studies
Increased frequency of extreme weather events	Increased damage to natural capital (M)	Garnaut (2008), IPCC (2007), Metroeconomica (2006), LCCP (2002)	Economic loss in sectors relying on urban development (e.g. tourism) (M)	Garnaut (2008)
	Increased risks to human safety (loss of human life) (M)	Garnaut (2008), IPCC (2007)	Cost of relocating affected populations, in cases where the natural capital is totally destroyed (M)	IPCC (2007)
			Increase in emergency hospital admissions due to extreme weather events (M)	Garnaut (2008), Vandentorren (2004)
	Damage to cultural heritage monuments (NM)	Metroeconomica (2006)	Economic loss in sectors relying on cultural monuments (e.g. tourism) (M)	Metroeconomica (2006)
Increased frequency of winter storms	Increase in damages to buildings and equipment (M)	Garnaut (2008), IPCC (2007), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003)	Increased expenditure for building repair/restoration after flood events (M)	Garnaut (2008), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003)
	Drainage system surcharge due to intense rainfall, making flood events worse	Wilby (2007), Metroeconomica (2006)		
	Increased flood events (M)	Garnaut (2008), IPCC (2007), Metroeconomica (2006), Kirshen et al. (2004), Plessis et al. (2003), LCCP (2002), Gonzalez-Rouco (2000)		
Decreased frequency of summer rainfall	Increased incidents of subsidence (M)	Garnaut (2008), Hulme et al. (2002), LCCP (2002)		
	Intense periods of summer drought leading to relative water shortage, on account of persistently high water demand (M)	IPCC (2007), Arnell (2004)	Conflicts between countries over shared water resource rights and 'climate migrants' management (NM)	IPCC (2007)
Increased frequency of summer fires	Damage to buildings and infrastructure from fires (M)	Garnaut (2008)	Decreased production due to service disruption from fire damage to power network (blackouts) (M)	Garnaut (2008)
Reduced soil moisture	Damage to natural capital due to soil subsidence (M)	Garnaut (2008), Metroeconomica (2006), Hulme et al. (2002), LCCP (2002)		
Reduced frequency of frost events	Lesser damage to buildings and road network from frost events	Garnaut (2008), Metroeconomica (2006), LCCP (2002)		

M=Market, NM=Non-market.

Sectoral studies of the impacts of climate change on the built environment tend to focus on urban centres. The reason for this is two-fold: first, the bulk of the built environment is concentrated in urban centres and, as concentration increases problems exponentially, the impacts of climate change are more pronounced in large cities;[33] and second, the majority of the global population is projected to concentrate in urban centres.[34] Similar studies have been carried out at a city level (LCCP, 2002; Kirshen et al., 2008; Jollands et al., 2007) as well as at the national level, with sectoral breakdowns (PESETA, 2009; Garnaut, 2008; Metroeconomica, 2006).

Climate change will drastically alter a number of environmental and climate factors. This change is, in turn, expected to have physical impacts on a number of parameters that affect human living conditions (e.g. damage to the built environment, additional operating costs in certain production sectors, loss of business, disruption of services, etc.). In many cases, climate change may also affect human welfare (e.g. lower thermal comfort levels, poorer health and living conditions, reduced prosperity, etc.).

Generally speaking, the impacts of climate change on the built environment can be divided into direct and indirect, as well as market and non-market impacts.[35] The direct and indirect impacts, as mentioned in the international literature, are summarised in Table 2.44. The study that follows is based on the climatological estimates of the Research Centre for Atmospheric Physics and Climatology of the Academy of Athens and focuses mainly on the temperature change-related impacts (in green in Table 2.44).

2.8.2 The building sector of Greece

Greece's building sector is responsible for roughly one third of total CO_2 emissions and around 36% of total energy consumption. Prior to the economic crisis, building sector CO_2 emissions had been growing at an annual rate of close to 4%, while the energy consumption of buildings was steadily rising.

Greek buildings are highly energy-consuming. According to Eurostat, Greek households have are the biggest energy consumers in the EU, consuming roughly 30% more energy than Spain's, almost twice as much as Portugal's and considerably more than even colder climate countries/regions, like Belgium or Scandinavia.

This has dire consequences for the country's energy balance and household budgets (low-income households, in particular), while also leading to dramatic increases in peak electrical

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[33] As noted in the IPCC Fourth Assessment Report (2007), the impacts of climate change will be clearly stronger in areas with rapid urbanisation and in all forms of coastal areas.

[34] According to the United Nations (2008), by 2050 urban dwellers will likely account for more than two thirds —around 68%— of the global population and around 86% of the population of developed countries.

[35] Alternatively, a distinction could be made between valuated and non-valuated impacts.

power loads, increasing the need for new power stations and condemning hundreds of thousands to energy poverty.

This adverse state of play of the built environment from an energy perspective has some major social and economic corollaries. Today, only 8% of low-income earners currently live in dwellings with thermal insulation and double glazing, as opposed to 70% for high-income earners. Thus, low-income earners spend roughly 120% more for heating and 95% more for air-conditioning per person and surface area than their high-income counterparts. Meanwhile, the thermal discomfort that low-income earners experience during summer can pose serious health risks.

Given that the energy demand of buildings depends directly on regional climate factors, it is evident that climate change will have significant consequences for the entire built environment. It is already well-established that the worsening thermal degradation in Greece's large urban centres, rising ambient temperature in response to local and global changes, the short-sighted empirical and/or outdated approaches to urban landscaping and building design, and the depletion of green areas in and around cities increase discomfort for urban dwellers, intensify the use of highly energy-consuming means to ensure thermal comfort, and even endanger the lives of a large part of the population with the means of coping with the emerging new climatic reality.

The present sub-chapter explores the energy-related, economic and social implications of the likely climate change for the built environment. The analysis aims, first, to calculate the increase in buildings' energy consumption as a result of climate change and the repercussions of such an increase on thermal comfort and overall quality of life, and, second, to explore and propose policies to offset the above impacts, while also calculating the cost of their implementation.

2.8.3 State of play

The insufficient protection of existing buildings from their surrounding environment, mass housing and commercial building construction with total disregard to the environment and local climatological conditions, phenomena such as the urban heat island, aging buildings, and the total lack, for nearly 40 years now, of any update in legislation on energy and environmental protection of buildings, have resulted in:

- an unsustainable widening of the country's energy deficit;
- an economic and social squeeze on the lower income brackets;
- an increase in the country's energy poverty; and
- Greece's failure to honour its international environmental commitments arising e.g. from the Kyoto Protocol or Directive 2002/91/EC of the European Parliament and of the Council on the energy performance of buildings (EPBD, 2003).

Some 65% of the country’s buildings were constructed prior to 1980, with practically no thermal protection systems, such as insulation, double glazing, etc. Meanwhile, the strong increase in living space per person has also contributed to increase the energy demand per person. Finally, the high penetration of air-conditioning use in recent years has increased the absolute consumption levels of the building sector and the country’s peak electrical power loads.

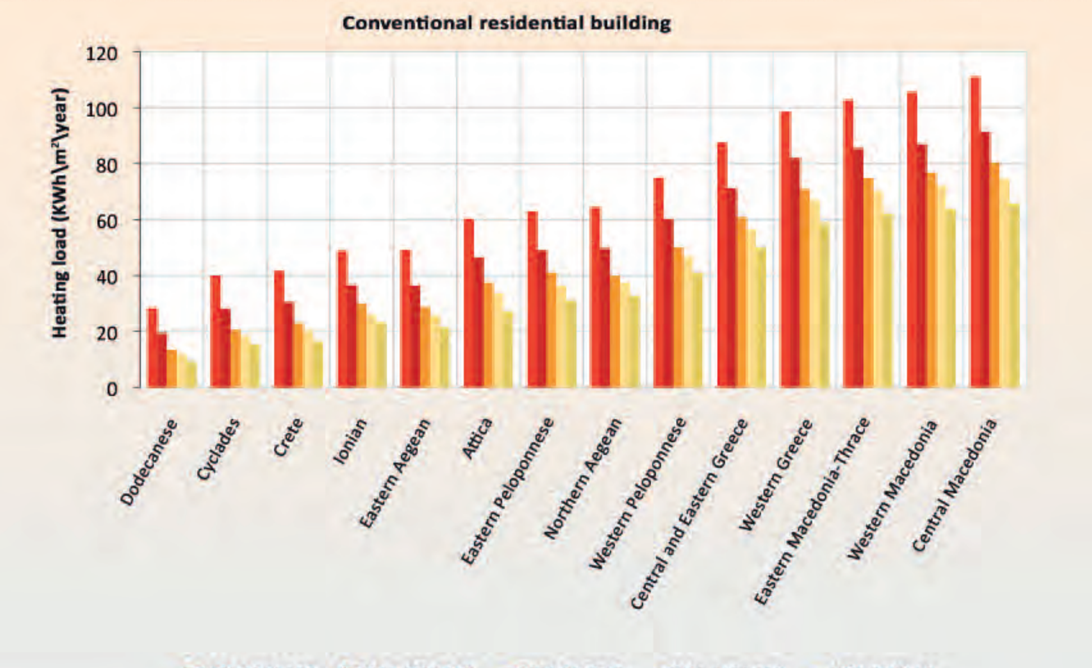
2.8.4 Physical impacts of climate change on the built environment

The likely physical impacts of climate change on the building sector involve, first, changes in the energy consumption of climate-controlled buildings and, second, changes in the indoor conditions of buildings unequipped with climate control systems.

Warmer climate conditions will obviously lead to a significant reduction in buildings’ winter energy requirements. In summer, however, warmer temperatures will lead to a significant increase in energy requirements for air-conditioning, while also seriously decreasing thermal comfort in non air-conditioned buildings.

The method used to estimate the impacts of climate change on the energy consumption and indoor thermal comfort conditions of buildings consisted of the following four phases:

Figure 2.11 **Estimated change in the heating load of a conventional dwelling in each climate zone under the five climate scenarios considered**



Phase 1) Using the detailed simulation tool TRNSYS, we calculated the heating and cooling loads of three types of buildings, for each of the country's climate zones and under all five climate scenarios available. More specifically, we estimated the energy load requirements for residential, office and education buildings. In all cases we assumed that the indoor thermal comfort conditions are maintained year-round (at 21ºC in winter and 26ºC in summer) with recourse to auxiliary heating and air-conditioning systems.

For each type of building, we simulated three different types of constructions (of low, medium and high energy efficiency): (a) a *conventional* construction (built after the introduction of the thermal insulation requirements of 1979); (b) a *modern* construction (built in compliance with the energy technology of 2010 and the specifications of the Energy Performance of Buildings Regulation); and (c) a *passive* construction (incorporating the currently available energy-saving technology as much as possible). For each type of construction, we calculated the annual heating and cooling loads (in KWh/m2) for three time periods (1961-1990, 2041-2050 and 2090-2100) and under three emission scenarios (A1B, A2 and B2). The changes in heating and cooling loads of a conventional residential building are presented, respectively, in Figures 2.11 and 2.12.

As can be seen, the projected decrease in the heating load of buildings under the four future scenarios is particularly large relative to today. More specifically, the average decrease is

Figure 2.12 Estimated change in the cooling load of a conventional dwelling in each climate zone under the five climate scenarios considered

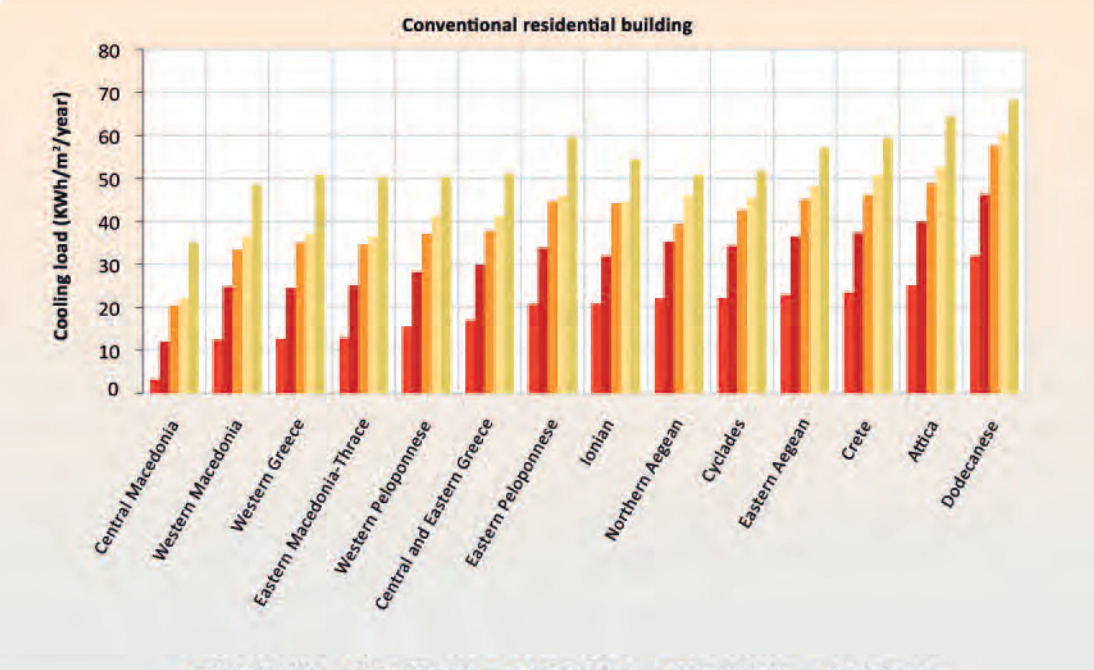


Figure 2.13

Estimated change in the heating load for three types of dwellings (conventional, modern, passive) in Attica under the five climate scenarios

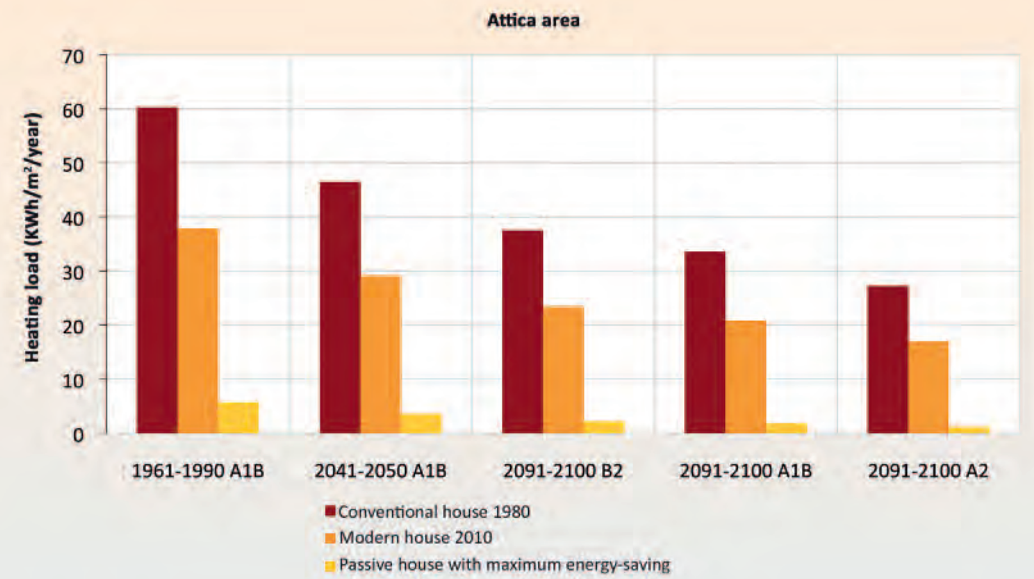
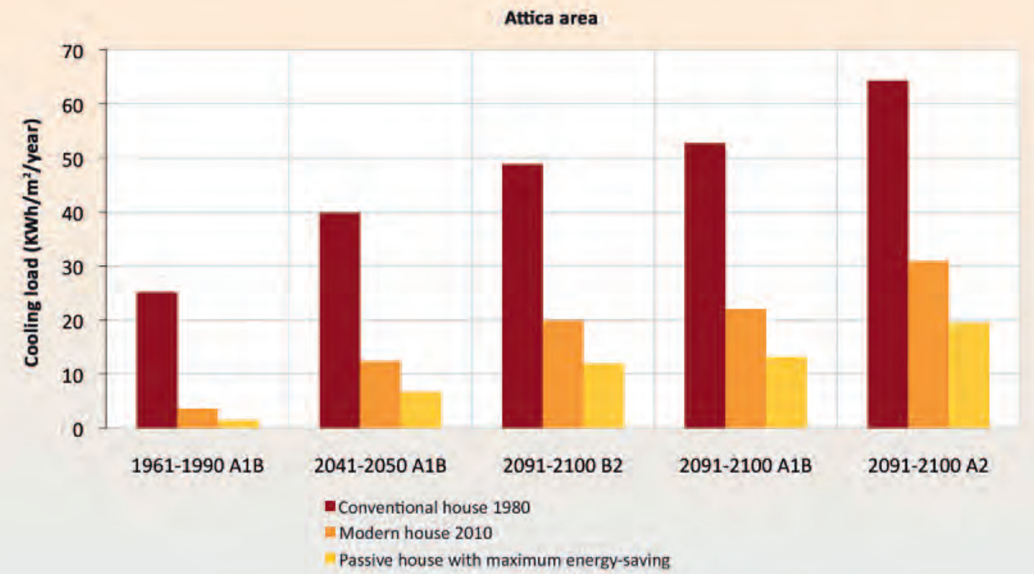


Figure 2.14

Estimated change in the cooling load for three types of dwellings (conventional, modern, passive) in Attica under the five climate scenarios



around 22.4% under Scenario A1B for 2041-2050, 50.1% under Scenario A2 for 2091-2100, 36.4% under Scenario B2 for 2091-2100 and finally 42% under Scenario A1B for 2091-2100.

Conversely, the increase in air-conditioning load relative to today is estimated at 83% under Scenario A1B for 2041-2050, while the average increase is estimated at around 248% under Scenario A2 for 2091-2100, 148% under Scenario B2 for 2091-2100 and finally 167% under Scenario A1B for 2091-2100.

The largest percentage decrease in heating load by 2050 is observed in the Dodecanese, followed by the Cyclades, while the smallest decrease is observed in Thessaly, followed by Eastern Macedonia-Thrace.

The largest increase in air-conditioning load is observed in Central Macedonia, followed by Western Macedonia, while the smallest increase is observed in the Dodecanese, followed by the Ionian.

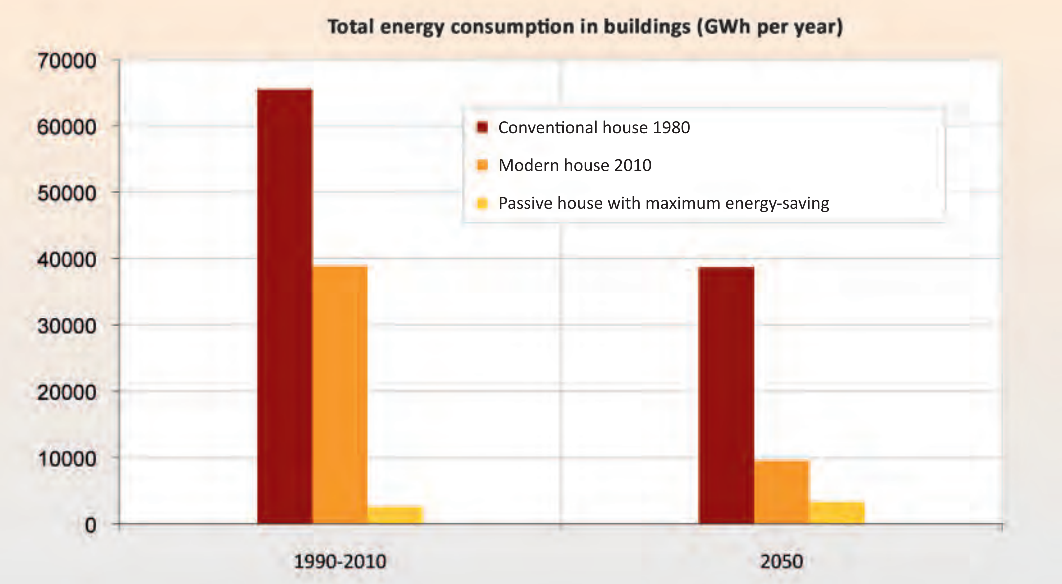
Similar results and findings were obtained for office and education buildings.

Phase 2) We studied the variation in heating and cooling loads in function of the construction standard (conventional, modern or passive). Indicatively, the variation in heating and air-conditioning loads of three types of residential buildings in Attica are presented for the five climate scenarios in Figures 2.13 and 2.14.

As regards *modern* constructions, the pace at which the heating load decreases under the four future climate scenarios relative to the current state of play is very similar to the pace observed for *conventional* constructions. In contrast, the percentage increase in the summer air-conditioning load is 4 to 6 times higher than the one observed for conventional constructions. The reason for this is that the main climatic change takes place in summer, while the improved level of construction (better shading and load management) reduces cooling loads by 50% to 70% compared with conventional constructions, and therefore increases the relative importance of the ambient temperature change, which affects buildings mainly through ventilation systems.

Finally, a *passive* construction, incorporating all the latest energy-saving technologies, has a heating load 10 to 40 times lower than that of a conventional construction, and a practically negligible air-conditioning load by today's standards. The percentage reduction in heating load attributable to climate change is roughly 50% greater than that of conventional constructions, while the respective percentage increase of air-conditioning loads is 6 to 10 times higher than that of conventional constructions and 50% to 70% greater than the respective increase in modern constructions. The higher rates of load increase or reduction are attributable, on one hand, to the drastic reduction in energy loads thanks to the incorporation of advanced energy-saving systems that contribute to the large percentage increase (increase of small figures) and, on the other hand, to the higher relative impact henceforth of ambient temperatures (via ventilation) as a result of the drastic reduction of the other loads.

Figure 2.15 **Estimated total energy consumption in Greece in 1990-2010 and 2050, per type of construction**



Similar results and findings were obtained for office and education buildings.

Phase 3) Based on the simulations of energy consumption by different types of construction in all the climate regions, we proceeded to calculate the total energy consumption of the entire building stock per geographic/climate region in 2010 and under the climate scenario for 2050. Databases were used to determine the type and characteristics of constructions in each region, while we also estimated the variation in the number of buildings by 2050.

The aim at this stage was to calculate total energy consumption in Greece (and not just the total load), as well as the change in total energy consumption attributable to climate change. The calculations at this stage are drastically affected by the coefficient of performance (COP) of heating and air-conditioning systems.

The buildings' characteristics were kept unchanged in both sets of simulation with regard to the climate scenarios. However, given that heating and air-conditioning systems will be much more efficient in 2050 than they are today, we altered the COP of conventional energy supply systems. More specifically, we assumed that a heat pump today has a heating COP of 3 and a cooling COP of 2. For 2050, the corresponding heating and cooling COP were set at 5 and 4, respectively.

The results obtained for the total energy consumption of the country's building stock for the three types of construction under the two climate scenarios are presented in Figure 2.15.

As can be seen, the almost certain improvement in energy production system technology in future and the better quality standards of buildings will, to a large extent, offset the effects of climate change. The following future scenarios regarding the course of buildings' energy consumption can thus be formulated.

The best-case scenario: The total energy consumption of Greece's building stock, which stands today at 90,000 GWh, could, in spite of climate change, be reduced to 5,000-10,000 GWh by 2050, if state-of-the-art energy production technology is used in all buildings, as discussed above, and if the features of the entire building stock are substantially improved to 'passive construction standards'. In addition, all new buildings constructed after 2020 would need to have nearly zero energy consumption.

The optimistic scenario: Use of high-performance energy production systems, as discussed above, in all buildings by 2050 the upgrading to 'passive construction standards' of the building stock constructed prior to 1980 and the nearly zero energy consumption of all new buildings would reduce total annual energy demand to roughly 22,000-25,000 GWh.

The realistic scenario: Use of high-performance energy production systems, as discussed above, in about 70% of buildings (with the rest remaining conventional), the upgrading to 'modern construction standards' of 60% of the building stock constructed prior to 1980 and the nearly zero energy consumption of all new buildings built after 2020 would reduce total annual energy demand to 50,000-55,000 GWh.

The worst-case scenario: Installation of high-performance energy production systems, as discussed above, in only 10% of buildings by 2050 (with the rest remaining conventional), the upgrading to 'modern construction standards' of only 20% of the building stock constructed prior to 1980 and the nearly zero energy consumption of all buildings built after 2020 would cause total annual energy demand to exceed 120,000-130,000 GWh.

Phase 4) Based on the analysis of climate change effects on the built environment, an attempt was made to quantify the impact on the quality of life as a result of the rise in indoor air temperature in low-standard buildings lacking an auxiliary energy production system.

We adopted the following methodology: having selected two typical constructions with a low-standard building envelope, we performed year-round indoor climate simulations under all the considered climate scenarios and periods: 1960-1990 (A1B), 2041-2050 (A1B) and 2091-2100 (A1B, A2, B2). The assumption was made that the buildings have no climate control, i.e. no installed air-conditioning system. The envelope attributes used were those of dwellings constructed prior to 1979 when the thermal insulation regulation first came into effect (conventional buildings).

We calculated three parameters that characterise and quantify the quality of the indoor environment:

a) maximum and minimum indoor temperatures each month;

b) the percentage of time in summer during which indoor temperature exceeds 26ºC, 28ºC, 30ºC or 32ºC; and

c) the number of degree-hours of indoor temperature higher than 26ºC.

The entire analysis was carried out for each of the country's climate regions, as defined by the Academy of Athens.

Degree-hours are defined as the sum of the differences between hourly indoor temperatures and 26ºC, or in more detail:

$$DH(26) = \Sigma\,(Tind(\iota) - 26)^{+}$$

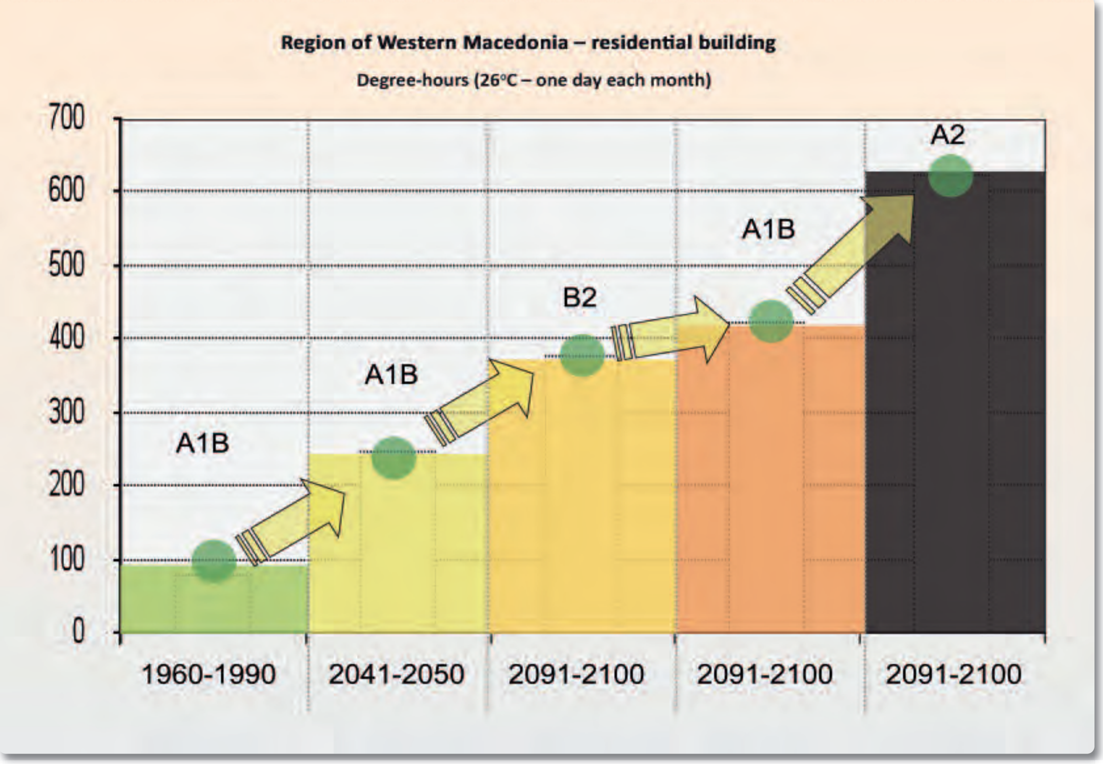
where Tind(ι) is the indoor temperature in hour (ι), while the sign (+) denotes that only positive difference values are taken into account.

Given that climate files contain one day per month, the calculations refer to all typical days of the year.

The change in air-conditioning degree-hours calculated under all climate scenarios is indicatively presented in Figure 2.16 for Western Macedonia.

The increase in cooling degree-days calculated under Scenario A1B for the years 1990 and 2050 ranges from 54% to as much as 1,000%. The largest increase is observed in Central Mace-

Figure 2.16 **Estimated change in cooling degree-hours at base temperature of 26°C for Western Macedonia under the five climate scenarios**

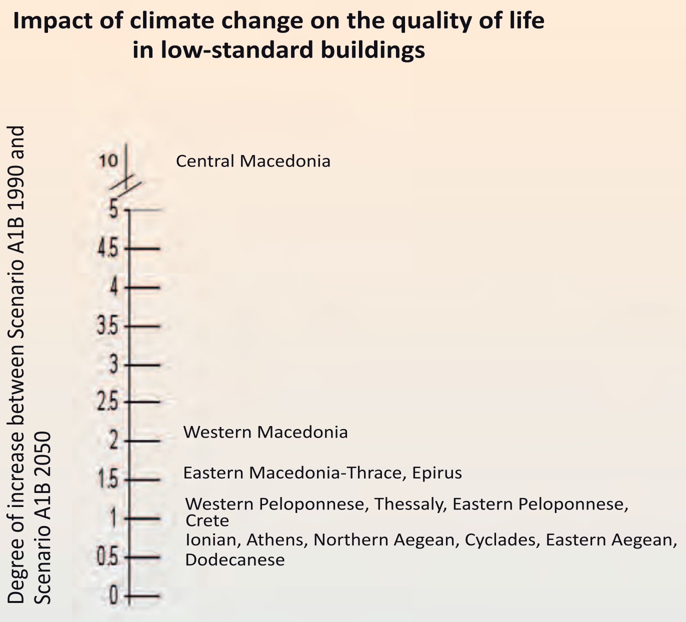


donia, followed by Western Macedonia. The smallest increase is observed in the Dodecanese. The Athens area and the other island regions present an almost uniform increase of roughly 90%. In parallel, the increase in cooling degree-days calculated between Scenario A1B for 1990 and Scenario A2 for 2100 ranges from 152% to up to 4,200%. The largest increase is observed in Central Macedonia, followed by Western Macedonia and then Eastern Macedonia-Thrace. The smallest increase is observed in the Dodecanese. The Athens area and the other island regions present an almost uniform increase in the order of 200-250%.

The increase in cooling degree-days calculated between Scenario A1B for 1990 and Scenario B2 for 2100 ranges from 100% to as much as 2,100%. The largest increase is observed in Central Macedonia, followed by Western Macedonia and then Eastern Macedonia-Thrace. The smallest increase is observed in the Dodecanese. The Athens area and the other island areas present an almost uniform increase in the order of 150%.

Finally, the increase in cooling degree-days calculated between Scenario A1B for 1990 and Scenario A1B for 2100 ranges from 115% to as much as 2,400%. The largest increase is observed in Central Macedonia, followed by Western Macedonia and Eastern Macedonia-Thrace. The smallest increase is observed in the Dodecanese. The Athens area and the other island regions present an almost uniform increase in the order of 170%.

Figure 2.17 **Estimated degree of increase in cooling degree-hours for a conventional dwelling in 2050, relative to 2010**



The rate of increase in cooling degree-days under the scenario for 2050 in all the regions studied is presented in Figure 2.17.

In parallel with the change in cooling degree-days, we also calculated, for each region and under each climate model, the maximum and minimum indoor temperatures in a typical dwelling. The results as regards the change in maximum monthly indoor temperature for a typical region, namely Western Macedonia, are presented in Figure 2.18.

The increase in maximum indoor temperature calculated between Scenario A1B for 1990 and Scenario A1B for 2050 ranges from 2.0ºC to 2.9ºC. The largest increase is observed in Western Macedonia, followed by Central Macedonia and Eastern Macedonia-Thrace. The smallest increase is observed in the Ionian. The increase in maximum indoor temperature calculated between Scenario A1B for 1990 and Scenario A2 for 2100 ranges from 4.5ºC to 7.5ºC. The largest increase is observed in Central Macedonia, followed by Eastern Macedonia-Thrace and Western Macedonia. The smallest increase is observed in the Cyclades. At the same time, the increase in maximum indoor temperature calculated between Scenario A1B for 1990 and Scenario B2 for 2100 ranges from 3.4ºC to 4.8ºC. The largest increase is observed in Central

Figure 2.18 Estimated maximum indoor temperatures for a conventional dwelling in Western Macedonia under the five climate scenarios

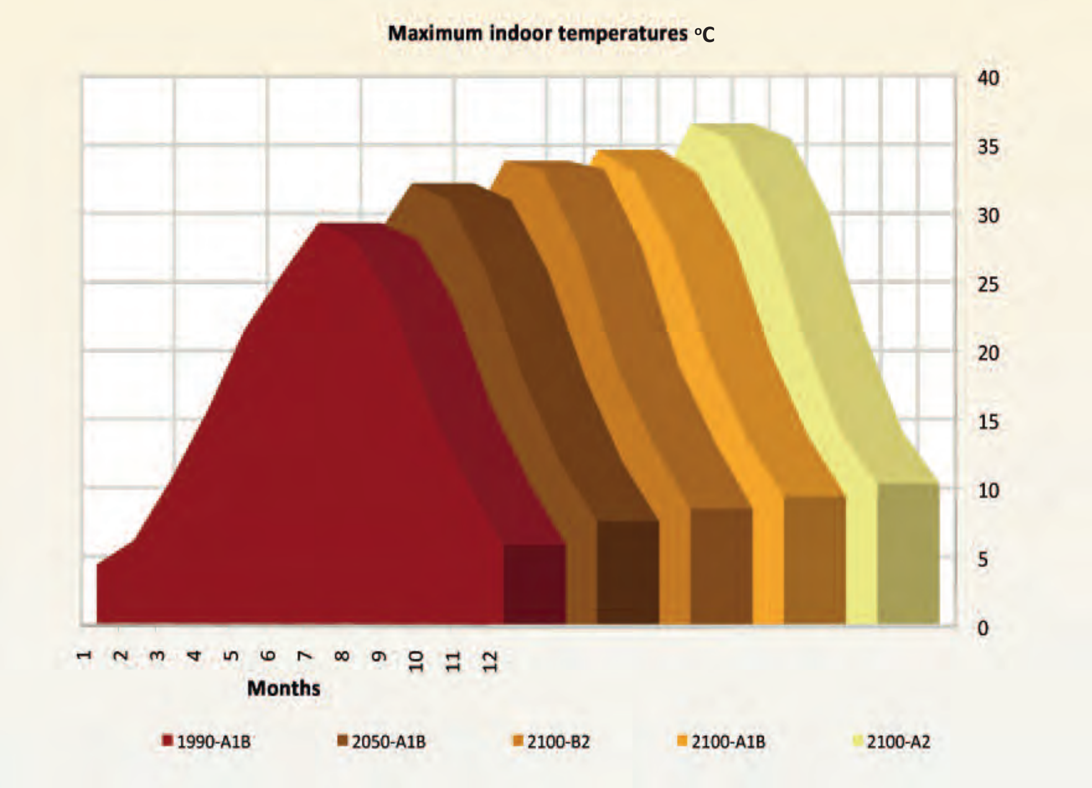
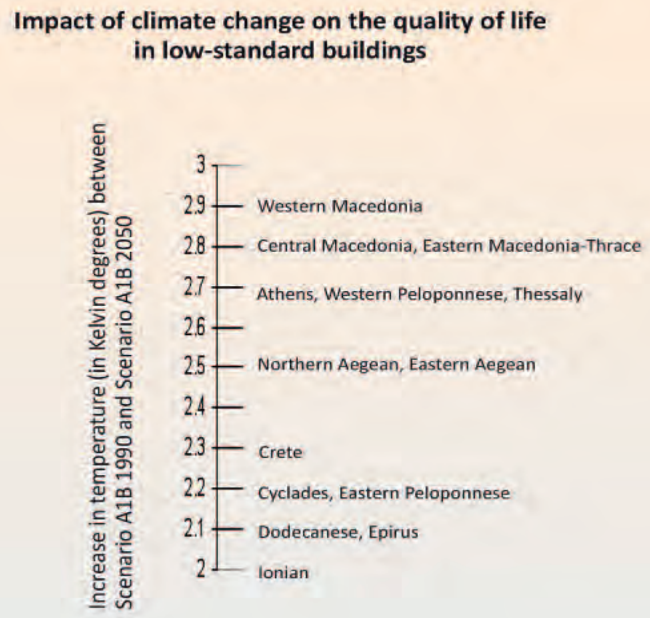


Figure 2.19 Estimated increase in maximum summer indoor temperature for a conventional dwelling in each climate zone in 2050, relative to 2010



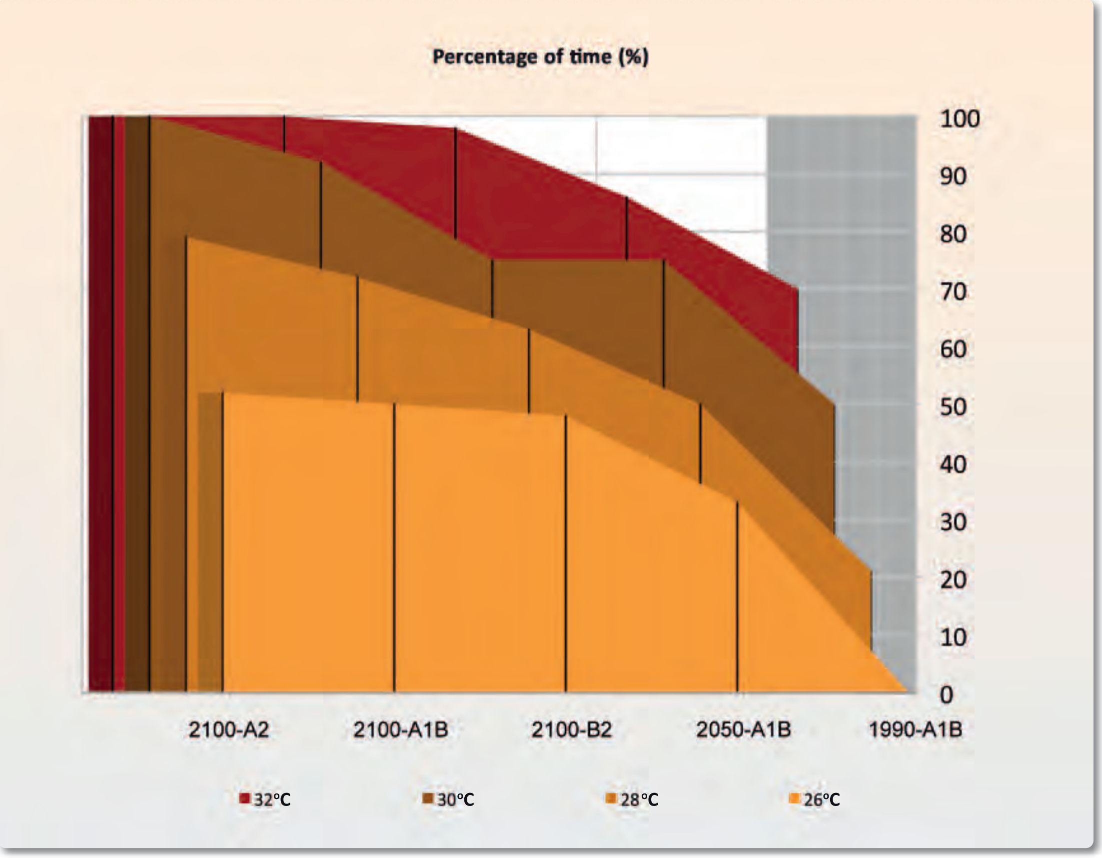
Macedonia, followed by Eastern Macedonia-Thrace, Thessaly and Western Macedonia. The smallest increase is observed in the Cyclades. Finally, the increase in maximum indoor temperature calculated between Scenario A1B for 1990 and Scenario A1B for 2100 ranges from 3.5ºC to 5.3ºC. The largest increase is observed in Western Macedonia, followed by Central Macedonia, Eastern Macedonia-Thrace, the Western Peloponnese and Thessaly. The smallest increase is observed in the Cyclades.

The relative increase in maximum annual indoor temperature in 2050 relative to 2010 for all of the regions is presented in Figure 2.19.

In parallel with the change in air-conditioning degree-days and the maximum and minimum indoor temperatures, we also calculated for each region and under all climate models the percentage of time in summer (in hours) during which the indoor temperature in a typical dwelling exceeds the temperature standards of 26ºC, 28ºC, 30ºC and 32ºC. The results as regards the change in maximum monthly indoor temperature in the Northern Aegean are presented in Figure 2.20.

Under Scenario A1B for the current period, the percentage of time during which the indoor temperature exceeds the standard temperature from June to September is always zero. In contrast, under Scenario B2 for 2100, this percentage increases drastically and ranges from 0% to

Figure 2.20 **Percentage of time in summer (June-September) during which indoor temperature exceeds four given temperature thresholds, Northern Aegean**



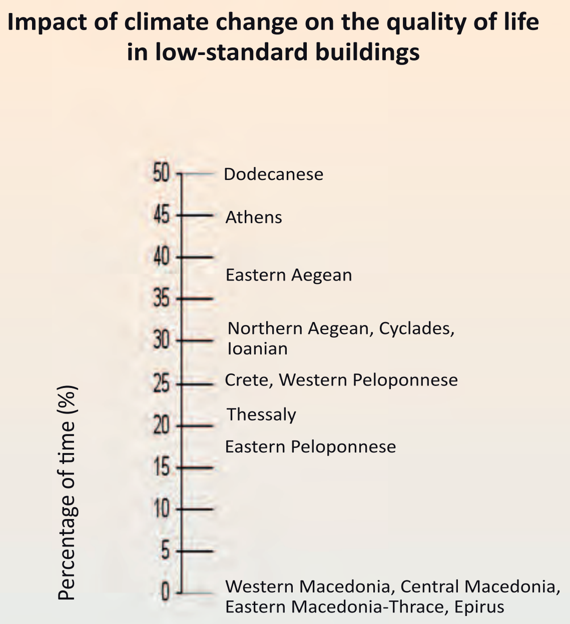
65%. The largest 'above standard temperature' value is observed in the Dodecanese, Athens and the Aegean, and the smallest in Central Macedonia. Under Scenario A1B for 2100, the percentage increases sharply, ranging from 0% to 68%. The largest 'above standard temperature' value is observed in Athens and the Dodecanese, and the smallest in Central Macedonia. Under Scenario A2 for 2100, the percentage also increases drastically, ranging from 40% to 98%. The largest 'above standard temperature' value is observed in the Dodecanese and Athens, and the smallest in Central Macedonia and Western Macedonia.

The percentage of time in summer during which indoor temperature exceeds 32ºC under Scenario A1B for 2050 for all climate regions is presented in Figure 2.21.

2.8.5 Economic impact on the built environment and potential for addressing and adapting to climate change impacts

The results of the simulations of useful cooling and heating energy demand in buildings were used to estimate the additional cost that climate change would entail for adapting build-

Figure 2.21 Percentage of time in summer (June-September) during which indoor temperature exceeds 32°C in each climate zone under Scenario A1B 2050



ings to the new climatic conditions. The technological adaptations required to address climate change consist, first, of equipping (or retrofitting) buildings with advanced energy-saving and alternative energy systems.

Simulations were aggregated at the regional level (total buildings per region), using estimates of the rates of change in number of buildings per use.

To estimate the cost of necessary interventions in buildings over the horizon extending to 2050, we assumed that all buildings will have advanced energy-saving and alternative energy systems, so as to have nearly zero energy consumption, as provided for by the revised EC Directive on the energy performance of buildings. More specifically, the following assumptions were made:

- All new buildings will have an insulation thickness of 15 cm.
- 60% of existing non-insulated buildings will be retrofitted with an insulation layer of 15 cm.
- The remaining 40% of existing buildings with insulation that meets current requirements will be retrofitted with 15 cm insulation.
- All glass units will be replaced with double-glazing with low emissivity and a U-value of 0.4 W/m^2-K.

Figure 2.22 Distribution of intervention costs per technology and region

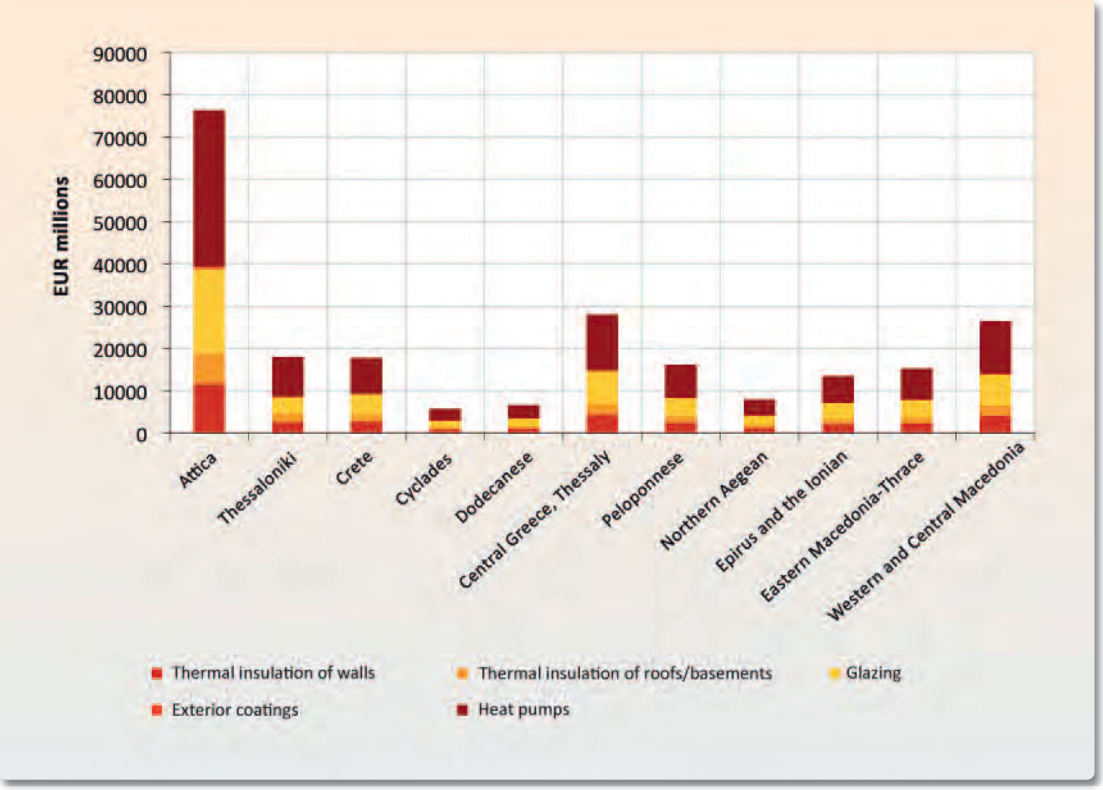
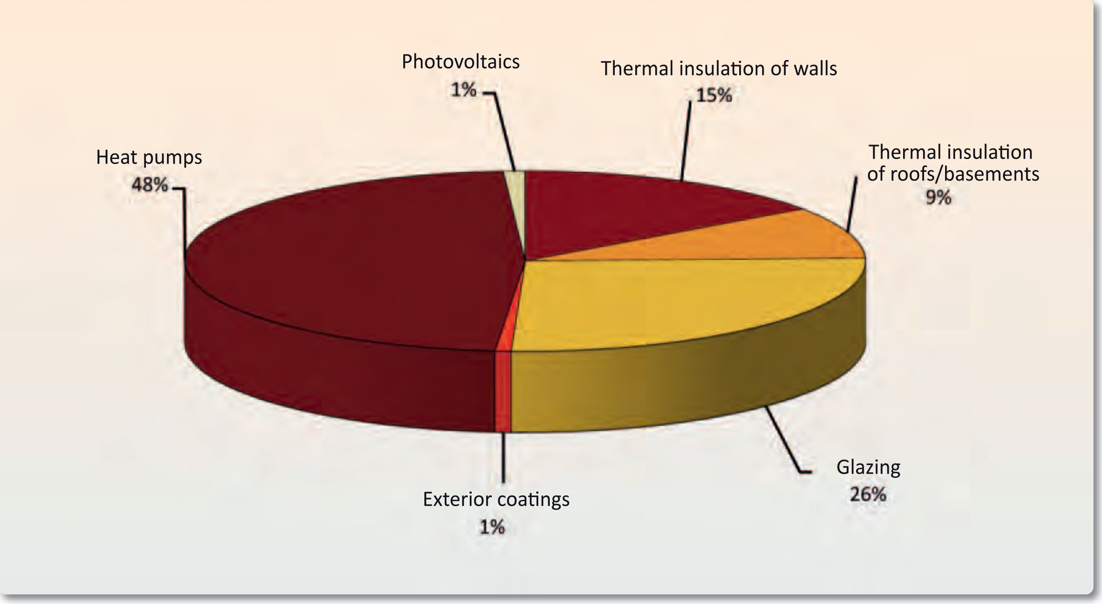


Figure 2.23 Percentage distribution of intervention costs per technology



- All external surfaces will be coated with highly reflective paint.
- All building heating and cooling will be achieved with electric heat pumps with a heating COP of 5 and a cooling COP of 4.
- All additional heating and cooling energy needs will be met with photovoltaic panels.
- The calculations were carried out for each climate region using comprehensive databases comprising qualitative and quantitative building attributes.
- The present analysis focused on residential, education and tertiary-sector buildings, which together represent 90% of the country's building stock.

Based on these assumptions, the examined scenario presents the cost needed for all buildings to have nearly zero energy consumption by 2050, taking climate change into account.

As can be expected, the cost is higher in the wider Attica area (Figure 2.22), where the largest share of the country's building stock is located.

The total cost of the measures needed to adapt the existing and anticipated building stock to the technological standards likely to be in effect in 2050 will amount to some €230 billion. A breakdown of these costs by technology for building envelope upgrading, heating system upgrading and photovoltaic panel installation is presented in Figure 2.23. Roughly 50% of the required cost involves building envelope upgrading. The small cost needed for additional photovoltaics to ensure zero energy consumption is a direct reflection of the extremely low energy demand for heating and cooling achieved with the thermal enhancement of building envelopes and the use of energy-saving systems.

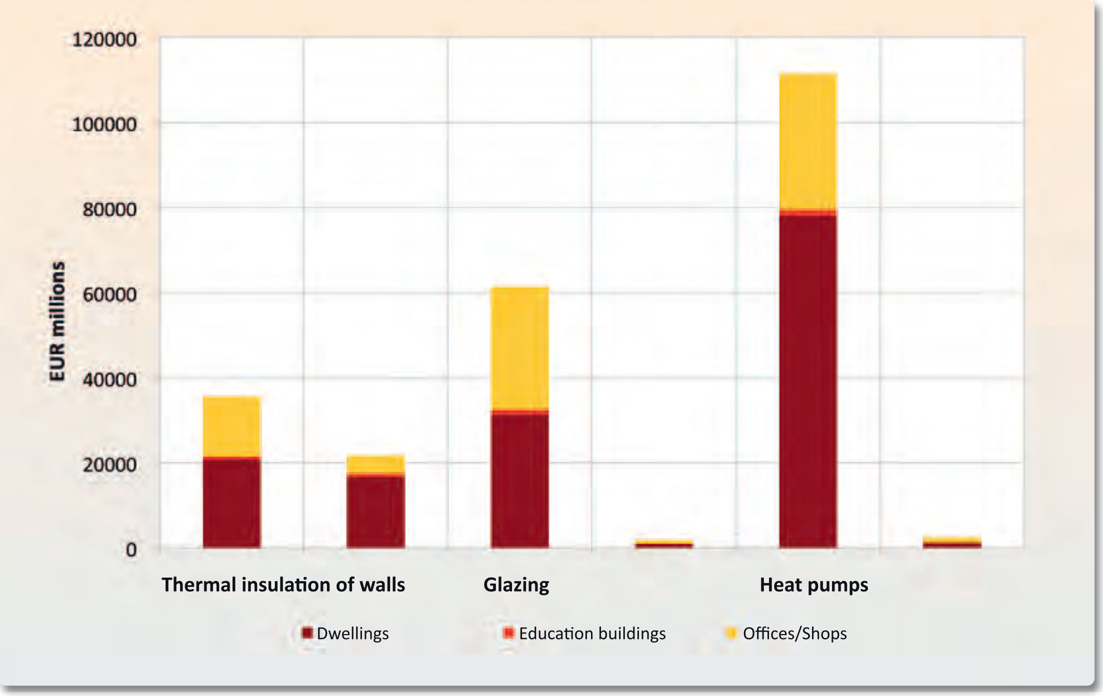
About 65% of the total cost involves residential buildings, which represent 80% of the total building stock. Absolute cost levels per building type and technology are presented in Figure 2.24.

In order to estimate the effect of climate change on these costs, we considered an alternative energy demand scenario, in which the climate parameters were assumed to remain similar to their mean values of 1960-1990. The proportion of additional costs attributable to climate change ranges from 7.6% to 10.3% of the total cost of building stock renovation, depending on the region, and averages 9% for the country as a whole. In other words, the additional expenditure for the building sector brought about by climate change by 2050 is estimated at around €20-21 billion.

2.8.6 Conclusions

The aims of the analysis were to explore the technical and cost implications of climate change on the building sector. First, calculations were made to estimate the variation in energy loads of buildings as a result of rising ambient temperatures. The average decrease in heating load was estimated at around 22.4% under Scenario A1B for 2041-2050, 50.1% under Scenario A2 for 2091-2100, 36.4% under Scenario B2 for 2091-2100, and finally 42.0% under Scenario A1B for 2091-2100. The increase in cooling load relative to today's levels

Figure 2.24 **Intervention costs per type of building and technology**



was estimated at 83% under Scenario A1B for 2041-2050, around 248% under Scenario A2 for 2091-2100, 148% under Scenario B2 for 2091-2100 and, finally, 167% under Scenario A1B for 2091-2100.

In addition to estimating the heating and cooling loads, the likely energy consumption of buildings was also calculated from the perspective of different technological scenarios for 2050.

The best-case scenario: Use of state-of-the-art energy production technology in all buildings by 2050 and substantial improvement in total building stock to ‘passive construction standards’ would, in spite of climate change, reduce the total annual energy consumption of today’s building stock (90,000 GWh) to 5,000-10,000 GWh.

The optimistic scenario: Use of high-performance energy production systems in all buildings by 2050 and the upgrading to ‘passive construction standards’ of the building stock constructed prior to 1980 would reduce total annual energy demand to roughly 22,000-25,000 GWh.

The realistic scenario: Use of high-performance energy production systems in about 70% of buildings (with the rest remaining conventional), and upgrading to ‘modern construction standards’ of 60% of the building stock constructed prior to 1980 would reduce total annual energy demand to 50,000-55,000 GWh.

The worst-case scenario: Installation of high-performance energy production systems in only 10% of buildings by 2050 (with the rest remaining conventional) and upgrading to ‘modern construction standards’ of only 20% of the building stock constructed prior to 1980 would cause total annual energy demand to exceed 120,000-130,000 GWh.

In addition, it was estimated that in non-air conditioned buildings the increase in cooling degree-days under Scenario A1B for 1990 and for 2050 ranges from 54% up to 1,000%. The increase in cooling degree-days between Scenario A1B for 1990 and Scenario A2 for 2100 ranges from 152% up to 4,200%. The increase in cooling degree-days between Scenario A1B for 1990 and Scenario B2 for 2100 ranges from 100% up to 2,100%. Finally, the increase in cooling degree-days between Scenario A1B for 1990 and Scenario A1B for 2100 ranges from 115% up to 2,400%.

The increase in maximum indoor temperature between Scenario A1B for 1990 and Scenario A1B for 2050 ranges from 2.0ºC to 2.9ºC, while under Scenario A2 for 2100 it ranges from 4.5ºC to 7.5ºC. The increase in maximum indoor temperature between Scenario A1B for 1990 and Scenario B2 for 2100 ranges from 3.4ºC to 4.8ºC, and under Scenario A1B for 2100 from 3.5ºC to 5.3ºC.

In parallel with the change in cooling degree-days and in maximum and minimum indoor temperatures, we also calculated the percentage increase in number of summer hours during which indoor temperatures rise above 26ºC, 28ºC, 30ºC and 32ºC. Under Scenario A1B for the current period, the percentages for the months from June to September are always zero. In contrast, they increase drastically under both Scenario B2 for 2100 (ranging from 0% to 65%) and Scenario A1B for 2100 (ranging from 0% to 68%), while under Scenario A2 for 2100, the percentage increases range from 40% to 98%.

The results of the simulations of useful cooling and heating energy demand in buildings were used to estimate the additional cost that climate change would entail for adapting buildings to the new climatic conditions. The proportion of additional costs attributable to climate change ranges from 7.6% to 10.3% of the total cost of building stock renovation, depending on the region, and averages 9% for the country as a whole. In other words, the additional expenditure for the building sector brought about by climate change by 2050 is estimated at around €20-21 billion.

2.8.7 Proposals and adaptation policies for the building sector

Climate change drastically raises the building sector’s energy consumption, particularly during summer, while also producing adverse effects on the indoor environment and indoor thermal comfort levels.

Addressing these problems calls for the planning and implementation of adaptation policies along the following two axes:

- actions to improve the thermal characteristics mainly of the urban environment; and
- actions to reduce buildings’ heating, cooling and other energy requirements.

Improving the urban environment calls for integrated action to alter the thermal balance of a given area, including landscaping and site redesign, improved air flow, increased use of cool materials, green areas, shading, ponds and fountains, etc. Such technologies are well-developed and have been shown to greatly improve urban thermal regimes.

Reducing the energy consumption of buildings or even minimising it to nearly zero can be achieved through a combined use of energy-saving technologies and renewable energy sources. Energy-saving technologies are now well-developed and have become far less costly and can reduce the energy consumption of a conventional building by as much as 90%. Meanwhile, renewable energy sources, mainly solar and geothermal, can be used to meet a large share of buildings' energy requirements. Care must be taken, however, to ensure that these combined technologies do not excessively increase the initial costs of buildings or unduly complicate the built environment.

The above adaptation techniques, apart from their beneficial impact in climatic terms, will also generate considerable economic activity, thereby contributing to the local and national economies and creating thousands of jobs.

2.9 Risks and impacts of climate change on the transport sector*

2.9.1 Introduction

Within the context of analyses regarding the transport sector, the research team —consisting of members of the *Hellenic Institute of Transport (HIT) of the Center for Research and Technology Hellas (CERTH)*— analysed the parameters of climate change in relation to the operation of the country's transport system and recorded the attributes of the phenomenon, so as to subsequently estimate and (where feasible) quantify the likely impacts.

This sectoral study analysed the 'direct' impacts on transport, and not 'indirect' ones (i.e. those that affect the sector via impacts on other systems, e.g. the economy, tourism, etc.).[36] We also analysed the 'physical' impacts on the transport sector, i.e. measurable impacts that affect physical infrastructure or installations and the system's operation.

The direct physical impacts of climate change on transport can be broken down into three main categories:

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* Sub-chapter 2.9 was co-authored by: George Giannopoulos, Eliza Gagatsi, Evangelos Mitsakis and Josep Salanova.

[36] Indirect impacts also include the impacts stemming from interaction between the system's different components, such as the problematic operation or even stoppage of operation in one part of the transport network or transport sector from problems caused to another sector of the network. For instance, if part of the country's railway network is not operational due to landslides caused by heavy rainfall, this will inevitably increase the traffic on the road network serving the same connections or destinations.

1. impacts on transport infrastructure involving:
    i. reconstruction and repair of damage from natural disasters; and
    ii. proactive/preventive works to protect existing transport infrastructure;
2. impacts on transport infrastructure maintenance; and
3. impacts due to alteration to the system's operation and reliability due e.g. to delays and other changes (e.g. rerouting).

The main objective of this sectoral study was to identify the particularities and 'vulnerability' of the Greek transport system to climate change impacts, and to valuate the cost to be incurred by the transport sector as a result of these impacts under specific scenarios and parameters developed for the purposes of the overall study. In addition to valuating the cost of climate change for the country's transport system, the study takes a step further with a set of proposed management policies aimed at preventing and addressing climate change impacts.

2.9.2 Methodology and main phases of the study

Due to the complexity of the transport sector, the lack of specialised national and international literature, and the often insufficient and/or absence of specific data and measurements at national or local level, the research team developed a methodology adapted to these particularities and to Greek reality.

The adopted methodology was then applied to three distinct scenarios, based on the general scenarios of the overall study. In more detail, calculations were made under:

- *Scenario A2:* the no adaptation/no mitigation scenario (also known as the 'trend scenario' or 'business as usual');
- *Scenario A1B:* the mild adaptation/mild mitigation scenario; and
- *Scenario B1*: the strong adaptation/strong mitigation scenario.

The methodology adopted comprised the following separate phases:

Phase 1: Mapping of the key Greek transport infrastructure network and 'vulnerability' classification/assessment of operation components (infrastructure and services). The transport network's individual components were examined for four different geographic zones, established for the purposes of the present study:

- Zone I: Western Greece;
- Zone II: Central Greece;
- Zone III: Eastern Greece; and
- Zone IV: Island regions.

Phase 2: Estimating transport demand. This phase included estimating the current levels of transport demand, and forecasting future demand levels over specific time horizons.

Phase 3: Valuating the cost of climate change impacts on Greece's transport sector. For each of the three climate change scenarios developed within the general framework of the overall study, valuations were made of the cost of climate change impacts on transport infrastructure and on the provided transport services.

Phase 4: General conclusions. General conclusions and 'messages' from the analysis and application of the above methodology were drawn as to the manners in which climate change is expected to affect the Greek transport system.

Phase 5: Proposed policy guidelines. The sectoral study is concluded with the formulation of a set of proposed policies which, according to the HIT research team, should be pursued as of now and over the next 20 years or so, in order to prevent climate change and mitigate its impacts on the country's transport network as part of a broader 'Mitigation Scenario'.

2.9.3 Main results by study phase

What follows is a presentation of the main results of each of the above-mentioned study phases.

2.9.3.1 Main results of Phase 1: Mapping of the Greek transport infrastructure network and 'vulnerability' assessment

The mapping of the transport network and the vulnerability of its individual attributes to specific climate change parameters was assessed for each of the four zones into which the country was divided (see Figure 2.25).

The analysis showed that, with respect to its national transport infrastructure system, Greece can be characterised as one of Europe's most 'vulnerable' regions, mainly because it has one of the longest coastlines, with 113 m of coast for every km^2 in area (compared with a global average of only 4.5 m/km^2). Thus, several (mainly) urban regions and transport networks are located within the distance of influence from this coastline. It should be noted that 33% of the Greek population lives in coastal cities, towns or villages situated within 2 km of the sea,[37] while 12 of the country's 13 former Administrative Regions are coastal. Moreover, the Greece's largest urban centres with the highest number of movements/trips, such as Piraeus, Thessaloniki, Patras, Heraklion, Volos and Kavala, are situated in coastal zones.

Based on the above, in combination with the data from the climate change scenarios examined in the study (which project SLR to be roughly 40 cm to 50 cm), it is clear that a significant part of the country's transport infrastructure network lies at the frontline of risk from climate change impacts.

Summary data on the transport network's vulnerability are presented for each zone examined in Table 2.45. The aim of the analysis was to identify what share of the road and

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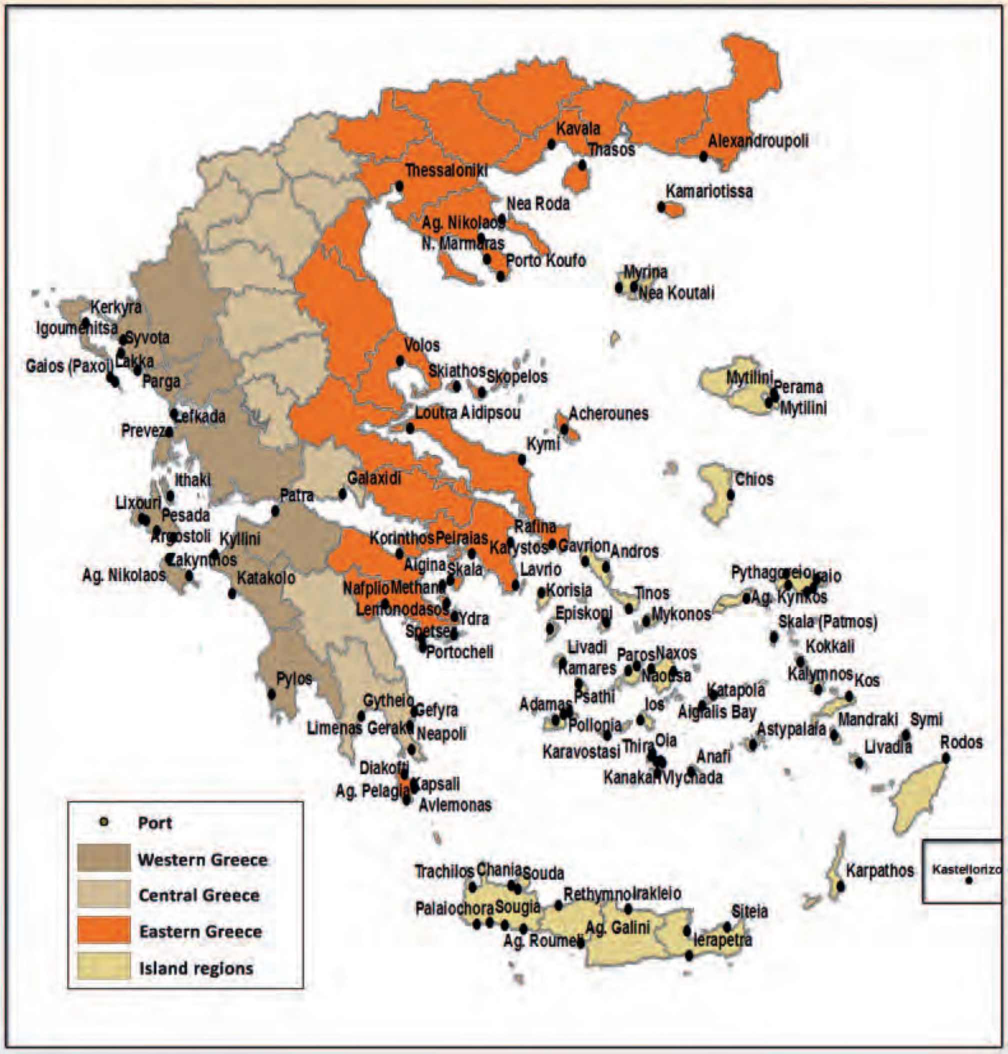
[37] Source: Europa, Maritime Affairs (http://ec.europa.eu/maritimeaffairs), European Commission, DG Fisheries and Maritime Affairs.

Figure 2.25 The four reference zones



railway networks and the number of airports that lie within a ‘high-risk’ zone, within 50 m of the coastline.

In addition, as emphasised earlier, the operation of most of the country’s ports is directly at risk from SLR, with direct implications for the operation of the national sea transport system, the existence and smooth operation of which are essential to the continuity and cohesion of the country’s transport network.

The sectoral study drew on the experience from previous cases of climate change effects in Greece (the 2007 Peloponnese wildfires, the January 2010 sea level rise in the Eastern Aegean,

Table 2.45 **Quantitative data on transport network vulnerability, per zone**

Zone I: Western Greece	Percentage of road network within 50 m of the sea	National: 1.41	Provincial: 1.93
	Percentage of railway network within 50 m of the sea	2.65	
	Number of airports at sea level	1 (State airport of Corfu "I. Kapodistrias")	
Zone II: Central Greece	Percentage of road network within 50 m of the sea	National: –	Provincial: 0.76
	Percentage of railway network within 50 m of the sea	0	
	Number of airports at sea level	0	
Zone III: Eastern Greece	Percentage of road network within 50 m of the sea	National: 1.53	Provincial: 1.92
	Percentage of railway network within 50 m of the sea	0.61	
	Number of airports at sea level	2 (Thessalonki international airport "Macedonia", Skiathos airport)	
Zone IV: Island regions	Percentage of road network within 50 m of the sea	6.64	
	Percentage of railway network within 50 m of the sea	0	
	Number of airports at sea level	1 (Heraklion international airport)	

Source: Calculations of the research team based on the digitalised road and transport network of Greece in the TRANSTOOLS model.

the 2009 floods in the Magnesia prefecture) to qualitatively describe the likely impacts of climate change on the Greek transport system, once again pointing out its 'vulnerability'.

2.9.3.2 Main results of Phase 2: Estimating transport demand

The next phase of the adopted methodology consisted in estimating the demand on Greece's existing transport network and overall transport infrastructure. The transport demand on the national road, railway, maritime and air transport networks (passengers and freight) was estimated up to 2050 using HIT data collected in the context of the *Transport Observatory* service it provides through its portal (www.hitportal.gr), and up to 2100 based on average annual rates of increase derived from existing studies and projects after a review of the international literature.

Tables 2.46 and 2.47 present the summary estimates of demand for passenger and freight transport, respectively, as derived from the HIT analysis for specific time horizons and based on the estimated rates of increase taken from existing studies, as mentioned above.

The figures point to a clear upward trend in demand for passenger and freight transport in Greece. The future levels of demand were estimated as part of the economic valuation of climate change impacts on the transport system over different time horizons, as presented in the next phase of the study.

Table 2.46 **Estimated demand for passenger transport, per mode of transport**

	Road transport[1] (billion vehicle-km/year)			Railway transport[2] (billion pkm/year)	Air transport (million pkm/year)[3]	Sea transport (million pkm/year)[4]
	National network	Provincial network	Total in pkm/year			
Reference year	12.9	8.7	38	1.9	38.7	86
2015	14.6	9.9	42	2.0	43.9	98
2030	16.0	10.5	46	2.3	53.0	107
2050	17.3	11.2	50	2.7	63.6	115
2100	20.0	12.9	58	3.3	85.2	132

Sources: 1 H.I.T., Transport Observatory, 2007 data.
2 European Transport Report 2007/2008, 2007 data.
3 Civil Aviation Authority, 2006 data.
4 European Commission, GD Maritime Affairs and Fisheries, 2005 data.

Table 2.47 **Estimated demand for freight transport**

	Road transport[1] (billion tkm/year)	Railway transport[2] (billion tkm/year)	Air transport (thousand tonnes/year)[3]	Sea transport (million tonnes/year)[4]
Reference year	25.6	0.7	130	151
2015	29.5	0.8	151.3	189
2030	37.0	1.0	190.0	240
2050	46.5	1.4	239.5	302
2100	67.5	2.0	335.0	350

Sources: 1 European Transport Report 2007/2008, 2007 data.
2 European Transport Report 2007/2008, 2007 data.
3 Civil Aviation Authority, 2006 data.
4 European Commission, GD Maritime Affairs and Fisheries, 2005 data.

2.9.3.3 Main results of Phase 3: Valuating the cost of climate change impacts on Greece's transport sector

Based on the data calculated in the previous phases (regarding transport network components, estimated network vulnerability, and existing and estimated transport demand) and on the detailed methodologies for estimating the specific aspects of climate change impacts likely to be felt in Greece (i.e. mean temperature rise, increased heat wave frequency, SLR anticipated for the wider Mediterranean basin, higher frequency and intensity of flooding incidents, and reduced snowfall), the third phase of the methodology consisted in calculating the additional costs likely to be incurred as a result of repair of infrastructure damage/deterioration, prevention, increased maintenance, and finally, the estimated delays to be expected from the average annual temperature rise under the three scenarios considered.

Table 2.48

Estimated maintenance and reconstruction costs for the Greek transport system due to different types of climate change impact (In euro)

Type of impact	Transport	Scenarios					
		2050 No adaptation	2050 Mild adaptation	2050 Strong adaptation	2100 No adaptation	2100 Mild adaptation	2100 Strong adaptation
Temperature rise	Road	150 million/year	100 million/year	50 million/year	300 million/year	200 million/year	100 million/year
	Rail	37 million/year	30 million/year	20 million/year	75 million/year	55 million/year	40 million/year
Sea-level rise	Road	3 billion one-off	3 billion one-off	3 billion one-off	-	-	-
	Rail	0.3 billion one-off	0.3 billion one-off	0.3 billion one-off	-	-	-
	Sea	0.6 billion one-off	0.6 billion one-off	0.6 billion one-off	-	-	-
Flooding	Road	200 million/year	120 million/year	60 million/year	300 million/year	200 million/year	85 million/year
	Rail	-	-	-	-	-	-
Benefits from decreased snowfall	Road	-40 million/year	-25 million/year	-15 million/year	-80 million/year	-50 million/year	-30 million/year
	Rail	-0.1 million/year	-0.07 million/year	-0.05 million/year	-0.2 million/year	-0.15 million/year	-0.1 million/year
Total		346 million/year & 4 billion one-off	225 million/year & 4 billion one-off	115 million/year & 4 billion one-off	594.8 million/year	405 million/year	195 million/year

Table 2.49

Estimated cost of delays in the transport system due to climate change (extreme weather events, overheating of transport infrastructure, etc.)

Scenarios	Road transport (EUR billions/year)	Railway transport (EUR billions/year)	Year total (EUR billions)
2050, No adaptation	9.9	0.010	9.91
2050, Mild adaptation	4.3	0.004	4.304
2050, Strong adaptation	1.4	0.001	1.401
2100, No adaptation	28	0.031	28.031
2100, Mild adaptation	9.3	0.011	9.311
2100, Strong adaptation	4.2	0.004	4.204

As can be seen from the estimated economic impacts presented in Tables 2.48 and 2.49,[38] the highest costs are expected to come from delays/cancellations (i.e. the cost of passenger

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[38] The detailed data and calculations in each of the cases examined can be found (in Greek) in the full text version of the transport study, posted on the webpage of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr).

value of time – VOT) in all types of transport as a result of the different aspects of climate change, without overlooking the costs associated with the redevelopment and redesign of transport infrastructure and increased maintenance needs.

In addition to the quantitative estimates presented in Tables 2.48 and 2.49, the research team proceeded to a qualitative description of the major impacts anticipated, placing an emphasis on those that were either difficult or unfeasible to calculate and/or estimate in the context of the present study.[39]

2.9.4 Proposed management policies and measures

Further to estimating the climate change impacts, the sectoral study has also formulated a set of proposed policies and specific policy measures for coping with the impacts on the transport system as a whole and on the respective networks per mode of transport. In summary, the proposals include:

1. Cooperation between the competent authorities with a view to ranking and evaluating the country's transport infrastructure components in terms of importance, vulnerability and current state.
2. Development of monitoring systems for crucial infrastructure and use of 'smart' decision-making, risk management and disaster management systems, etc.
3. Recording of detailed data concerning the operation of the country's transport system in cases of extreme weather events; development of impact evaluation indicators.
4. Revision of the design specifications of current transport infrastructure, taking climate change parameters into account (e.g. port infrastructure design based on new weather patterns and respective data on wave size and frequency, etc.).
5. Use of new materials, more resilient to extreme weather conditions.
6. Strategic planning of land use and transport infrastructure, taking into account the forms of climate change impact in Greece's vulnerable regions.
7. Policy measures aimed at reducing transport demand, e.g. teleworking, car pooling, mobility management, school transport, etc.
8. Promotion and support of ecodriving.
9. Use of 'smart' technologies and systems with a view to improving freight transport and maximising capacity use of all means of transport (target: zero empty routes).
10. Strengthening intermodal freight transport and reducing the share of road transport in favour of sea and railway transport.
11. Promotion of the use of energy efficient (hybrid/electric) vehicles through incentive measures and the construction of necessary infrastructure (e.g. electric vehicle charging stations).

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[39] Table M-16 in the full text of the transport study; more details in footnote 38.

Finally, the study also included a number of policy measures that could be gradually explored and applied over a longer time horizon.[40]

2.10 Climate change and health*

2.10.1 Introduction

It is well known that climate and weather conditions are among the major factors that affect human health. This means that globally observed climate change alters parameters that in turn have an effect on the health and welfare of human populations. This is a well-established fact, often overlooked, as people tend to think that their state of health mainly depends on their own behaviour (e.g. diet, exercise, lifestyle), heredity and access/use of health services.

Recent climatic changes are believed to have already determined certain epidemiological facts on a global scale. According to the 2002 annual report of the World Health Organisation (WHO), climate change is responsible for roughly 2.4% of the world's cases of diarrhoea, as well as for 6% of the malaria cases in certain developing countries in 2000 (WHO, 2002). One problem related to the assessment of such results is that health is affected by a score of factors, thus making it difficult to measure and isolate the effect of climate change from the other factors. Despite this difficulty, and given that climate change affects several aspects of human health, the impacts of anthropogenic climate change on health have become a major issue not only for the theory of medical and environmental sciences, but above all from a practical standpoint, underlining the need for appropriate socioeconomic policy.

As pointed out in the WHO report, climate change has a profound impact on the health of European citizens. As stressed, a temperature rise of 1ºC is expected to result in a 1% to 4% increase in mortality. This means that the mortality attributable to higher temperatures could increase by 30,000 deaths per year by the 2030s, and by 50,000 to 110,000 deaths per year by the 2080s.

2.10.2 Health impacts of climate change

Climate change affects the human organism both directly and indirectly. Direct exposure is associated with changing weather conditions, such as temperature, rainfall, SLR, and increased frequency of extreme weather events. Indirect exposure stems from the lower quality of drinking water and meteorological conditions, as well as changes in ecosystems, agriculture, industry, settlements and the economy. Thus, climate change is globally associated with

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[40] Table M-17 in the full text of the transport study; more details in footnote 38.

* Sub-chapter 2.10 was co-authored by: John Yfantopoulos, Andreas Papandreou, Tassos Patokos, Panagiotis Nastos, Pavlos Kalabokas, Mihalis Vrekoussis, John Kapsomenakis, Demosthenes Panagiotakos, Christos Zerefos and Vilelmini Psarrianou.

existing diseases, but can also cause premature death due to increase frequency of extreme weather events.

According to the WHO, climate change impacts on health can be grouped into the following three categories (WHO, 2003):

a) Direct impacts, usually caused by extreme weather events (e.g. death due to heat waves).

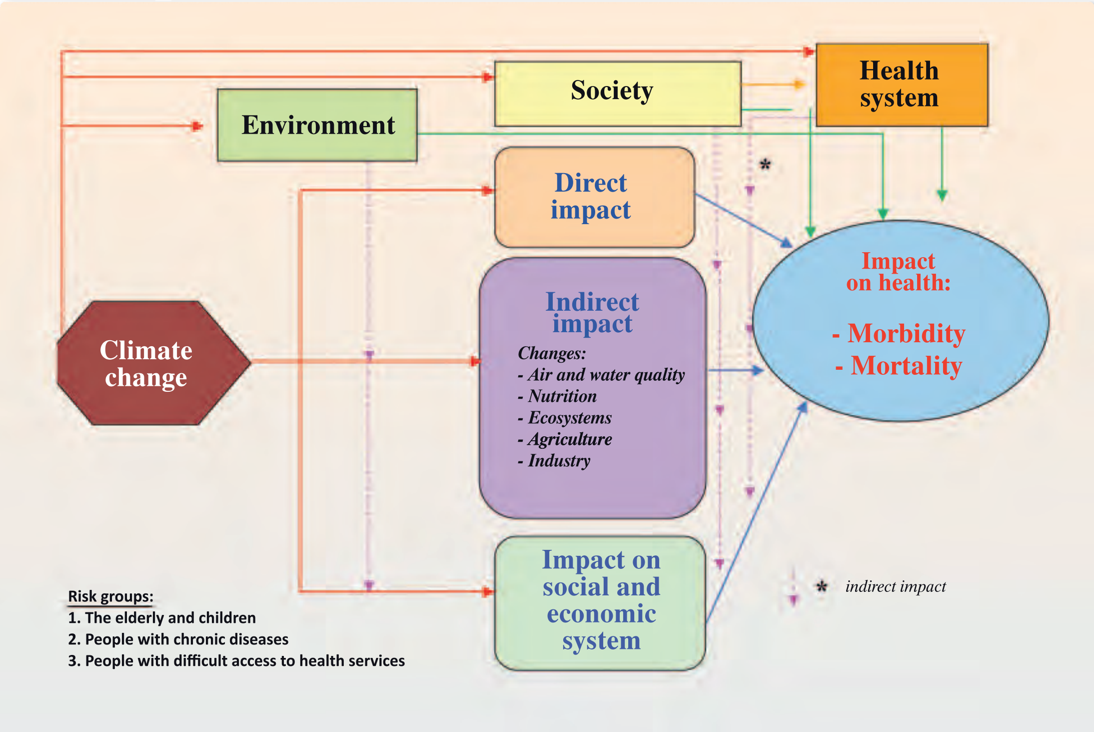
b) Indirect impacts, as a result of environmental changes and ecological disruptions due to climate change (e.g. higher risk of vector-borne or rodent-borne infectious diseases).

c) Other impacts on populations confronted with environmental degradation and economic problems as a result of climate change (e.g. nutritional or even psychological problems).

The link between climate change and health is schematically represented in Figure 2.26.

According to WHO forecasts, climate change and global warming are expected to have significant impacts on human health. These impacts will stem from more frequent occurrences of storms, floods, dry spells and fires, with effects on water and food availability and on overall healthcare system management. The rise in temperature will contribute to higher morbidity and mortality associated with nutrition, water and air quality. The increased frequency of heat waves is expected to lead to higher mortality due to heat stroke and heat stress.

Figure 2.26 **Climate change and health**



The core conclusion of studies on the impacts of climate change on human health on a global scale is that climate change can lead inter alia (WHO, 2003) to:

a) increased mortality due to the temperature rise and, conversely, decreased mortality in colder countries for the same reason;
b) greater frequency of infectious disease epidemics due to floods and extreme weather events;
c) substantial impacts on human health due to the relocation of populations in response to rising sea levels and the increased frequency of extreme weather events.

The US health authorities have identified 11 broad human health categories likely to be affected by climate change (CDC, 2009):

i) asthma, respiratory allergies and airway diseases;
ii) cancer;
iii) cardiovascular disease and stroke;
iv) food-borne diseases and nutrition;
v) heat-related morbidity and mortality;
vi) human developmental effects;
vii) mental health and stress-related disorders;
viii) neurological diseases and disorders;
ix) vector-borne and zoonotic diseases;
x) waterborne diseases; and
xi) weather-related morbidity and mortality (due to extreme weather events).

The populations particularly at risk from these climate change-related diseases are:

- the elderly;
- children;
- people with pre-existing chronic medical conditions;
- poor people with poor nutrition or suffering from malnutrition, living in low-income areas and with difficult access to healthcare services;
- the populations of islands and mountainous regions at risk of water and food shortages; and
- undocumented immigrants, at the fringe of society, faced with labour market, social and healthcare exclusion.

2.10.3 *Climate change and health in Europe*

The heat wave of 2003 and its devastating impact in several Western Europe countries served to highlight the possible impacts of climate change on health. Twelve countries with advanced healthcare systems reported a total of more than 60,000 deaths from that particularly lethal heat wave. The epidemiological data found the elderly to have been most at risk, as ageing impairs the body’s ability to regulate temperature.

A source of valuable information for investigating the impact of climate change on various sectors —including health— is the PESETA project (Projection of Economic Impacts of Climate Change in Sectors of the European Union based on Bottom-Up Analysis, Watkiss et al., 2009). The methodology of the PESETA project is applied to two periods, from 2011 to 2040 and from 2071 to 2100, under IPCC climate scenarios A2 and B2. The project combines models with daily climate data and empirically established links between climate and health conditions in order to estimate the number of additional deaths (excess deaths) attributable to temperature change in Europe.

For analytical purposes, the geographical area of Europe was divided into square grids of 2,500 km^2 each, and the daily data were aggregated so as to obtain annual percentage changes in mortality for each grid. The obtained annual numbers of deaths were examined in parallel with the socioeconomic parameters per grid, as well as with data on each region's demographics and mortality rate. Comparing the annual figures obtained from running the climate change scenarios with the numbers resulting from the forecasting taking only the socioeconomic factors into account enabled an isolation of the climate change impact and the calculation of the number of cases attributable exclusively to climate change.

The findings of the PESETA project show inter alia (Watkiss et al., 2009) that:

a) By 2020, under Scenario A2, there will be a small increase in average heat-related numbers of deaths in Europe, estimated at 25,000 extra deaths per year. The number will increase significantly by 2080, reaching around 105,000 extra heat-related deaths per year.

b) Acclimatisation —i.e. the ability of the population to adapt to new climate conditions— both in practical terms (e.g. through increased recourse to air-conditioning) and in psychological/awareness terms – could considerably reduce these figures. Assuming a fixed rate of acclimatisation of 1ºC per three decades (i.e. that the population has by then engaged in actions and behaviour capable of incorporating a 1ºC higher temperature), the number of deaths caused by climate change could be reduced to 4,000 per year for the period 2011-2040, and to 20,000 per year for the period 2071-2100.

c) The number of cold-related deaths across Europe will decline slightly. Despite the great variation in the analysis, it is estimated that 50,000 to 100,000 cold-related deaths per year will be avoided due to warmer winter temperatures in 2011-2040, and 86,000 to 184,000 such deaths per year will be avoided in 2071-2100. This, in conjunction with point (a) above, means that the avoided cold-related deaths will most likely outnumber the additional heat-related deaths. However, this finding depends heavily on population acclimatisation and on the model parameters, which also involve a degree of uncertainty. Moreover, rising temperatures may make populations more sensitive to cold weather conditions. Controlling for this factor in the models entails a large decrease in the number of cold-related deaths avoided thanks to climate change.

d) The foregoing findings concern all the EU Member States in general, although (predictably) higher numbers of extra heat-related deaths are expected in the Mediterranean countries and lower ones in the north (e.g. Scandinavia). The countries of Central and Eastern Europe will see the highest increase of climate change-related deaths. For the period 2071-2100, the largest potential mortality increases from climate change were projected to occur in Italy, Bulgaria, Estonia, Greece and Spain, and the smallest potential increases in Norway, Ireland, the UK and Sweden.

e) As regards avoided cold-related deaths, the largest potential mortality benefits from climate change are expected to occur in Baltic and Scandinavian countries, while the smallest benefits are found in Ireland, Luxembourg, the UK and some Mediterranean countries.

f) A significant difference was found between Scenarios A2 and B2. Under Scenario B2, heat-related deaths per year decrease by approximately 50%, which translates into a benefit of 49,000 to 56,000 fewer deaths per year in the period 2071-2100. However, under Scenario B2 the cold-related deaths avoided thanks to climate change also decrease, by roughly 33% to 45% (which means 28,000 to 83,000 fewer avoided cold-related deaths per year compared with Scenario A2).

g) With respect to salmonella, the average annual number of cases attributable to climate change under Scenario A2 will come to roughly 20,000 in the period 2011-2040 and to roughly 40,000 in the period 2071-2100. Using Scenario B2 for the period 2071-2100, this estimate is roughly 25,000 cases per year. A number of other food-borne diseases could follow similar trends, although it should be noted that actual cases may be significantly fewer given that populations may adapt to the new conditions by adopting improved food storage and preparation practices.

h) The number of psychological stress incidents due to flooding was also estimated. Additional cases per year for the period 2071-2100 could reach as many as 5 million under Scenario A2 and 4 million under Scenario B2, although these numbers could be significantly reduced through proper acclimatisation.

i) As regards vector-borne diseases, the current incidence, in general, of these diseases in Europe is largely governed by factors other than the climate. Mosquito-borne diseases are not currently endemic in Europe; however thousands of cases of malaria occur in travellers who have been infected elsewhere in the world. Similarly, there are a few cases of travellers with Dengue fever or yellow fever. The incidence rate of these diseases increases with rising temperature, and is also affected by rainfall. In any event, the report points out that the likelihood of a reckonable threat from these diseases on account of climate change is very low, particularly as populations are expected to take the necessary healthcare precautions.

j) Rodent-borne and tick-borne diseases are uncommon in Europe. Although no precise data exist to determine the effect of climate change on the incidence of these diseases, they are not deemed a cause for concern. The same holds also for Leishmaniasis, with a few hundred cases recorded each year, mostly in immuno-compromised individuals (e.g. HIV carriers). Plague is not present in Europe and is confined to rare cases in travellers from other countries. Lyme borreliosis and tick-borne encephalitis may pose a threat, as they are already endemic in Europe. Owing to climate change, encephalitis cases are likely to also start occurring at higher altitudes and latitudes. The higher frequency of flooding due to climate change may also increase the risks of such diseases.

2.10.4 Economic impacts

As regards the economic impacts of climate change on health, the PESETA report states, inter alia, the following:

a) For the period 2011-2040, without acclimatisation, the cost of climate change will amount to €30 billion per year (based on a value of a ‘statistical life’ of €1.11 million) or to €13 billion per year (based on a value of a ‘life year’ of €59,000). Assuming that acclimatisation takes place, this cost is drastically reduced to €4.5 billion and €1.9 billion, respectively. The benefit from fewer cold-related deaths comes, respectively, to €55.8 billion and €23.7 billion (without acclimatisation) and to €21.5 billion and €9.2 billion (with acclimatisation). It should be noted that the balance is, in any event, positive, i.e. using economic costs as the sole criterion, climate change is estimated to be beneficial.

b) For the period 2071-2100, under Scenario A2 (without acclimatisation), the cost of climate change will amount to €118 billion per year based on the value of a statistical life, or €50 billion per year based on the value of a life year. Adopting Scenario B2, this cost is estimated at €56 billion and €30 billion, respectively. For this period, the economic benefit of fewer cold-related deaths is estimated at €95.8 billion (Scenario A2, without acclimatisation) based on the statistical life value, and at €40.7 billion (Scenario A2, without acclimatisation) based on the life year value. Under Scenario B2 in the absence of acclimatisation, these figures are estimated at €64.2 billion and €27.3 billion, respectively. It should be noted here that the economic benefits from fewer cold-related deaths are not always outweigh the economic loss from additional heat-related deaths.

A similar cost valuation procedure for flood-related depression estimated the relevant costs at €1 billion to €1.4 billion per year (under Scenario A2) or €0.8 to €1.1 billion per year (under Scenario B2). The PESETA report does not valuate the economic cost of increased vector-borne diseases due to climate change, but proceeds to a qualitative assessment stating that this cost is forecast to be lower than the foregoing one.

In light of all the above, the PESETA report concludes by prioritising a series of issues that need to be further explored, and underlines the need for more epidemiological studies to allow a more valid correlation of temperature with mortality, so that models can provide more reliable (and less uncertain) results. The variables incorporated in the relevant models must also be expanded to include factors related to the acclimatisation actions of populations. As regards research priorities, the report emphasises inter alia that models need to be further detailed, in order to reflect climate change impacts more accurately – e.g. taking account of factors overlooked by current models, such as atmospheric pollution, unpredictable events or diseases.

2.10.5 Natural disasters and mortality in Greece

The number of recorded natural disasters in the period 1900-2010, as well as the number of deaths and the economic impact related thereto, are presented per disaster category for all of Greece in Table 2.50.

Table 2.50 **Impact of natural disasters on population mortality and the Greek economy in 1900-2010**

Natural disasters	Type of event	Number of events	Deaths	Population affected	Cost (USD thousands)
Drought	Drought	1	-	-	1,000,000
	average per event		**-**	**-**	**1,000,000**
Earthquakes (seismic activity)	Earthquakes	29	951	960,398	7,099,300
	average per event		**33**	**33,117**	**244,803**
Temperature extremes	Cold waves	1	5	-	-
	average per event		**5**	**-**	**-**
	Heat waves	5	1,119	176	3,000
	average per event		**224**	**35**	**600**
Floods	Unspecified	8	66	9,730	188,000
	average per event		**8**	**1,216**	**23,500**
	General flood	12	18	6,100	1,043,359
	average per event		**2**	**508**	**86,947**
Storms	Unspecified	6	56	612	690,000
	average per event		**9**	**102**	**115,000**
	Local storm	1	22	-	-
	average per event		**22**	**-**	**-**
Volcano	Volcano eruption	1	48	-	-
	average per event		**48**	**-**	**-**
Wildfire	Forest fire	11	94	8,559	1,750,000
	average per event		**9**	**778**	**159,091**
	Scrub/grassland fire	2	14	500	675,000
	average per event		**7**	**250**	**337,500**

Source: EM-DAT, The OFDA/CRED International Disaster Database, www.emdat.be, Université catholique de Louvain, Brussels, Belgium.

Of all the presented categories of natural disasters with an impact on human populations, climate change is expected to affect the frequency of low and high temperature extremes, floods, storms and fires. In more detail, the results of future climate model simulations point to a sharp increase in the frequency of heat waves and forest fires and, conversely, to a decrease in the frequency of cold waves by 2100. As for heavy rainfall and flooding events, their frequency in most of the country (including Athens, where more than 50% of the total national population is concentrated) is expected to rise. The implies that the number of deaths due to climate change-related extreme weather events in the course of the 21st century will gradually increase, not only in Athens, but in other large cities as well. The following section attempts to quantify the variation in number of deaths in the Athens area due the variation in temperature extremes, which, as can be seen from Table 2.50, account for most weather extreme-related deaths.

2.10.6 Climate change and mortality in the Athens area

The epidemiological and climatological analyses in the relevant literature identified a 'U-type' relationship between daily temperature and daily mortality. An illustration of this relationship is presented in Figure 2.27, distinguishing between extreme cold-related and extreme heat-related deaths.

Figure 2.27 **Relationship between daily deaths and temperature**

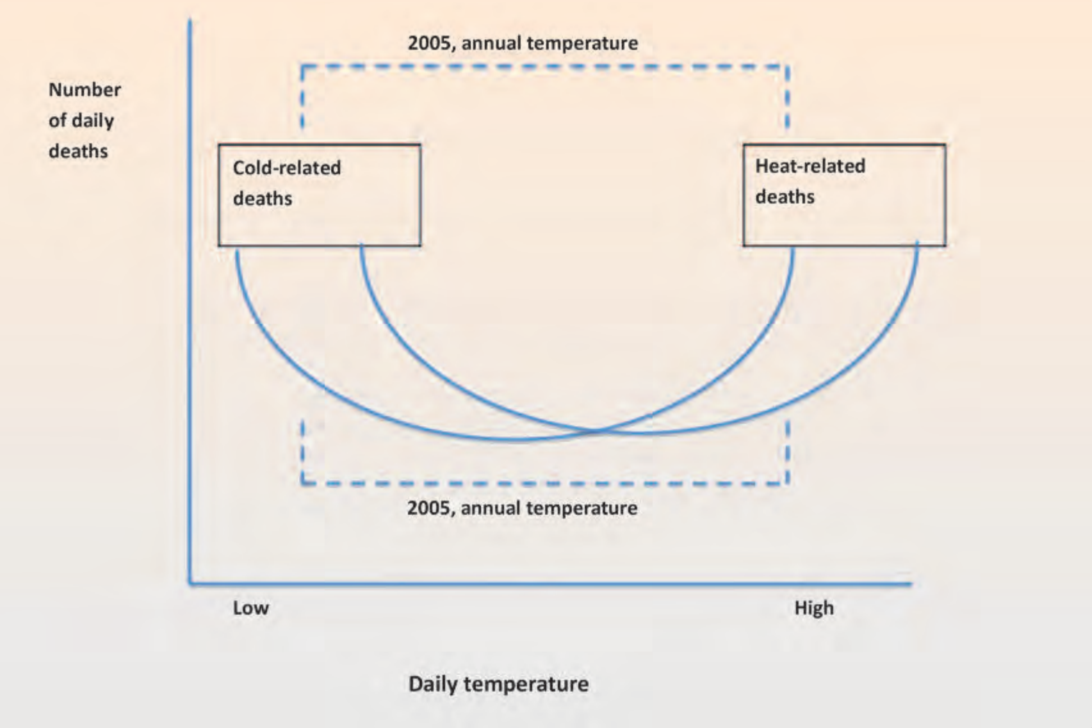
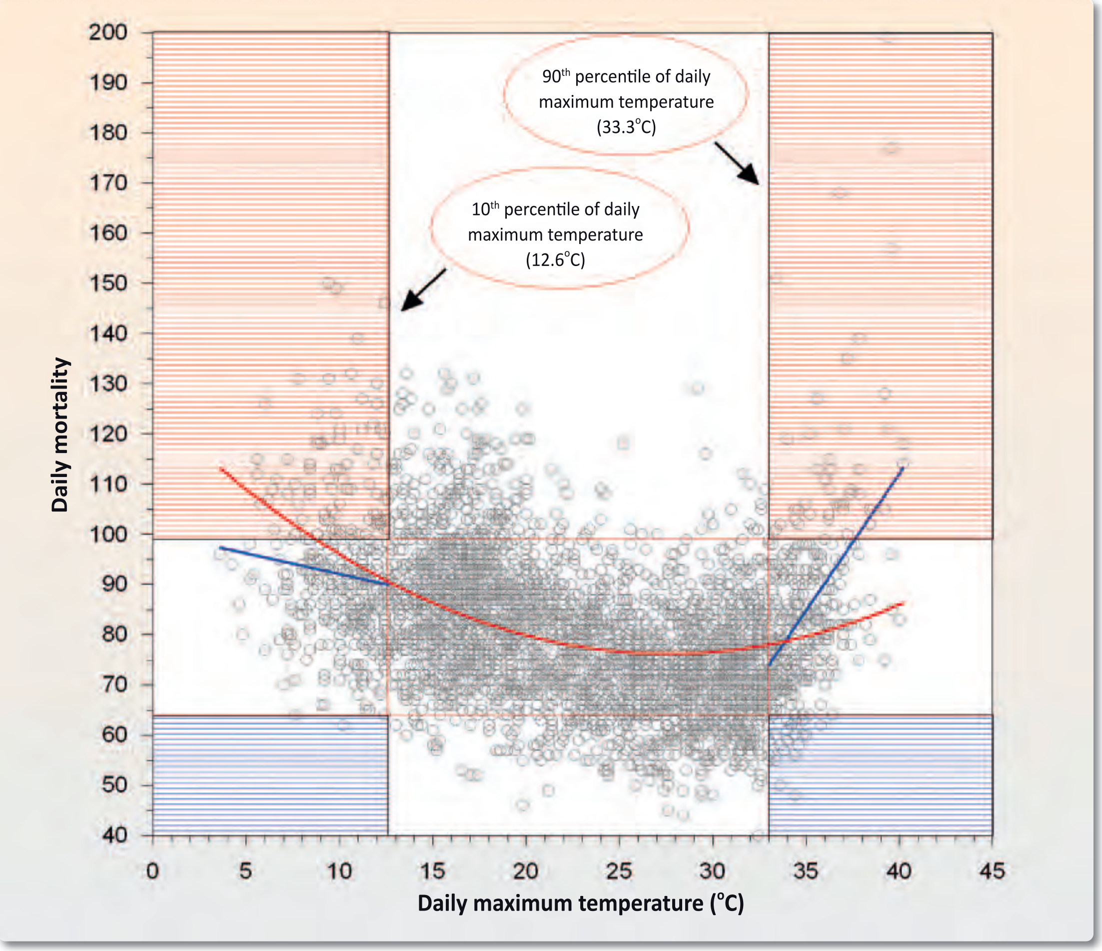


Figure 2.28 Daily number of deaths in the Attica region in relation to daily maximum temperature (Tmax)



In an effort to further explore this relationship for Greece in particular, we present the results of a study (Nastos et al., 2011) correlating daily mortality with maximum daily temperature in Attica (Tmax °C) and confirming the existence of a U-type relationship (Figure 2.28).

According to the research data of Nastos et al. (2011), the number of deaths (N_d) for daily temperature maximum values (Tmax) above 33°C (90th percentile of the distribution) is captured by the following equation:

$$N_d=5.451509164*Tmax-106.0651761 \qquad (R^2=0.24399)$$

A test use of this equation —assuming that the mean maximum summer temperature in Attica will have risen by 2100 by about 4.4°C (Scenario A1B)— led to the provisional estimate that the number of deaths due to global warming in the Attica area may by then have increased by about 25%. Conversely, the rise in winter temperature in future will result in a lower number of deaths from exposure to extreme temperature lows. It should be noted that the decrease in number of cold-related deaths is not expected to exceed 3%. This latter estimate (Nastos et al., 2011) stems from the following equation:

$$N_d = -0.8220675372*Tmax + 100.2719899 \qquad (R^2=0.0114113)$$

which estimates the number of deaths (N_d) for daily temperature maximum values (Tmax) below 12.6°C (10th percentile of distribution), as a result of a 3.5°C higher temperature during the winter period.

Based on the above estimates, the annual additional deaths were as follows:

- In summer, the additional deaths are estimated at 21 per day (25% x 85 deaths≃21).
- In winter, the additional deaths will be 3 fewer per day (3% x 95 deaths≃3).
- In the intermediate seasons (spring and autumn), no substantial change in death numbers is expected.
- Thus, total excess deaths per year will come to 90 x (21-3) = 1,620.

Based on the above calculations, the economic impact for the Attica region will thus be in the order of €95 million per year.

The above calculations were repeated to estimate the variation in death numbers and the associated economic impact under Scenarios A2 and B2. The results of our calculations under all three scenarios are summarised in Table 2.51.

It should also be noted that these estimates do not take into account possible improvements from increased awareness and, more importantly, from prevention action taken by people at high risk (e.g. the elderly, the chronically ill) to avoid exposure to temperature extremes. A case in point is Central Europe where, in the aftermath of the deadly 2003 heat wave, the number of annual additional deaths due to hot temperature extremes has remained noticeably below 2003

Table 2.51 **The economic cost of climate change impact on health under Scenarios A2, A1B and B2**

Emission scenarios	Season	Temperature change (°C)	Change in number of deaths per year	Cost (EUR millions per year)
Scenario A2	Winter	4.2	-340	
	Summer	5.6	2,600	
	Total		**2,260**	**135**
Scenario A1B	Winter	3.5	-270	
	Summer	4.4	1,890	
	Total		**1,620**	**95**
Scenario B2	Winter	3.1	-215	
	Summer	3.8	1,760	
	Total		**1,455**	**85**

levels. This can only be attributed to raised awareness and to prevention/risk avoidance action taken by the vulnerable groups themselves. With successful awareness campaigns and proper preventive measures, the increase in heat-related deaths forecast in this study could possibly be reduced to below 10%.

2.10.7 Changes in air pollutant levels and impacts on mortality in the Athens area

Forecasting the trends in air pollutant concentrations in coming decades is important for the study of climatic changes and their impacts on human health, agricultural production and natural ecosystems. These changes, including rising temperatures and changes in meteorological parameters and different emissions, affect the levels of atmospheric pollutants.

Surface ozone (O_3), also called tropospheric ozone, belongs to the category of atmospheric pollutants that adversely impact human health. Unabated emissions of ozone-producing precursor compounds, such as nitrogen oxides (NO_x) and volatile organic compounds (VOC), in conjunction with the changes mentioned above, are expected to have a multifaceted impact on future ozone levels. It should be noted that high levels of surface ozone have already been recorded in Greece, as well as in the broader Eastern Mediterranean region, including non-urban areas, particularly in summer (Zerefos et al., 2002; Kourtidis et al., 2002; Kouvarakis et al., 2002; Lelieveld et al., 2002; Gerasopoulos et al., 2006; Kalabokas et al., 2007; Kalabokas et al., 2008).

According to the results obtained using the CTM Oslo model and based on the simulations carried out under Scenario A1 (detailed in Chapter 1), ozone levels are expected by 2100 to have fallen by 20% in Greece and by 16.5% in Athens. It should be noted that the CTM Oslo model does not take temperature changes into account.

Gryparis et al. (2004) studied the link between mortality variation and ozone levels for the Athens area and found that an increase in ozone concentration by10 $\mu g/m^3$ was associated with 0.5% higher mortality.

Assuming that (a) the population of Athens will remain broadly unchanged, (b) the total number of deaths occurring in Athens per year (30,000) will remain broadly unchanged, and (c) the percentage (0.5%) stated in the above study is linear, it is estimated that *the change in ozone levels in the Athens area by 16 $\mu g/m^3$ —corresponding to a decrease in concentration from 97.5 $\mu g/m^3$ in 2000 to 81.5 $\mu g/m^3$ by 2100— would result in 0.8% (or 245) fewer deaths per year.*

The roughly 70% decrease in NO_2 levels by 2100 forecast by the CTM Oslo model will have a positive impact (further decline in pollution-related mortality), even if specific figures cannot be advanced due to statistical uncertainties (Analitis et al., 2006; Samoli et al., 2006). Nonetheless, the results of Sections 2.10.6 and 2.10.7 taken together indicate that under Scenario A1B, particularly in Attica, the number of annual additional deaths due to higher temperature extremes in summer and lower temperatures in winter will amount to 1,620 in 2091-2100. The economic impact of temperature extremes under the same scenario (A1B) for Attica is estimated at €95 million per year. Under Scenarios A2 and B2, extreme temperature-related deaths are forecast to increase by 2,260 and 1,455 per year, respectively, while the economic costs are expected to come to €135 million (Scenario A2) and to €85 million (Scenario B2). The projected changes in air pollutants particularly harmful to human health, like ozone, are expected by the end of the 21st century to lead to a fewer number of deaths (around 10% fewer than the expected number of deaths from temperature extremes).

2.10.8 Adaptation policies in the health sector

A problem as global as climate change requires action on an international scale. According to WHO estimates (Neira et al., 2008; WHO, 2008), a significant number of deaths each year are attributed to climate change, including:

i. 800,000 deaths due to urban atmospheric pollution;
ii. 1.7 million deaths due to lack of access to clean water and sanitation;
iii. 3.5 million deaths from malnutrition; and
iv. 60,000 deaths due to extreme weather conditions and disasters.

International strategic action and policies for climate change and health have been undertaken by the European Commission, the WHO and other international organisations. In the WHO Global Conference on Health Promotion in 2008, all 193 Member States unanimously supported the adoption of preventive measures to address the impacts of climate change on health. What follows is a brief presentation of the international and national policy actions taken.

At the international level, a series of measures have been developed with a view to:

1) Developing the scientific documentation on the public health, social and economic implications of health-related climate change impacts. Research networks that study the link between climate change and health have been set up, with co-funding from international organisations and national governments. The results of their research have contributed substantially to the formulation of international action plans to address climate change impacts more effectively.
2) Raising public awareness through prevention programmes and specially-designed actions to address the public health impacts of climate change promptly and effectively. Preventive actions in the health sector generate multiple benefits for society and are assessed as highly cost-effective.
3) Promoting major infrastructure works (dams, etc.), co-financed by international organisations, to help improve health standards and prevent future disasters due to climate change.

At the national level, the governments of Europe have been developing actions to address the impacts of climate change:

1) The national health ministries have launched actions to ensure equal access to health services and social justice for all victims of climate change. This requires investment in relevant infrastructure (e.g. climate-controlled hospital rooms, operating theatres, sanitation) to prevent even partial discrimination in the provision of healthcare.
2) The national health ministries will also need to design special action plans to address the public health problems associated with climate change and/or natural disasters. The ability to treat large numbers of patients in disaster situations calls for special planning and measures, to be undertaken by experts in 'disaster management'.
3) Primary and out-hospital healthcare services must adequately designed, equipped and staffed to be able to cope with the problems caused by climate changes.
4) Hospitals will also need proper infrastructure and equipment to promptly diagnose and efficiently treat patients affected by climate change.
5) Healthcare personnel will need to receive training in environmental epidemiology and the health implications of climate change, as well as courses and training on matters of social mobilisation and sudden disaster management.

Finally, as Dr. Margaret Chan, WHO Director General, once boldly stressed (Chan, 2008) "lack of resources and too little political commitment. These are often the true 'killers'".

2.11 Climate change impacts on the mining industry*

2.11.1 Introduction

Scientific research efforts in recent years have drawn attention to the climatic changes observed worldwide as a result of both natural processes and anthropogenic activity. In some cases, these changes are expected to have dramatic economic and social impacts (IPCC, 2007). Economic activities that are linked to natural resources, due to their direct dependence on the natural environment, will soon be faced with a broad range of challenges and problems (see e.g. Ford et al., 2010; 2011; Sauchyn and Kulshreshtha, 2008).

Mining is among such activities, given that an increased intensity and frequency of climate change-induced extreme weather events – e.g. floods, wildfires, extreme temperature highs or lows – could put the viability of the mining industry at risk. In fact, recent research shows that mining activities are already suffering the effects of climate change, with considerable economic repercussions (Ford et al., 2010; 2011). The response of the global mining industry has so far been disproportionate to the magnitude of the potential impacts, although the influence of climate change on the industry is acknowledged.

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* Sub-chapter 2.11 was co-authored by: Ioannis Oikonomopoulos, Dimitrios Damigos, Michail Stamatakis and Emmanuel Baltatzis.

The present sub-chapter attempts to estimate and valuate the climate change impacts on the Greek mining industry, subject to the assumptions and limitations described.

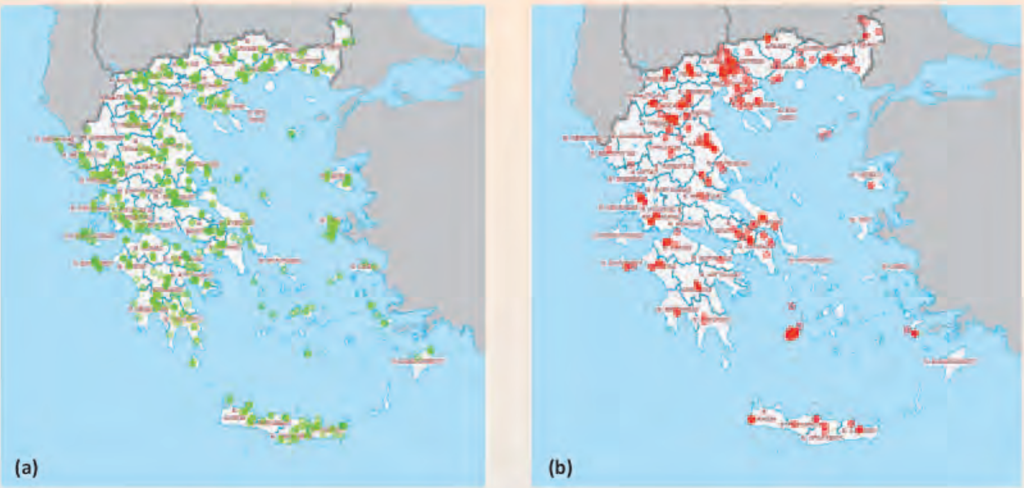
2.11.2 The Greek mining industry

The mining industry with its strong export orientation is of high national importance, as it helps round out the trade balance, contributes to the country's energy security and self-reliance, and generates employment. Being interrelated with several other branches of the economy, it drives the development of several other activities.

The sector's contribution to national GDP has contracted considerably relative to past, levels, and currently stands at 3-5% taking the metal and mineral manufacturing sector into account (Tzeferis, 2009). Nevertheless, Greece has important mineral wealth and, despite the declining figures, still has noteworthy performance levels. More importantly, there are serious prospects of improvement, given that a large number of mineral deposits remain unexploited.

The regions either already active or presenting a potential for mining operation development, as illustrated in Figure 2.29, cover almost the entire Greek territory.

Figure 2.29 **Areas of extraction of (a) aggregates and (b) industrial minerals**



Άγιο Όρος	Mount Athos
Ν. Αιτωλοακαρνανίας	Etoloakarnania P.
Ν. Αργολίδος	Argolis P.
Ν. Αρκαδίας	Arcadia P.
Ν. Άρτας	Arta P.
Ν. Αττικής	Attica P.
Ν. Αχαΐας	Achaea P.
Ν. Βοιωτίας	Boeotia P.
Ν. Γρεβενών	Grevena P.
Ν. Δράμας	Drama P.
Ν. Δωδεκανήσου	Dodecanese P.
Ν. Έβρου	Evros P.
Ν. Εύβοιας	Euboea P.
Ν. Ευρυτανίας	Evritania P.
Ν. Ζακύνθου	Zakynthos P.
Ν. Ηλείας	Ilia P.
Ν. Ημαθίας	Imathia P.
Ν. Ηρακλείου	Heraklion P.
Ν. Θεσπρωτίας	Thesprotia P.
Ν. Θεσσαλονίκης	Thessaloniki P.
Ν. Ιωαννίνων	Ioannina P.
Ν. Καβάλας	Kavala P.
Ν. Καρδίτσας	Karditsa P.
Ν. Καστοριάς	Kastoria P.
Ν. Κέρκυρας	Corfu P.
Ν. Κεφαλληνίας	Cephalonia P.
Ν. Κιλκίς	Kilkis P.
Ν. Κοζάνης	Kozani P.
Ν. Κορινθίας	Corinthia P.
Ν. Κυκλάδων	Cyclades P.
Ν. Λακωνίας	Laconia P.
Ν. Λαρίσης	Larissa P.
Ν. Λασιθίου	Lasithi P.
Ν. Λέσβου	Lesbos P.
Ν. Λευκάδας	Lefkada P.
Ν. Μαγνησίας	Magnesia P.
Ν. Μεσσηνίας	Messenia P.
Ν. Ξάνθης	Xanthi P.
Ν. Πέλλας	Pella P.
Ν. Πιερίας	Pieria P.
Ν. Πρέβεζας	Preveza P.
Ν. Ρεθύμνου	Rethymno P.
Ν. Ροδόπης	Rhodope P.
Ν. Σάμου	Samos P.
Ν. Σερρών	Serres P.
Ν. Τρικάλων	Trikala P.
Ν. Φθιώτιδας	Phthiotis P.
Ν. Φλώρινας	Florina P.
Ν. Φωκίδας	Phocis P.
Ν. Χαλκιδικής	Chalkidiki P.
Ν. Χανίων	Chania P.
Ν. Χίου	Chios P.

Source: www.latomet.gr – access: April 2011.

Table 2.52 **Production of mineral commodities (Thousand tonnes)**

Product	2004	2005	2006	2007	2008	2009
1. Alumina hydrate	786	782	780	789	807.5	796
2. Aluminium	166	165	164.5	168	162.3	129
3. Calcium carbonate-talc-dolomite	181	200	250	350	500	600
4. Limestone aggregates	-	90,000	100,000	90,000	85,000	70,000
5. Feldspars (final products)	79	99	56	38	35.7	27.12
6. Attapulgite	4	7	7	7	25	28
7. Bauxite	2,444	2,495	2,194	2,128	2,174	1,935
8. Gypsum	912	915	900	940	900	580
9. Dead-burned magnesia	46	67	51	42	46.7	22.37
10. Kaolin	44	44	40	40	-	-
11. Caustic magnesia	86	73	69	72	70.5	57.5
12. Pumice	835	852	801	838	828	381
13. Magnesite	413	410	373	340	396.5	326.3
14. Lignite	71,900	69,064	64,100	66,100	65,000	64,000
15. Marbles, extracted products	1,738	1,500	1,790	1,690	1,500*	950*
16. Marbles, blocks	362	398	420	440	430	300*
17. Mixed sulphide ores	-	-	180	214	272	231
18. Mixed sulphide concentrates	-	-	69	144	82	60
19. Bentonite, crude	1,100	1,125	1,166	1,342	1,580	750
20. Activated bentonite	856	880	962	1,113	1,262.8	850
21. Nickel (incl. in alloys)	18	19	18	18.67	16.6	8.3
22. Nickeliferous iron ores	2,485	2,776	2,320	2,367	2,262	1,398
23. Olivine			35	40	40	33.3
24. Perlite, crude	1,067	1,075	1,049	1,100	1,000	700
25. Perlite, screened	630	600	700	650	600	450
26. Pozzolan (Santorin earth)	1,268	1,459	1,525	1,520	1,059	830
27. Refractory masses	24	26	30	31	22.6	31.6
28. Silica	93	113	110	52	52.5	38
29. Quartz – quartz products	16	15	14	15	16.2	14.3
30. Huntite – hydromagnesite	13	9	25.7	15	19.6	10

* Estimate.
Source: Greek Mining Enterprises Association (MEA), 2010.

The total annual output of mining products for the years 2004-2009, based on data collected by the Mining Enterprises Association (MEA) of Greece (MEA, 2010), is presented in Table 2.52.

2.11.3 Climate change and the Greek mining industry

2.11.3.1 Methodological approach

Estimating climate change impacts on the mining industry is a complex task involving a number of uncertainties related to climate change scenarios and the particularities of each mining operation. An additional factor hindering impact estimation and valuation is the absence of relevant research, in both the Greek and the international literature. Relevant studies (e.g. Ford et al., 2010; 2011; Pearce et al., 2011) deal mainly with a qualitative exploration of the problem through questionnaire-based surveys of mining sector businesses and staff.

We developed our methodological approach taking into consideration the availability of crucial data, the mining operations' lifespan and the weight of impact of various climate change components in total financial loss.

As regards the forecast changes in climate parameters, the results under Scenario A1B covering the period 2021-2050 were used given that the lifespan of the vast majority of known mineral deposits, including those still unexploited today (e.g. Greece's gold deposits) will have been exhausted by 2050. Although the results under Scenario A1B were available for 12 geographical regions, we carried out our analysis at an aggregate countrywide level, using a 'top-down' approach. Further reasons for this approach were the wide geographic distribution of Greece's mining operations and the difficulties posed by the present study's time constraints for the collection of data per region and mining operation. For impact estimation and, subsequently, valuation purposes, the results under Scenario A1B in terms of temperature rise, decreased precipitation, etc. were compared with the levels of the baseline period 1991-2000.

With respect to the type of impacts examined, our analysis considered both direct (e.g. increase in extreme weather events) and indirect impacts (e.g. higher cost of electricity) arising from the need to reduce greenhouse gas emissions. It was not possible in all cases to quantify and value the impacts on the industry as a whole, as some impacts depend directly on parameters specific to each mine site.

2.11.3.2 Estimated impacts

For methodological purposes, a distinction was made between the direct and indirect potential impacts of climate change on the mining industry. The direct impacts involve the cost of adaptation to climate change, while indirect impacts concern impact mitigation issues, i.e. measures to reduce greenhouse gas emissions.

2.11.3.2.1 Direct impacts

i. Infrastructure damage

Damage to mining infrastructure in Greece usually comes as the result of extreme weather events, e.g. heavy rainfall, capable of causing flooding or landslides and posing a threat to both infrastructure and personnel. Based on the results for the climate parameter variations under Scenario A1B (see Chapter 1), the chances of landslide occurrence increase as much as two-fold in the larger part of Greece, while the chances of flooding increase, almost everywhere in the country, by as much as 168%.

The exploitation of mineral wealth is closely linked with the presence and harnessing of water flows, and is consequently directly affected by precipitation levels, flood severity and the presence of aquifers. If a ‘normal’ inflow of water into an open-cast or underground mining site is ‘manageable’, i.e. capable of being pumped out, then the problem caused is essentially financial. However, a sudden massive inflow of water, resulting for instance from a flood, may not be manageable with the existing pumping facilities, may cause incalculable damage and may put the very existence of the mining site at risk (Oikonomopoulos, 1971).

Cases such as the ones listed immediately below highlight the vulnerability of mining sites to climatic factors.

- In 1897, a tremendous flood destroyed almost all of the surface lignite-mining facilities in Aliveri (Euboia), while the underground mine was inundated and rendered useless.
- Works to deepen the central shaft (total depth: 200 m) of the major lignite mine of Aliveri were interrupted in 1954 after the inflow of large volumes of water and only resumed several weeks later.
- The mining of chromite in Domokos (Central Greece, Fthiotis prefecture) was abandoned in the mid-1960s due to high mining costs caused by excessive water pumping costs (constant need to pump out large quantities of water from a depth of 200 m).
- A case worth noting was the flood in the mining region of Stratonio (Central Macedonia, Chalkidiki prefecture) on 6-10 February 2010, marked by 164 mm of rainfall within just a few hours (70 mm/h). The duration and intensity of the rainstorm caused the region’s streams to swell to unusually high levels and to displace large quantities of debris. The result was the deflection of the water flow through the settlement’s road network and considerable damage. Fortunately, there were no casualties, but the overall damage restoration costs were quite high.

Apart from the above cases, it is not unusual for floods to disrupt the extraction of quartz sand from river beds, mainly in Central and Northern Greece. Flooding events have a direct and potentially catastrophic effect on mining infrastructure. The ensuing disruption of the mining activity, whether temporary or permanent, entails multiple consequences.

Landslides represent another danger, particularly for open-cast mines, capable of disrupting mining operation schedules, jeopardising the mines’ economic stability, and even endangering workers’ lives. Landslides of different sizes have occurred during the open-cast mining of various mineral deposits in Greece. Indicatively, one could mention the landslides that have occurred at the lignite mining sites in the Ptolemais region (Kozani prefecture) and in the Vevi and Vegora (Amyntaio) regions (Florina prefecture), and well as at bauxite mining sites on Mounts Helicon, Parnassus and Giona, etc.

Despite possible underlying anthropogenic causes, all of these incidents coincided with an extreme weather event. The study of such incidents, in light of climatic changes, can thus help draw very useful conclusions. With catastrophic events having become almost twice as likely to occur, it is normal that mining operations should factor in the risks and modify their operations accordingly. Generally speaking, operating costs are projected to increase due to the need for maintenance of internal haul roads, for protection against erosion, for landslide restoration at mine pit excavations and/or waste heaps, for safer mining and smelting waste management practices, etc.

ii. Forest fires

Forest fires are directly related to fuel moisture content, which in turn is determined by rainfall, relative air humidity and temperature, and wind speed. Based on the overall analysis conducted for the entire study (Chapter 1), in the period 2021-2050 the number of extreme fire danger days is likely to increase by 20 in all of Eastern Greece, from Thrace down to the Peloponnese. Smaller increases are expected in Western Greece, mainly due to the region's wetter climate.

Fires have a negative effect on mining operations due to fact that licenses cannot be obtained for expansion into fire-stricken areas (such areas are automatically earmarked for reforestation). The pozzolanic tuff deposits on the island of Milos (Cyclades) are a typical example, where mining operations cannot be developed due the area's previous devastation by fire.

Due to the lack of detailed data on the number and size of mining units (by category of extraction) operating within or near areas characterised as forest land, it was not possible to quantify the impacts of forest fires on the mining sector.

iii. Decrease in available water resources

The decrease in available quantities of water resources, associated with climate change, results from the disruption of the hydrological cycle. Based on the projections of Scenario A1B for 2021-2050, western continental Greece will experience fewer than 10 additional days of drought, in contrast with eastern continental Greece and northern Crete where the number of additional drought days will increase by 20. The decrease in precipitation and water infiltration will be in the order of 7-8% countrywide in the period 2021-2050 (Stournaras, 2010).

The decrease in surface and groundwater reserves can have multiple impacts on the mining industry, leading in the best of cases to higher mining costs and in some cases to the curtailing or even discontinuation of mining operations.

Based on MEA (2010) data, the total net consumption of water from water networks, groundwater aquifers and surface water reservoirs came to about 17 million m^3 in 2009. In addition, roughly 5 million m^3 were consumed by recycling processes. The average aggregated net consumption of water per tonne of marketable product was estimated at 0.17 m^3, while the consumption of water for environmental restoration amounted to roughly 908,000 m^3.

Assuming for argument's sake that there is such thing as an 'average mining product' (due to the lack of data regarding the weight of water in the output function of each type of mining unit), the decrease in water availability could potentially lead to a proportionate decline in mineral product. Considering that the total output of marketable product amounted to roughly 97 million tonnes in 2009, the loss of marketable product could amount to 7.5 million tonnes. Considering that 0.31 man-hours are needed per tonne of marketable product (according to the MEA 2010 data, the number of man-hours lost on account of decreased production could amount to about 2,325,000, the equivalent of some 1,200 full-time jobs.

iv. Increased particulate matter emissions

The rate of release of particulate matter depends on the attributes of the overburden and the deposit, the mining method, the characteristics of the working area, the rate of operations, and climate conditions. To estimate the suspended dust produced, emission factors, such as the AP-42 coefficients of the US Environmental Protection Agency (USEPA), can be used, according to the following general equation:

$$E_{kpy} = [A * OH] * EF * [(1 - CE)/ 100]$$

where:

E_{kpy} = total pollutant emissions, in kg/year;

A = annual production of the mining unit;

OH = operation hours per year;

EF = pollutant emission factor, in kg/tonne; and

CE = effectiveness of pollutant control measures, as a percentage.

Indicative dust emission factors are presented in Table 2.53.

Table 2.53 **Dust emission factors**

Source	TSP	Units
Overburden excavation	1-3	kg/t
Loading in trucks	0.4-0.7	kg/t
Truck transport	1.5-3	kg/km
Primary crushing	1.5-2.5	kg/t
Screening	2.5-5	kg/t
Stockpiling	1.5-4	kg/t
Wind erosion	0.85	Mg/ha/year

Sources: Ghose (2004) and USEPA (1995).

The climate change models under Scenario A1B (see Chapter 1) forecast a decrease of 1.2% in mean relative humidity countrywide for the period 2021-2050. The decrease is expected to be greater in summer, reaching 12% in western and northern continental Greece, 6-8% in the remaining mainland, and 3-5% in the island regions. Apart from the variation in humidity, precipitation levels will decrease and the number of drought days will increase. These changes will affect the moisture content of mined material, haul road surfaces, etc.

In order to estimate PM10 dust emissions resulting from changes in critical climate conditions, we relied on the data of Table 2.53 and made the following assumptions:

- the mining industry takes no further preventive measures to control additional dust emissions;
- the total annual output of mineral products amounts to 97 million tonnes, and the total annual output of mineral waste to 546 million tonnes (MEA, 2010);
- the total area of mined land is around 15,800 hectares (MEA, 2010);
- the moisture content of the mined material decreases from 15% to 10% and the dust emission factors double; and
- the period of low humidity lasts around 4 months.

Based on the above, annual PM10 emissions are expected to increase by 180,000 tonnes on account of climate change.

It should be noted that these estimates are only approximate, given the uncertainty surrounding emission factors, the different extraction methods used in mining operations, the role of the regional microclimate in dust emissions, etc.

v. Loss of working hours due to extreme conditions

According to the climate change models for the period 2021-2050 (see Chapter 1), the number of days per year with a humidex index >38ºC will increase, with an impact on general population and worker discomfort. The Dodecanese and the coastal areas of the Ionian are expected to experience 20 additional days with humidex values >38ºC, and the low-lying mainland regions and Crete 15 additional days, whereas the mountainous regions will not experience any significant change in this parameter.

Based on the labour safety and health legislation presently in force (e.g. Circular 130427/26.6.90 issued by the Ministry of Labour), employers must ensure worker protection from heat stress and therefore provide for work breaks, depending on the (dry thermometer) temperature and relative humidity. In order to quantify the impacts of these work breaks on the mining industry, the following figures and assumptions were used:

- total man-hours worked per year: 29.9 million (MEA, 2010);
- 250 days worked per year;
- 10 days per year with conditions requiring 25% rest time to avoid heat stress for every 75% of work time;

- 3.24 tonnes of marketable product per hour worked (MEA, 2010); and
- impact on 10% of mining sites operating in (non-mountainous) regions where the humidex rises.

On this basis, the amount of mineral products lost due to the loss of working hours is about 97,000 tonnes per year.

Aside from the lost working hours they entail, warmer temperatures are also likely to accelerate or even cause spontaneous lignite combustion either in the yards of lignite-fired power plants or at lignite mining sites. This would not only result in a potential loss of fuel, but would also release gaseous pollutants (mainly CO and CO_2) into the atmosphere, which, apart from being unpleasant, could be a health concern to the local population. Due to lack of data, however, it was not feasible to quantify the impacts of this specific factor.

vi. Strengthening measures and actions for environmental protection and restoration

Climatic variations are expected to affect the environmental impact of the mining industry in various ways. Indicatively, a higher number of drought days and reduced humidity and precipitation may increase the frequency of irrigation needed at restoration sites; flood occurrences may exacerbate soil erosion; and reduced surface drainage may require further treatment of the liquid waste or water pumped out of underground mines into surface recipients, etc. (Oikonomopoulos, 1991; Menegaki and Damigos, 2009).

Quantifying such impacts (e.g. loss of x-number of tonnes of soil per year) poses considerable difficulty, as it involves extremely localised parameters. In section 2.11.3.3 below, we will nevertheless attempt a cost valuation of such impacts in relation to current expenditure for environmental protection.

2.11.3.2.2 Indirect impacts

The mining industry can be indirectly affected by (a) a broader effort to reduce CO_2 emissions (e.g. restrictions on fossil fuel exploitation for energy or mineral commodity production), and (b) increased production costs, as a result of the internalisation of external costs (CO_2 emission rights) after 2013.

The effect of such impacts is best exemplified by lignite mining operations, where the internalisation of external costs (CO_2 emission rights), the national effort to meet the European “20-20-20” target and other environmental factors are expected to lead to a steady reduction in power production from this specific resource. In line with these developments, the installed capacity of lignite-fired power plants is expected to decrease from 4,826 MW in 2010 to 3,362 MW in 2020 (down by roughly 30%) and to 2,295 MW in 2030 (down by 52.5%). Assuming that power plant availability, performance levels and other parameters affecting power production remain unchanged, lignite-fired power production is expected to be in the order of 22.2 TWh in 2020, and 15.1 TWh in 2030.

According to a recent research study (Tourkolias, 2010), a state-of-the-art lignite-fired power plant requires 1.38 tonnes of lignite to produce 1 MWh of electricity or 1.38 million tonnes per TWh. Thus, decreases of 12.7 TWh and 19.8 TWh, respectively, in power production by 2020 and 2030 would bring about decreases in lignite mining of 17.5 million tonnes and 27.3 million tonnes, respectively.

Turning to the impacts on employment, according to the same study, about 119.5 man-years are needed for each TWh of electricity produced for the fuelling of a state-of-the-art lignite-fired power plant. Decreases of 12.7 TWh and 19.8 TWh, respectively, in electricity production by 2020 and 2030 would therefore bring about decreases in employment in the order of 1,520 and 2,370 man-years.

Finally, the effort to reverse the negative impacts of anthropogenic activity on the greenhouse effect is expected to indirectly increase the operating costs of the mining industry, which, as part of the broader effort to reduce greenhouse gas emissions, will be required to replace outdated equipment and production means and adopt other measures. The international literature mainly mentions the collection of methane released from underground coal mines for subsequent use in energy production. This prospect, though interesting in theory, is of no practical relevance in the case of Greece's mining industry. At a secondary level, efforts are being made to develop lower emission equipment. However, there are no quantitative or economic estimates of their emission reduction levels and cost.

2.11.3.3 Impact valuation

The present section attempts to assess the cost of the anticipated climate change impacts on the mining industry. The fact that certain impacts depend directly on specific regional and mining-site characteristics made it impossible in some cases to provide aggregated estimates at the industry-wide level. We have nevertheless chosen to report a few typical examples as a means of underscoring the magnitude of the problem.

2.11.3.3.1 Direct impacts

i. Infrastructure damage

The cost of damage to mining property and infrastructure as a direct result of extreme weather events, e.g. heavy rainfall, can vary significantly depending on the specifics of each case. The international literature has focused extensively on disasters that have required major damage restoration. Eriksson and Adamek (2000), for instance, studied the impacts of the tailings dam wall failure at the Aznalcóllar mine in Andalucia, Spain. Total damage restoration costs amounted to some €225 million (2010). Similarly, Prommer and Skwarek (2001) estimated the total cost of damage from the failed Aurul tailings impoundment dam in Romania's Baia Mare region at €10-14 million (2010).

ii. Forest fires

As already mentioned, due to lack of data, it was not feasible to perform a valuation of the direct impacts of forest fires on the industry as a whole. Thus, no relevant cost estimates are provided.

iii. Decrease in available water resources

According to recent research (Vagiona and Mylopoulos, 2005), the price elasticity of demand for industrial water was estimated at -0.2 (other studies have produced estimates of -0.3 to -0.4). Thus, an 8% reduction in supplied water would lead to a 40% price increase. Even though the water used in mining processes is mostly taken from water wells or surface water resources, and not water networks, for our calculations we used the rate that the Athens Water Supply and Sewerage Company (EYDAP S.A.) charges its industrial consumers for consumptions exceeding 1,000 m^3 per month, i.e. €0.9866 per m^3. On this basis, the extra cost for industrial water would amount to about €0.4 per m^3, meaning that the mining industry, in order to fully cover its needs, would face additional costs in the order of €6.8 million (the industry's annual consumption of industrial water amounts to roughly 17 million m^3).

Moreover, as mentioned above, water scarcity could lead to around 1,200 lost full-time jobs. A recent research (Tourkolias et al., 2009) estimated the value of a new job (using a public expenditures approach) at €6,400 (or €4,000 to €12,000). Consequently, the annual cost to society of job loss is estimated at around €7.7 million. It should, however, be noted that the mining industry would only incur worker compensation costs.

iv. Increased particulate matter emissions

Assuming that the mining industry has taken all the necessary measures to minimise the impact of particulate matter emissions during the baseline period, the nuisance caused by increased dust emissions in proximity to the mining sites is expected to force the mining companies to take control measures (enclosed crushing plants, sealed conveyor skirts, etc.).

The cost of water-spray suppression on mine haul roads is rather insignificant, given that water-spraying frequency, currently 7-8 times per work shift, will have to be increased to 14 times per shift on dry days. However, the construction of enclosed facilities may entail significant cost for mining companies, considering that depreciation costs represent between 10% and 40% of total operating costs, whereas the construction costs, for instance, of an enclosed crushing plant using sealed conveyor skirts, water spraying systems, etc., to limit dust emissions is roughly 20% to 30% higher.

In order to approximate the cost of addressing the industry's increased emissions, we used MEA (2010) data on business turnover, financial statements of Greek mining companies, and information from personal communications.

The operating profit margin appears to range between 12% and 30%, with an average value of 20%. Operating costs therefore amount to 80%. Given that the industry's total turnover was roughly €1.8 billion in 2009, operating costs are estimated at around €1.44 billion. Assuming that depreciation costs represent 20% of operating costs and that dust prevention measures account for 5% of total investment costs and that the cost of construction of an enclosed crushing plant may be 20-30% higher (25% on average) than the cost of a non-enclosed facility, the additional cost on an annual basis is estimated at around €3.6 million.

v. Loss of working hours due to extreme conditions

According to the estimates, the loss of marketable product may amount to some 97,000 tonnes, i.e. around 0.1% of total production (MEA, 2010). Using an average aggregate estimated value per tonne of marketable product based on total turnover, this cost could amount to roughly €1.8 million per year.

vi. Strengthening measures and actions for environmental protection and restoration

In order to assess the cost implications of environmental protection and restoration, we used MEA (2010) data on expenditure for mine restoration and environmental protection. In 2009, the total expenditure for environmental purposes came to around €9.4 million, which corresponds to €0.1 per tonne of marketable product. Assuming in line with a conservative approach that a 50% increase in such expenditure would be needed to address problems of erosion, irrigation, liquid waste management, etc., the additional cost is estimated at roughly €4.7 million.

2.11.3.3.2 Indirect impacts

Our economic analysis of reduced production was limited to fossil fuels, due to lack of data on the other components of the mining industry. However, we performed an economic valuation of the indirect impacts on the industry as a whole in relation to the increase in electricity costs, based on Input-Output tables for the Greek economy.

According to estimates (Leonardos, unknown), lignite production costs come to roughly €12 per tonne and the ‘selling price’ (cost of fuel for lignite-fired power plants) to €16 per tonne. Thus, decreases in lignite production of 17.5 million tonnes and 27.3 million tonnes, respectively, by 2020 and 2030, would entail a loss of (gross) profits in the order of €70 million and €109.2 million respectively, on an annual basis, relative to the baseline period. Given, however, that nine lignite-fired power plants are scheduled to shut down between 2019 and 2022 (mainly due to problems with sulphur emissions), the economic impact of reducing greenhouse gas emissions is estimated at €39.2 million, which corresponds to the decrease in production between 2020 and 2030.

According to MEA data (2010), the mining industry consumes 20.16 billion MJ each year. It is not clear, however, what share of this energy concerns electricity. Therefore, in order to estimate the economic impact of higher electricity costs (estimated to increase by 25-30%) on the industry as a whole, we used the latest Input-Output table available for the Greek economy (for year 2005) published by Eurostat (2011) and comprising 59 economic sectors.

In more detail, we examined the mining industry expenditure, at base prices, for electricity purchase. As the acquisition of electricity cost the industry €113 million in 2005 and the total mining production was roughly 110 million tonnes, the average cost of electricity was in the order of €1.03 per tonne. Assuming a 30% increase in this cost (i.e. by about €0.3 per tonne) and an average annual production of 90 million tonnes, the additional cost for the entire industry would come to €27 million per year.

The cost of lost jobs due to reduced lignite mining activity is mainly a cost to society and not to the mining industry (which would only incur worker compensation costs). Based on assumptions detailed earlier, the cost of job loss is estimated at €9.8 million for 2020 and €15.2 million for 2030.

The cost to the industry of participating in the greenhouse gas mitigation effort, basically through the use of state-of-the-art equipment, has not been estimated. Although additional costs will certainly be incurred, these costs will tend to decrease with gradual improvement and adoption of new technological solutions.

2.11.3.3.3 Estimation of the total economic costs

The total economic cost of climate change impacts on the Greek mining sector for the year 2010 was calculated based on the present value of the annual additional cost for the period 2021-2050. The calculations were based on the following assumptions:

Direct impacts

i. Infrastructure damage: the present value of an accident costing €15 million. This cost was based on the assumption that one serious accident will occur during the period, as determined from similar incidents.

ii. Forest fires: not valuated.

iii. Decrease in available water resources: annual cost of €6.8 million for the purchase of water at a higher price.

iv. Increased particulate matter emissions: annual cost of €3.6 million for taking additional measures to control dust emissions.

v. Loss of working hours due to extreme conditions: annual cost of €1.8 million due to lower production.

vi. Strengthening environmental measures and actions: annual cost of €4.7 million for additional measures related to environmental protection and restoration.

Indirect impacts

Additional electricity costs: annual cost of €27 million due to higher electricity prices.

It should be noted that the calculations take no account of revenue loss due to reduced lignite production.

Table 2.54 **Estimated present value of economic impact (discount rate=1%) (In euro)**

	2021	2010
Direct impact		
i. Infrastructure damage	-15,000,000	-13,450,000
ii. Forest fires	0	0
iii. Decrease in available water resources	-170,450,000	-152,780,000
iv. Increased particulate matter emmissions	-9,030,000	-8,090,000
v. Loss of working hours due to extreme conditions	-90,240,000	-80,890,000
vi. Strengthening environmental measures and actions	-117,810,000	-105,600,000
Total direct impact	-438,620,000	-393,170,000
Indirect impact		
Higher cost of electricity	-676,780,000	-606,620,000
Total	-1,115,400,000	-999,790,000

Table 2.55 **Estimated present value of economic impact (discount rate=3%) (In euro)**

	2021	2010
Direct impact		
i. Infrastructure damage	-15,000,000	-10,840,000
ii. Forest fires	0	0
iii. Decrease in available water resources	-130,490,000	-94,270,000
iv. Increased particulate matter emmissions	-69,080,000	-49,910,000
v. Loss of working hours due to extreme conditions	-34,540,000	-24,960,000
vi. Strengthening environmental measures and actions	-90,190,000	-65,160,000
Total direct impact	-339,300,000	-245,140,000
Indirect impact		
Higher cost of electricity	-518,090,000	-374,280,000
Total	-857,390,000	-619,420,000

The net present values were calculated using two discount rates (1% and 3%) to test the sensitivity of the outcome to alternative discount rates.

The results are presented in Tables 2.54 and 2.55.

Based on the above, the present value of estimated costs comes to roughly €1 billion at a discount rate of 1%, and to roughly €620 million at a discount rate of 3%.

2.11.4 Adaptation and impact mitigation

The debate on the mining industry’s adaptation to climate change has already been launched at the international level, but the results have so far been meagre. Some mining companies that have already experienced the impacts of climate change have taken short-term measures, without any far-sighted planning (Ford et al., 2010).

With regard to impact mitigation, the efforts of the mining industry have so far been almost exclusively focused on commitments and actions involving the mitigation of greenhouse gas emissions (Williamson et al., 2005; MAC, 2007; Ford et al., 2010). Such actions are often seen as a means for the industry to improve its public image, and help the mining companies implement environmental management systems that also spare them the risk of being exposed for not complying or keeping up with climate change-related legislation.

This emphasis on reducing emissions is detrimental, however, to adaptation efforts. According to Pearce et al. (2009), this stance is, to some extent, attributable to lacking awareness among mining industry practitioners and company representatives of climate change impact issues. It is also attributable to the fact that the industry’s adaptation is a function of many parameters, not all of which are technological (Pearce et al., 2011).

With respect to Greek mining activity, given that the lifespan of the vast majority of known mineral deposits (including those still unexploited today) will have been exhausted by 2050, the assessment of the climate change impacts was based on Scenario A1B which covers the period 2021-2050 (see Section 2.11.3.1).

The cost of the mining industry’s adaptation to climate change, as established based on the anticipated direct impacts (see Sections 2.11.3.3.1 and 2.11.3.3.3), is estimated at between €245 million (at a discount rate of 3%) and €393 million (at a discount rate of 1%).

The mitigation cost arising from the industry’s contribution to greenhouse gas reduction effort (e.g. use of state-of-the-art equipment) was not estimated due to lack of data (see Section 2.11.3.2.2). However, the mitigation cost incurred indirectly by the mining industry from the rise in electricity costs (see Sections 2.11.3.3.2 and 2.11.3.3.3) was estimated at between €374 million (discount rate: 3%) and €607 million (discount rate: 1%).

Based on the above, the total cost of climate change impacts for the entire period 2021-2050, expressed in present value terms (2010), ranges from €0.6 billion (discount rate: 3%) to €1 billion (discount rate: 1%) or 0.2% to 0.4% of GDP, respectively.

Bibliography of Chapter 2, per sub-chapter

2.1 Climatic changes and impacts on Greece's water systems

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Chapter 3

The cost of climate change for Greece

3.1 Some economics of climate change*

3.1.1 Why markets fail to protect the environment

Mainstream economics explain the mismanagement of the environment primarily as the malfunctioning of a market economy when natural resources or environmental services are inadequately protected by property rights. When a firm emits pollutants into a river, it is using river services without having to pay for them. By altering the state of the river, it is damaging others who draw on the river's services for recreation, fishing, water extraction, life support, etc. If the river was protected by property rights, no one would be able to use it without the "owner's" consent. Essentially, all potential users of the river would have to compete for its use and the value of its services would be protected and command a positive price. Without some kind of institutional protection, the river will be overexploited by the polluting firm that treats it like a free (zero-priced) resource. This problem is known as an "externality", because the firm views the damages it causes others as being "external" to its own concerns. Not having to "pay" for the damages, it tends to over-pollute and destroy other important services of the river. For markets to work properly, all resources should be protected by property rights (private or public)[1] and command a positive price.

While many standard goods and resources are handled more or less effectively by the market, many environmental services have attributes that make them difficult for the market to manage.[2] The fact that the atmosphere is treated as a free unpriced resource is what prevents the market from protecting its many valuable services. Furthermore, because of the complex nature of many environmental services, it is much harder to formulate property rights to adequately protect them. Environmental services are often in the nature of public goods, in that improving the quality of the environment affects many people simultaneously, so that individuals will not offer to pay for a cleaner environment if they expect to reap benefits from others who will pay.

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* Sub-chapter 3.1 was authored by Andreas Papandreou.

[1] Property rights are not necessarily private. They can also be state-owned. By imposing a usage tax or fee, a government can give the underlying resources a value or command a positive price for them. The institutional control of the use of state-owned resources is therefore of crucial importance.

[2] For instance, oil extraction and distribution are subject to clearly defined property rights. As oil becomes more scarce, higher prices prevent the exhaustion of reserves or the irrational use of the resource.

In case of market failure with ill-defined property rights for oil, an important part of the solution can be simply to better define and protect rights for the resource. For many environmental services, standard property rights cannot be formed, and even when they can, they may not be a good way of protecting them. The functions and uses of the atmosphere cannot be parcelled out to individuals to sell and consume as they please. The atmosphere does not have self-evident physical limits that could serve to indicate a risk of depletion.

In the presence of these kinds of market failures, environmental economics try to determine what the “proper use” or “care” for the environment is. What substances can we dispose of into our atmosphere and at what levels? Which uses of the atmosphere are acceptable? How do we decide who should or should not be able to use the atmosphere to emit substances? In the context of climate change, the question becomes what level of greenhouse gases or how much climate change to allow. Economists attempt to shed light on this question by trying to determine the damage or cost that will result from emitting greenhouse gases, and comparing this to the cost of reducing emissions. If economists can help identify the right or acceptable level of emissions, the next question is usually to determine the most effective or least costly way of achieving this level.

3.1.2 How the economics of climate change differ

The causes and consequences of climate change are global. Greenhouse gases (GHGs) emitted from any location and any activity contribute to climate change. Though different countries and sectors of the economy may emit different amounts of GHGs, the impact of an incremental tonne of GHG is the same irrespective of its origin. In fact, the impact is global and not restricted to the emitting country. Almost every human activity and sector of the economy contributes directly or indirectly to GHG emissions, making climate change unprecedented in the breadth of activities implicated. Similarly, the impacts of climate change are so extensive that no part of our economies and societies remain untouched.

The way local climates respond to climate change may differ, but they all depend on the global climate system and how it is affected. The fact that climate change is associated with cumulative emissions over time is central to the economic analysis and to the timing of desired emission reductions.

Climate change impacts develop and persist over very long periods of time. GHGs stay in the atmosphere for hundreds of years and the climate system responds slowly to increased concentrations. Lags and inertia also define the way that the environment, economy and society respond to climate change. An understanding of the impacts and policy response need to deal with these complex time profiles. A particularly difficult issue is the way that benefits and damages are spread out over time. Most of the potential damages from climate change will fall on future generations, while the costs of taking action must be borne by the present ones.

The nature and depth of uncertainty involved in climate change and its impacts mean that the handling of risk and uncertainty is a major challenge and a central feature of the analysis of climate economics. It is important to note that, while many aspects of the impacts of climate change are uncertain, there is a near-consensus among scientists that man-made climate change is happening, and also about the range of possible increases in global mean temperature. This does not diminish the great uncertainties about many aspects of climate change and its impacts, like how high the temperature might rise including the possibility of catastrophic climate change, how countries will adapt to a changed climate, the nature and extent of physical and economic damages, etc.

Economic analysis of relatively small or marginal projects, impacts and market failures has a long history and has become quite sophisticated, but for large, non-marginal impacts affecting substantial portions of an economy or region, these methodologies confront serious strains. This extraordinary scope of causes and consequences of climate change, with so many complex interdependencies and dynamics, pushes the limits of any economic analysis. "The analysis must cover a very broad range, including the economics of: growth and development; industry; innovation and technological change; institutions; the international economy; demography and migration; public finance; information and uncertainty; and the economics of risk and equity; and environmental and public economics throughout" (Stern & Treasury, 2007).

All these special features make climate change by far the biggest and most complex institutional failure of all time in dealing with external costs. It also means that despite a growing wealth of economic analysis of climate change, climate economics often remain in unchartered lands, requiring innovative theoretical and empirical work.

3.1.3 Counting costs and benefits

Any economic analysis that attempts to understand how actions and their consequences affect human welfare unavoidably involves ethical judgments regarding, inter alia, such questions as resource allocation across social groups, countries and generations. Given the scale and breadth of impacts of climate change on many dimensions of human welfare, ethics and transparency about ethical assumptions need to be a central part of the analysis.

Most policy-oriented analysis of climate economics relies on a particular ethical framework that underlies standard welfare economics. Usually income and consumption are used as proxies for an individual's satisfaction. Since the consequences of policies often differ across people, time and space, attempts are made to find a common unit of costs and benefits so that they can be added up to give a measure of success. This framework is quite versatile and allows for a number of alternative ethical viewpoints, but still has serious limitations.

For instance, individual preferences are taken as given and no room is made for the possibility of a fundamental change in preferences. If people value cars highly, then an economy that produces more cars is good. The possibility of preferences being fundamentally altered by discourse or self-examination is not envisaged. There are alternative ethical frameworks that put less emphasis on preference satisfaction or give importance to rights and processes. The concerns and implications of other ethical perspectives should be explored even when these lack the analytical and practical tools of welfare economics. There are also fascinating alternative theories of economics and how economies may interact with the environment.[3] Many of these are deeply critical of mainstream economics and welfare economics. Though these theories can provide important insights and can influence mainstream economics, they usually lack the analytical tools to provide more fine-tuned policy support. It is important to keep in mind alternative ethical perspectives and theories of economy-environment interaction and the consequent limitations of welfare economics. The analysis conducted in this report follows mainstream welfare economics, inheriting its strengths and weaknesses.

When deciding on a course of action, it is almost second nature to weigh potential costs and benefits. It is certainly the way we often debate about whether to use nuclear energy, build a stadium or road, or regulate different pollutants. Cost-benefit analysis as a distinct approach begins with a demand that there be explicit valuation or full explication of the reasons for making a decision rather than relying on some implicit argument or conviction. Another basic principle is that costs and benefits are evaluated according to the consequences of actions. Consequences need not only include such things as happiness or satisfaction of preferences that utilitarians tend to focus on, but whether rights have been violated or certain actions performed. Cost-benefit analysis also tries to add up cost and benefits to determine whether the net benefits are positive or negative. This means that a common unit of measurement for all consequences is required, which raises the issue of how different things are given weights to translate them into a common unit (Sen, 2004).

A fundamental question for the economics of climate change has to do with whether the costs of acting to stop climate change are smaller than the benefits of averting climate change, or whether we should take strong action or follow a more gradual approach. The cost of action needs to be compared to the cost of inaction but this comparison is complex.

There is great uncertainty about many issues: technologies that will be available in the future and their cost, the ability of societies and ecosystems to adapt, the extent of climate change damages, climatic conditions, the temperature level, whether there are tipping points or thresholds beyond which catastrophic impacts occur, etc. Value judgments are raised in comparing distributional issues across time and space. Costs of mitigation borne by one generation bring benefits to future generations. Some areas will benefit more from reduced

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[3] "Ecological economics" challenge several assumptions of "environmental economics". Alternative theories include: Institutional Economics, Evolutionary Economics, and Marxist Economics.

emissions and some may pay more for mitigation. Impacts on goods and services that are traded in markets can more easily be compared, but things become difficult when trying to compare these to impacts on goods and services that do not have market prices, like health, quality of life, ecosystems and biodiversity.

3.1.4 The new debate: the case for action

While there is broad consensus among scientists about climate change, there is far less agreement among economists about the economics of climate change and what action needs to be taken. The main area of disagreement among economists concerns the estimation of damages from climate change. The debate is not about whether we should take action, but how drastic and fast it should be. The answer depends mostly on how large we expect damages to be. Most models of the costs of climate change resulting from allowing emissions to increase without taking action (business as usual) have suggested a range between 1% and 2% of global GDP. The Stern review suggested a range of damages between 5% and 20% of global income.[4] It took a fuller account of impacts as well as a greater range of possible outcomes (a greater account of uncertainty) using an unusually low discount rate.[5] The inclusion of direct impacts on the environment and health (often not measured in some models) increased their measure of damages from 5% to 11% of global income. Inclusion of evidence that the temperature increase may be more sensitive to emissions increased the estimated damages to 14%. Finally, giving a higher weight to damages to poor regions pushed their damage estimate up to 20%.

The striking difference between the more traditional economic estimates of damages and the highly publicised results from Stern sparked a heated and continuing debate[6] about the underlying assumptions of models and how they could affect the results so drastically. Clearly, if damages are only expected to be around 1-2% of global income and costs to be less than 1%, it is worth taking action, but the action need not be too aggressive. If damages are likely to be 5-20% and there is a danger that, if we do not act soon, we are more likely to see catastrophic outcomes, then the case for strong and speedy action is overwhelming.[7] As long as economists are divided about the potential damages of climate change and the best course of action, it will be more difficult to achieve the kind of consensus needed for global political action.

The most prominent models all conclude that business as usual would be disastrous and that the benefits of stabilisation are greater than the cost of a warming of 2.5°C.[8] Economists tend

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[4] See Parry (2007), Chapter 2, for a more detailed review and comparison of economic estimates of costs of climate change impacts.

[5] The matter of the discount rate is discussed later in Section 3.1.5.

[6] The Wikipedia article on the Stern Review provides a good overview of this debate (“Stern Review”, Wikipedia).

[7] The need to take action at a much quicker pace is also related to the fact that, if emissions are allowed to rise early on, it will be more difficult to reduce concentration levels of greenhouse gases later on and there is a much greater danger of passing certain thresholds that could accelerate temperature increases.

[8] See Nordhaus (2008).

to agree that the costs of mitigating GHG emissions are below 1% of global GDP, ranging from 0.3% to 0.7% (Sterner and Persson, 2008). There are far fewer studies and estimates of adaptation costs and this remains an important focus of present research efforts. Those advocating mild and gradual action to reduce GHGs find that an optimal target could be well above 3°C, though they acknowledge that the additional cost of attaining a target of, at most, 2°C would be less than 0.5% of GDP.[9] So even though economists may disagree about the urgency and strength of action or how important it is to keep the global mean temperature from rising above 2°C, there is agreement that the additional cost of lowering the target increase of global mean temperature from 3°C to 2°C is not that large.

Keeping global average temperature increases below 2°C requires strong and immediate action to reduce emissions by 50-80% by 2050 compared with 2005. Recently, economists have been focusing on a number of key issues and assumptions that provide a rationale for a strong and more immediate course of action. The way that damages from warming in the future are weighted and compared to costs of taking action in the present is being reconsidered in a way that strengthens the case for action. The implications of the distribution of impacts and costs between the poor and the rich, now and in the future, are also a critical factor determining the decision to act. How economists value non-market impacts on environmental services and health has substantial implications. The built environment has great inertia, which means that, if high-emission fixed capital is put into place today, the costs of reducing emissions in the future will be much greater. Recognition of the great uncertainty of potentially unimaginable catastrophic impacts suggests that an insurance perspective is the best way to approach climate policy.

3.1.5 Weighing costs and benefits across time

How benefits and costs are weighed over time has always generated a lot of debate and controversy among economists. When economists compare monetary values across time, they use a weighting system called "discounting" to translate values in the future to a present-day counterpart. The intuition can most easily be conveyed when considering how we would usually go about comparing two different sums of money we are to receive at different moments in time. If we had to choose between receiving €100 today or €100 in a year, we would choose the immediate amount. If the bank gives an interest on money deposited of 5%, we would only consider an amount above €105 to forego €100 today. Essentially, we would "translate" or "discount" €105 in the future to be equivalent or comparable to €100 today. If the monetary amounts to be compared are even further apart in time, the conversion of future into present values is even starker. The power of discounting can be dramatic, and this is seen especially

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[9] See Swiss Re (2007).

when considering climate change where benefits (avoided climate change costs) and costs (action costs) are unevenly spread over unusually long time spans. Though at first glance this sounds like a simple mathematical technique of monetary conversions, the issue of weighing values or translating monetary units across time raises many deep philosophical and ethical issues often concealed in the technical debate.

What then are the underlying issues in the discount debate? There are a number of reasons why we might give different weights to values at different times. One reason is called the “pure rate of time preferences”. This is meant to capture a tendency that humans have to prefer things near in the future to things farther away. It is a kind of impatience. A principle of “consumer sovereignty” says that if individuals value consumption today more than an equivalent consumption in the future, then this preference should be respected. This would still leave the question of how big this discount rate might be. In the case where costs and benefits are spread across generations, many economists and philosophers argue that it is unfair to weigh the benefits and costs from the vantage point of one generation (that living in the present). The impatience of today’s consumers over consumption in their lifetime should not affect the way we value consumption that will be enjoyed by future generations. It would be similar to placing different values on identical incomes of people who live in different locations. For this reason, many economists argue for a zero or near-zero pure rate of time preference value when considering reasons to discount benefits or costs far in the future.

Another reason we often value incomes of different people differently has to do with distributional ethics. An amount of €100 going to a rich person is often deemed less valuable than €100 going to a poor person. Depending on one’s distributional ethic, one may prefer to give €1 to a poor person over giving €100 to a wealthy person. The rate at which an economist “converts” or discounts €1 going to a rich individual into €1 going to a poor person is called the “elasticity of marginal utility”.[10] If the economy is expected to grow so that people become wealthier over time, this distributional ethic provides a rationale for giving less weight to future consumption relative to present consumption. If we expect people to be twice as rich as us in 100 years, then we may think it unfair for us to sacrifice even 1% of our income to spare a loss of 10% to wealthier future generations.

Because the benefits of climate action accrue primarily to future generations, while the cost of action is borne by the present generation, how we weight these different values is crucial. The weighting depends both on our distributional ethic (how egalitarian we are), as well as on

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[10] More formally, the elasticity of marginal utility tells us how, for a given individual, each additional unit of consumption translates into well-being or preference satisfaction. The standard assumption is that as we consume more, each additional unit does not generate as much satisfaction as the previous one. Since most growth models use a single representative agent to capture the preferences of society, the value of additional consumption falls as the economy grows over time and the representative individual becomes wealthier.

our expectations of how the economy will grow. If we think that the world per capita income will continue to grow at a rate of, say, 2% per annum, then people 100 years from now will be much richer than us and we will be less willing to sacrifice for them.

Taking these three possible reasons[11] to discount future values on their own and giving each a symbol gives rise to a well-known equation that captures the influence of each factor: ρ for the pure rate of time preferences, η for the elasticity of marginal utility of consumption and g for the rate of growth (which is uncertain).

The (total) consumption discount factor $r = \rho + \eta g$. This equation is actually derived from a simple model of optimal growth of an economy. It tells us that the higher the pure rate of time preference, the greater the elasticity of marginal utility (i.e. the more egalitarian we are), and the higher the growth rate of the economy, the lesser weight we will give to income or consumption in the future relative to today. The lesser weight we give to future damages relative to present costs of action, the less ambitious climate policy becomes.

Note that two factors determining the consumption rate of discount depend on ethical judgment. Whether we apply a pure rate of time preference across generations or how strongly we discount income going to wealthier individuals depend on ethics. The other critical factor is what we expect the wealth of future generations to be relative to ours, i.e. how much the economy will grow.[12]

3.1.6 Taking nature into account

The increasing scarcity of ecosystem services and wilderness could substantially increase their importance for future generations. Most economic models do not include environmental stock as a separate good in addition to produced and tradable goods. Even though it is difficult to assess the value of biodiversity and ecosystem services, we know that their value or "price" will increase as they become relatively and absolutely more scarce. In essence, the future damage from climate change would be much greater because a particularly scarce (and thus valuable) service is bearing the brunt. Modifying a well-known model to include environmental stock as a good (Gerlagh and Van der Zwaan, 2002) radically transforms the optimal transmission path of CO_2, completely overturning results that would otherwise warrant a gradualist approach to climate policy. Even with a high discount rate, its tendency to shrink future

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[11] Another factor that tends to reduce the discount rate is uncertainty about future climate changes. Heal (2008) points out that there is a non-zero probability that climate change will be far more severe than currently estimated. Indeed, the possibility of catastrophic consequences cannot be ruled out. Dealing with this uncertainty requires the inclusion of a risk premium. This, in turn, drives down the net discount rate. Gollier and Weitzman (2009) argue that when there is uncertainty about the choice of discount rate, we should discount the distant future at a declining rate that trends toward the lowest possible rate considered.

[12] In many models, e.g. wealth optimising integrated assessment models or dynamic multi-sector general equilibrium models, the pure rate of time preferences and the elasticity of marginal utility are exogenously determined by the model, and the growth of consumption, as well as the consumption discount rate, are part of the solution of the model. In models where economic growth is determined through scenarios, the modeller chooses a consumption rate of discount to find present values.

damages is fully countered by the expanding damages that result from the loss of increasingly scarcer environmental services.[13]

3.1.7 Equity[14] across space

In many models, equity is captured by the elasticity of the marginal utility of consumption represented with the symbol η. The question arises as to whether future generations are expected to be wealthier than present ones and whether poorer generations will be willing to sacrifice less to avoid losses to future generations. Essentially, as long as we expect economies to grow, the more egalitarian we are, the less we will be willing to act against climate change. But climate damages, mitigation and adaptation costs are distributed unevenly not only in time, but in space as well, so that equity issues and assumptions must also be addressed when people in different places are affected in different ways.

The majority of accumulated GHGs have been put there by rich countries, and while developing countries will be changing this historical balance, the poorer regions of the world are the ones that will bear the greatest losses from climate change. From this geographical perspective, the stronger our equity sentiments, the more aggressively we need to act to prevent climate change that disproportionately harms the poor.

The implications of a greater desire for equity on policy action become ambiguous. In a growing economy, the time dimension will demand fewer sacrifices in the present, since people in the future will be wealthier, while the space dimension will require greater sacrifices in the present to prevent damages hitting the poor regions. A problem with most economic models of climate change is that they only reflect values of equity between generations treated as aggregates and take no account of how damages may affect different segments of the population or regions of the world. This is largely because they model the economy on one representative agent so there is no way to incorporate other kinds of distributional impacts. A fuller appraisal of distributional ethics would require a model with many agents to allow for representation of the rich and the poor.[15] It would also require a model with many goods, since the climate impacts on environmental services may be felt more by the poor than by the rich who have a greater capacity to substitute environmental losses with man-made goods. For

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[13] A similar argument has also been made by Weitzman (2007), who considers the implications of treating environmental goods as substitutes or complements to manufactured goods. If there is limited substitutability, the growing scarcity of environmental goods will lead to a rise in their value. This can also be seen from the perspective of multiple discount rates, where the discount rate on environmental stock can actually be negative.

[14] The term "equity" means equal treatment and equal consequences across the board, whether we are speaking of social groups, countries or generations.

[15] Models that maximise welfare for different regions are in principle able to consider equity across space, but they confront a difficult problem. If they follow the standard assumption on equity that gives less weight to future generations because they are wealthier, consistency requires that they recommend huge immediate transfers of wealth from rich to poor regions. In order to overcome this problem, they use a technique known as "Negishi weights" that effectively ends up treating human welfare as being more valuable in wealthier regions. See Stanton (2010) for a good discussion of this issue.

instance, the poor will be less able to avoid the consequences of more intense and frequent heat waves, while the wealthy will rely on air conditioning or travel to cooler regions.

3.1.8 Damage functions, irreversibility and tipping points

Most of the well-known cost-benefit analyses use damage functions that model monetary damages as rising smoothly with increases in temperature. There is no scientific basis for this functional form and mounting evidence suggests that natural systems could respond in non-linear or abrupt ways to climate change. There are numerous examples of reinforcing feedbacks. The thawing of permafrost could lead to the releasing of vast amounts of methane, further accelerating climate change. With the melting of ice and snow, a tipping point could be reached as the Earth's albedo or reflectiveness changes. As fewer of the sun's warming rays are reflected back out into the atmosphere, more energy is absorbed on the Earth's surface, further aggravating the melting and warming. The melting of the Greenland ice sheet could reach a threshold, where summer melt will not refreeze in winter, leading to a cycle of melting and ultimately a sea-level rise of six metres.

The way that monetary damages rise with a warming climate is not just related to natural systems, but also to the behaviour of socioeconomic systems. Housing, commercial buildings and infrastructure are designed and built to be robust to certain variations in weather extremes. If climate change pushes impacts beyond a certain level, the damages to the built environment may dramatically increase. The direct physical damages to an economy's infrastructure will give rise to indirect damages, like supply and business interruptions and negative macroeconomic feedbacks.[16] The presence of natural or socioeconomic thresholds or tipping points with irreversible consequences further strengthens the case for early strong action.

Natural and socioeconomic systems also exhibit inertia or irreversibilities and these are also important factors influencing the appropriate pace of action. Investment in mitigation involves a sunk or irreversible cost and some have argued[17] that this loss should be weighed against the irreversible damages resulting from climate change. When this is combined with a smoothly rising damage function and discounting, it tends to push policy towards greater flexibility and a "wait and see" policy stance as the large mitigation costs cannot be undone, while the damages from climate change are in the future and not too severe.

A problem with this reasoning, beyond the assumption of the shape of the damage function, is that it ignores that non-climate sensitive investment also involves inertia and locks society into long-term commitments to higher emissions.[18] When decisions to invest in standard coal

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[16] The direct losses from hurricane Katrina were assessed at $107 billion, with an additional $42 billion resulting from indirect losses (Pindyck, 2000).

[17] Kolstad (1996), Fisher and Narain (2003) and Shalizi and Lecocq (2009).

[18] See Stanton (2010) for the implications of long-term capital investments on climate policy.

power plants or conventional high energy buildings are made (essentially delaying mitigation), the economy becomes partly committed to higher emissions for the lifetime of the plants or buildings. If it were easy to retrofit a building or plant (or cheaply incorporate carbon capture and storage), then this might not be a problem, but generally retrofitting plants and buildings is far more expensive than designing them to have low emissions from the start.

3.1.9 Uncertainty and economics of extreme climate change

Uncertainty is a central fact in the analysis and understanding of climate change and its economics. Even though the underlying mechanisms driving the Earth's temperature rise are simple and well-understood, there are still fundamental uncertainties about such matters as the extent of the temperature rise, how the temperature rise will affect weather patterns like precipitation and wind, and how the various climate impacts will affect the economy and our welfare.

Economists regularly deal with uncertain outcomes when evaluating policy choices, since most aspects of economic life involve some degree of uncertainty. As long as the likelihood of different outcomes is known, modellers can use this information to evaluate the consequences of different courses of action. The problem with climate change is that the uncertainty is of a more fundamental kind in that we don't have enough prior information to even assign probabilities to possible outcomes.[19]

In a series of recent papers,[20] Weitzman argues that the particular nature of uncertainty regarding the probability of catastrophic climate change undermines attempts to meaningfully calculate benefits and costs and provides a strong rationale for taking immediate strong climate action.[21] When undertaking assessments of climate change, economists usually avoid the problem of uncertainty by focusing on the most likely or central forecasts of temperatures or damages as if they were certain.

One way in which modellers attempt to account for uncertainty is by varying certain parameters and seeing how "sensitive" results are to these changes.[22] In the rarer cases where their models formally incorporate uncertainty, it is usually done by using a probability

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[19] Whereas in most cases of uncertainty we either know the probabilities of possible outcomes or have "known unknowns", with climate change we don't even know the probabilities, so we are in the realm of "unknown unknowns".

[20] Weitzman (2009a, b, c, d; 2010a, b) and Stern and Treasury (2007).

[21] Weitzman questions the capacity of integrated assessment models to provide reasonably accurate estimates of costs and benefits as a guide to policy formation. On a broader or looser interpretation of benefits and costs, his argument can be seen as saying that the damages from low-probability catastrophic climate change could be so large that the benefits of action totally outweigh the costs.

[22] Dietz et al. (2007) used the model PAGE2002, which is one of the best-known models incorporating uncertainty and follows the approach of varying parameters. It runs scenarios many times, each time randomly selecting parameters from ranges of possible values suggested by the scientific literature. The model output is a distribution of possible outcomes rather than a single most likely outcome. The inclusion of this kind of uncertainty increased the expected damages by 7.6% of world GDP relative to the same model without uncertainty (see Pindyck, 2007). Since the different parameters are chosen from normal distributions, this way of including uncertainty does not address the issue of non-zero, low-probability catastrophic events.

density function that associates probabilities with different outcomes.[23] Potential future damages are weighted by how likely they are to occur in order to arrive at an average or expected level of damages.

To calculate expected damages[24], very likely damages are weighted heavily and added to less likely, but more extreme, damages.

Clearly, the shape of the probability density function matters in the calculation of the expected damages. For many natural phenomena, like the height of adult humans, the normal distribution is a good representation of likely outcomes. Most economic models of climate change that have incorporated probability density functions have used the normal distribution.[25] A feature of normal distributions is that extreme outcomes (far from the average or most likely outcomes) are so unlikely that we can effectively ignore them. It is the thinness of the tails (or edges) of the normal distribution that reflects how unlikely extremes are.[26] In the context of climate change, Weitzman argues that scientists have so little prior knowledge of what might happen at high levels of GHG emissions that very extreme outcomes cannot be excluded or assigned a near-zero likelihood. Accordingly, the probability density function should be treated as having "fat tails". The probability of extreme climate change or catastrophic damage, while small, is not zero. Given the nearly unimaginable consequences, or enormity of the damages, even if these are "weighted" by a 1% (non-zero) chance of occurrence, it greatly augments the overall expected damages from climate change.

This argument rests on the nature and extent of scientific uncertainty regarding extreme climate change and damages. Weitzman says that there are so many deep uncertainties in every aspect of our understanding and assessment of climate change and its impacts that, when compounded, they allow for a far from insignificant possibility of catastrophe.[27] In defense of this position, he provides a few "exhibits" of the many areas of deep structural uncertainty.

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[23] Including an arbitrary truncation or cut-off of the tails of the probability distribution function. For reviews of how uncertainty is modelled in the economics of climate change, see Quiggin (2008) and Intergovernmental Panel on Climate Change (2007).

[24] "Expected damages" refer to the notion of "expected value" in probability theory.

[25] Also known as the "Gaussian distribution".

[26] The standard shape of a probability density function is a bell curve, where the peak represents the most likely outcome (high density) and the edges or tails of the bell the less likely outcome (low density). These functions have only one peak. However, many non-linear extreme events correspond to multi-modal probability functions, i.e. probability density functions with more than one peak. In this case, there is no point in calculating the expected value.

[27] "The economics of climate change consist of a very long chain of tenuous inferences fraught with big uncertainties in every link: beginning with unknown base-case GHG emissions; then compounded by big uncertainties about how available policies and policy levers will transfer into actual GHG emissions; compounded by big uncertainties about how GHG low emissions accumulate via the carbon cycle into GHG stock concentrations; compounded by big uncertainties about how and when GHG stock concentrations translate into global average temperature changes; compounded by big uncertainties about how global average temperature changes decompose into regional climate changes; compounded by big uncertainties about how adaptations to, and mitigations of, climate-change damages are translated into utility changes at a regional level via a 'damages function'; compounded by big uncertainties about how future regional utility changes are aggregated into a worldwide utility function and what should be its overall degree of risk aversion; compounded by big uncertainties about what discount rate should be used to convert everything into expected-present-discounted values. The result of this lengthy cascading of big uncertainties is a reduced form of truly enormous uncertainty about the form of an integrated assessment problem whose structure wants badly to be transparently understood and stress tested for catastrophic outcomes" (Weitzman, 2010a, pp. 3-4).

Exhibit A (Unprecedented increases in GHGs): The best data that exist in the science of paleoclimate from ice-core drilling show that carbon dioxide has never been outside a range of between 180 and 300 ppm during the last 800,000 years. We are already at 390 ppm. Humanity has increased GHG far beyond their natural range and at a stupendously rapid rate. The levels that may ultimately be attained have probably not existed for at least tens of millions of years and the rate of increase is likely to be unique on a time scale of hundreds of millions of years.

Exhibit B (Possible temperature response to unprecedented increase in GHGs): Climate sensitivity is a measure of how the Earth will respond to a doubling of GHGs. It is likely to be in the range of 2°C to 4.5°C with a best estimate of 3°C. Though climate sensitivity is not the same as temperature change, other things being equal, a higher climate sensitivity will lead to higher temperatures in the remote future. Weitzman (2009a) states that climate sensitivity "values substantially higher than 4.5°C cannot be excluded". Twenty-two peer-reviewed studies cited by IPCC-AR4 (2007) suggest that there is a roughly 15% chance of climate sensitivity surpassing 4.5°C, a 5% chance of it surpassing 7°C and a 1% chance of it surpassing 10°C. "Once the world has warmed by 4°C, conditions will be so different from anything we can observe today (and still more different from the last ice age) that it is inherently hard to say where the warming will stop."

Exhibit C (Unaccounted for bad-feedbacks): As the globe heats up, a number of bad-feedback components of the carbon cycle could be triggered that have not been accounted for by most general circulation models of climate change. Two examples are "the huge volume of GHGs currently sequestered in the arctic permafrost and other boggy soils" and the "yet more remote possibility of release of the ever-vaster deposits of CH_4 trapped in the form of hydrates". Including these would further augment the likelihood of extreme outcomes.

An additional source of uncertainty (or "fattening of the tail") that comes into the economic analysis of climate change is the way modellers attempt to translate potential temperature changes into damages to human welfare. The damage function used in most economic models assumes that damages increase gradually and continuously as the global mean temperature rises. It does not consider the possibility of abrupt changes (discontinuities) or accelerating damages at higher temperatures.[28] The decision to use this particular form of damage function is totally arbitrary and more a reflection of mathematical convenience than knowledge of the link between temperature increases, physical impacts and human welfare. Very plausible alternative specifications of damage functions can lead to totally different damage assessments from higher temperatures.

Low-probability catastrophic damages in the remote future might be tolerable if climate change was reversible in a short time span, but that is not the case. High stocks of CO_2 will

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[28] See Weitzman (2010b) and Gerst et al. (2010) for a lengthier discussion on the relevance of how the damage function is specified in the economics of catastrophic climate change.

persist for a very long time, making climate change effectively irreversible. Given the deep and multiple sources of uncertainty regarding extreme outcomes, a "wait and see" policy stance in the hope of resolving this uncertainty is not warranted. Weitzman does not just rely on the evidence and intuition of the deep uncertainty about extreme climate change, but develops theoretical arguments along with simple models that present the implications of including fat-tailed probability density functions in a formal analysis, strengthening the case that immediate and strong action is needed.[29]

Weitzman and others[30] are suggesting a different way of framing the decision for taking action on climate change than that of fine-tuned cost-benefit estimation, seeking an optimal trajectory of emissions. When considering the strength and speed of climate action, instead of focusing on the most likely outcome, we should be taking out insurance against low-probability catastrophic climate change. The focus should be on finding the temperature increase that can be tolerated while still eliminating any chance of future catastrophe.

This "precautionary" framework is similar to decisions about insurance against fires and floods or other kinds of calamities.[31] Being risk-averse, we are generally willing to pay to avoid a small probability of a big loss. If we focused only on the most likely events, we would not insure.[32] An insurance perspective that views climate action as a way to avoid a low-probability risk of catastrophic damages could easily justify paying 0.5% of GDP to insure against a 1% chance of disaster. Putting this in context, the world spent 3% of GDP on insurance in 2006.[33]

A question might arise as to how climate change risks compare to extreme risks from other "nightmare scenarios" of environmental disasters, like biotechnology, pandemics, nuclear proliferation or an asteroid hitting the Earth. Ultimately, these need to be compared and assessed in a similar fashion, but there are grounds for believing that climate change is unique among global environmental disaster scenarios.[34]

3.1.10 The case for action is strong

Economists will continue to debate about theory, models and the assumptions regarding the costs and benefits of taking action on climate change. Most models suggest that the additional

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[29] Ackerman et al. (2010) have shown how the incorporation of fat-tailed probability density functions into integrated assessment models (DICE) that "advocated" gradual and mild policy action is enough to make aggressive action optimal.

[30] See Pindyck (2007) for a very accessible presentation of some of the main debates in the economics of climate change and a justification for an insurance perspective in making the case for action. Dasgupta (2008) and Weitzman (2009d) raise questions about the usefulness of cost-benefit analysis in the face of climate change uncertainty.

[31] Similar approaches are used in US policy in countering terrorism, building anti-ballistic missile shields or neutralising hostile dictatorships possibly harbouring weapons of mass destruction. These matters correspond to highly unlikely possibilities, the avoidance of which would nonetheless entail huge benefits though at a considerable cost Weitzman (2009d).

[32] Heal and Kriström (2002) consider what factors determine how much we would be willing to pay to avoid the risk of climate change.

[33] World Bank Group (2009).

[34] See Sunstein (2009) for a discussion on some of these other threats and how they differ to climate change risk. For a broader and non-technical discussion of how the public should make decisions in view of low-probability catastrophic events, see Posner (2005) and Weitzman (2010a).

costs to the world from taking more aggressive climate action are not that substantial. Given the many key assumptions of the ongoing debate, there are more ways to make a case for than against strong action.

A belief that we should not weight future damages less than present ones just because in our lives we prefer the immediate to the remote enhances the case for action. A stronger emphasis on equity may have an ambiguous impact if we expect the world to be wealthier in the future. The more importance we attach to the natural environment and its services, the stronger the case for action. The more account we take of thresholds and inertia in the climate system, the economy and society, the stronger the case for action. The more we take into account uncertainty in modelling, as well as the potential for low-probability catastrophic climate change, the stronger the case for taking strong action now.

Given that fundamental uncertainties are not likely to be resolved soon, there is a good case to be made that, when judging the case for action, the whole exercise of counting costs and benefits may be questionable. An insurance perspective is much more compelling. The main reason why we should take strong action is that it is worth paying a small price to avoid a non-negligible probability of an unimaginable global catastrophe.[35]

Even an insurance perspective still requires some understanding of costs and benefits, though it focuses on the potential costs and degree of likelihood of extreme climate change. Cost-benefit analysis (or economic analysis more generally) still helps us get a grasp of the more likely damages of climate change, its regional distribution, and the expense of taking different actions to limit emissions, or how these costs will be distributed across different sectors of the economy and population, among other things.

As long as we don't overly rely on the specific monetary estimates of costs and benefits to determine whether we should take action or not, but use these numbers and the analysis to inform ourselves of how we may need to adapt to a changing world or what kind of policies will be more effective or less expensive in reducing emissions, there is much to gain from a richer economic appraisal. Much of the debate about the economics of climate change remains pertinent in providing decision and discussion support for a whole range of issues and at every level of decision-making.

Given the global causes and consequences of climate change, analysis has often taken a world perspective. A world perspective will always be central in considering global action or even how action should be distributed across nations and sectors of the economy. The case for action is better addressed from a global perspective and it should underlie our motivation as citizens, local communities and nations of the world. Though the benefits and costs of climate

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[35] This holds even before we take into account many other potential benefits of taking action, like reduced atmospheric pollution, increased energy security, etc.

change may vary across countries, the same issues that make a case for action for the global community also make a case for action by individual countries.

For this reason, a country-level economic analysis of climate change has other main objectives. A country-level analysis requires a far more detailed analysis of how global climate change will affect local weather conditions, local sea level rise and frequency of extreme weather events. This detail provides a basis for understanding how the different regions of a country and sectors of an economy and society will be impacted by climate change through time. It provides the basis for being able to effectively design policies to adapt to climate change, as well as policies to minimise the costs of emission reductions. It will provide critical information for making investment decisions at all levels of decision-making. In short, it will help a country formulate its path to sustainable development.

3.2 Climate-economy modelling*

A wide range of models have been developed over the years to explore climate-economy interactions and to provide a basis for policy formation. Apart from climate models, developed to support the prediction of meteorological phenomena, there are also a number of special technical and economic models that project greenhouse gas emissions, taking into account ways to reduce them (e.g. energy sector modelling and manufacturing process modelling). Researchers often link climate models to energy sector and manufacturing process models to achieve an integrated study of emissions and their climate impact. Macroeconomic, multi-sector and economic growth models have all had to be extended, so as to incorporate mechanisms simulating greenhouse gas emissions, ways to reduce them and damage estimates derived from climate models. Scientists from different disciplines have worked together to develop interfaces between these models[36] so that the interactions between climate, energy, manufacturing processes and the economy could be investigated in greater depth. One of the results of these interlinking efforts was the development of the integrated Economy-Energy-Environment models.[37]

3.2.1 Key features of integrated assessment models

Integrated assessment models (IAMs) of climate change combine models of the climate system, climate impacts and the economic system that enable the evaluation of alternative

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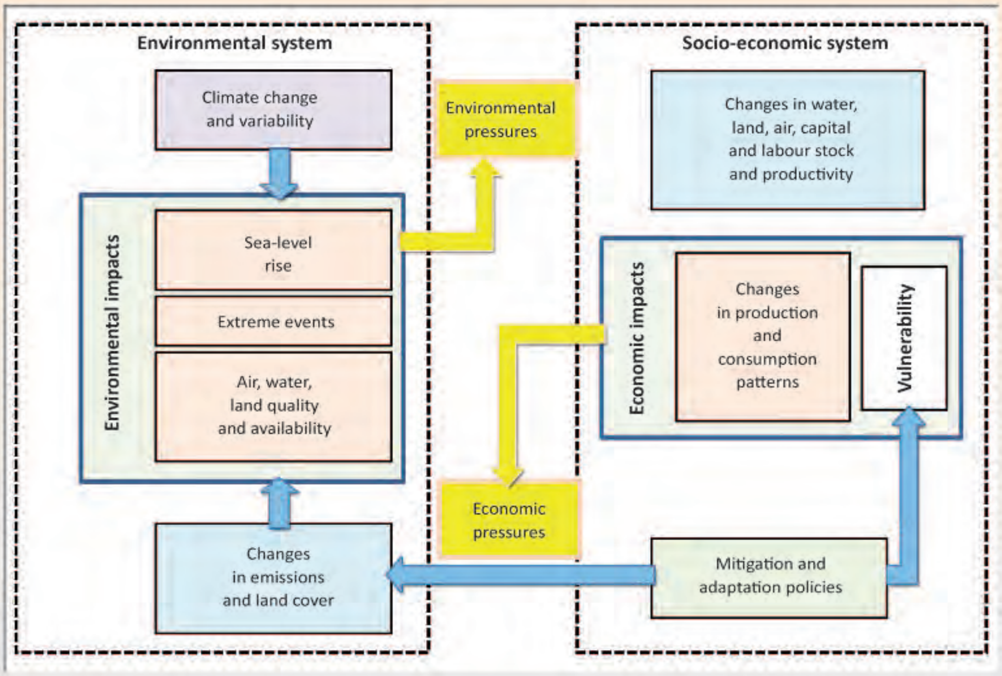
* Sub-chapter 3.2 was co-authored by A. Papandreou and P. Capros.

[36] Weyant (2009) encourages greater communication between researchers (and model developers) across a wide range of disciplines.

[37] Also known as the 3E models. See Capros (1995).

Figure 3.1 **Climate-economy dynamics**



Source: Bosello (2003).

policy responses. An economic assessment of the physical, biological and social aspects of climate change effectively involves translating the latter into monetary terms, which may be viewed as (or further transformed into) a measure of social welfare. The interlinked chain of interactions in these models is the following:

- Human-induced climate change results from an increase in GHG emissions and their levels of concentration in the atmosphere.
- The concentration levels of GHG affect the temperature, precipitation, cloud formation, wind and sea level rise, etc.
- These changes, in turn, result in various physical and biological impacts, such as changes in crop yields, water supply, biodiversity, ecosystems and even migration.
- These impacts can then be translated into monetary terms.
- Finally, impacts are aggregated to give a single measure of the economic cost of climate change.

Such interactions are examined in terms of their time dynamics. The economy is not only affected by climate change, it is also the perpetrator of climate change, as growth in production and consumption gives rise to more GHG emissions. Among the largest contributors to GHG emissions is the energy sector to the extent that it relies on fossil fuel combustion. Other major contributors are: agriculture, stock-breeding and manufacturing. Policies and reforms that reduce gas emissions can lead to lower concentration levels of GHGs in the atmosphere, thus mitigating climate change as well as their impact on the physical, biological, social and production system. Such policies typically entail action costs but, at the same time, allow part of the cost of climate change to be avoided.

While IAMs are often complex systems based on interlinking a number of special models,[38] there are also compact IAMs that integrate several conventional intertemporal optimisation models and simple relationships, which constitute representations of complex special models dealing with various aspects of climate change. These compact IAMs, developed mainly by W. Nordhaus[39] of Yale University and A. Manne[40] of Stanford University, have been used in the United Nations IPCC assessments of climate change.

The dominant modelling approach, as far as the economy module is concerned, is based on the neoclassical theory of general equilibrium, according to which agents (consumers) maximise their utility or satisfaction, firms (producers) maximise their profits and the economy is driven towards equilibrium under full market and full employment conditions. Different models can lead to substantially different results.

3.2.2 Computable General Equilibrium models

Computable General Equilibrium (CGE) models[41] are based on the general equilibrium paradigm of Arrow-Debreu and compute the equilibrium prices of goods, services and factors that simultaneously clear all markets, depending on the decentralised supply and demand decisions taken by agents.

CGE models are usually multi-sectoral and detailed, and it is in this respect that they differ from the compact IAMs mentioned above. They also differ in terms of their dynamic features: CGE models, whether static or dynamic, are imperfect foresight models, while IAMs perform inter-temporal optimisation with perfect foresight.

The main advantage of CGE models is that they can simultaneously model a number of sectors, capturing in detail exchanges between sectors, consumers and producers, as well between countries. CGE models are thus suitable for linking to other detailed models and for carrying out sectoral impact assessments. On the contrary, compact growth models have the disadvantage of representing less detail, but the long-term growth trends they project have a better theoretical foundation.

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[38] See Hope (2005), Füssel and Mastrandrea (2009), Tol and Fankhauser (1998), Weyant et al. (1999), Grubb at al. (2006), Hitz and Smith (2004), and Yohe (1999) for an overview of integrated assessment models.

[39] See Nordhaus (2008) for a presentation of the DICE model.

[40] See Manne et al. (1993) for a presentation of the MERGE model.

[41] See Sue Wing (2010), Kehoe (1998) Sue Wing (2004) and Peng (2007) for simple descriptions of computable general equilibrium models and numerical examples.

Precisely because of their analytical and decentralised structure, CGE models are suitable for incorporating relationships that, to a certain degree of detail, (a) capture the energy sector, (b) link economic activities to emissions of GHGs and other pollutants, and (c) represent emission mitigation options (involving either a sectoral restructuring of the economy, substitutions, or direct emission abatement techniques), the mechanisms through which emissions impact the environment and the climate, the emissions levels of concentration in the atmosphere, and finally the various sectoral impacts of climate change. Moreover, thanks to their decentralised representation of goods and prices, CGE models incorporate environmental services represented as goods, as well as emission monitoring mechanisms through the purchase of tradable emission permits. CGE models, in their extended version,[42] can therefore integrate all the functions of IAMs, whereas the IAMs are more complex, since they interlink different mathematical systems.

3.2.3 Partial equilibrium models and the bottom-up approach

Partial equilibrium models,[43] as their name suggests, differ from general equilibrium models primarily in that they focus on a part (usually a sector) of the economy, without seeking to address the interactions with the rest of the economy. Partial equilibrium models are used either to estimate the impact that climate change has on specific sectors of the economy or conversely to calculate the GHG emission levels caused by specific sectors and to assess the cost and possibilities of reducing these emissions.

Energy sector models are partial equilibrium models that simulate supply and demand for different energy forms, usually in considerable detail and from a techno-economic perspective. Model designing has gone as far as to design detailed models for very specific manufacturing processes that estimate GHG emissions other than CO_2.

A form of partial equilibrium analysis is also used when attempting to monetise the impact of climate change on specific sectors, for instance, when the analysis of the biophysical impacts of climate change on agriculture is used jointly with a statistical and a market equilibrium analysis (see Mendelsohn et al., 1998, Adams et al., 2004, and Tol, 2010).

The above analysis can be applied to multiple sectors of the economy and is referred to as the “enumerative approach”. The first step of this approach is to estimate the “biophysical effects” of climate change. Economic valuation methods are then used to place a monetary value on the biophysical impact. This approach, often referred to as “direct” or “first-order” valuation, can, depending on the case, rely on a variety of methods, from simple expert estimates to sophisticated analytical models. The direct costs are obtained for each sector to assess the total economic cost of climate change.

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[42] One such extended CGE model is the GEM-E3, see Capros et al. (1997).

[43] For the theoretical founding of the partial equilibrium analysis, see Pigou and Aslanbeigui (2001) and Marshall (1997).

This approach is also known as the bottom-up[44] approach, as opposed to the top-down approach of the computable general equilibrium models.

All of the cost estimates presented in Chapter 2 are bottom-up estimates, calculated using an enumerative approach, whereas the cost estimates presented in Sub-Chapter 3.3 (below) are top-down estimates, obtained using a computable general equilibrium model. The cost estimates presented in Chapter 4 were obtained using a partial equilibrium model designed for the energy sector and manufacturing processes.

Theory does not suggest that adding up separate sectoral impacts will lead to the same result as evaluating total climate change impacts using a computable general equilibrium or macroeconomic model that incorporates all market interactions. The reason for this is that the computable general equilibrium model allows all of the indirect impacts on the economy to be estimated, taking into account the interactions between sectors and the rest of the economy.[45]

3.2.4 Using sectoral analysis data as inputs into computable general equilibrium models

Bottom-up estimates of sectoral impacts, as well as partial equilibrium estimates can be used to prepare data for subsequent feeding as inputs (as exogenous variables) into general equilibrium models. This was the method followed in the present report.

Jorgenson et al. (2004) with their Intertemporal General Equilibrium Model (IGEM) and Ciscar et al. (2009) under the European PESETA project, as well as many others, have carried out extensive cost-benefit analyses of climate change, by combining sectoral damage functions with computable general equilibrium models. This type of approach, drawing heavily on more detailed studies per sector, produces more refined and reliable assessments of first-order sectoral costs. It also has the advantage, compared with the enumerative approach, of ensuring consistency with cost-benefit assessment for the whole economy, taking sectoral interactions and indirect costs/benefits into account thanks to the use of the general equilibrium model. The PESETA project, which carried out an in-depth study of the costs of climate change for the European Union, used the GEM-E3 model, as did the research team that prepared the present report. The Garnaut Climate Change Review for Australia[46] (Garnaut 2008) is another important recent example of a detailed climate change assessment combining a bottom-up sectoral approach with a top-down computable general equilibrium model. It is worth noting that the Stern Review (Stern, 2008) also made use and recognised the importance of bottom-up or sectoral analysis of climate change impacts.

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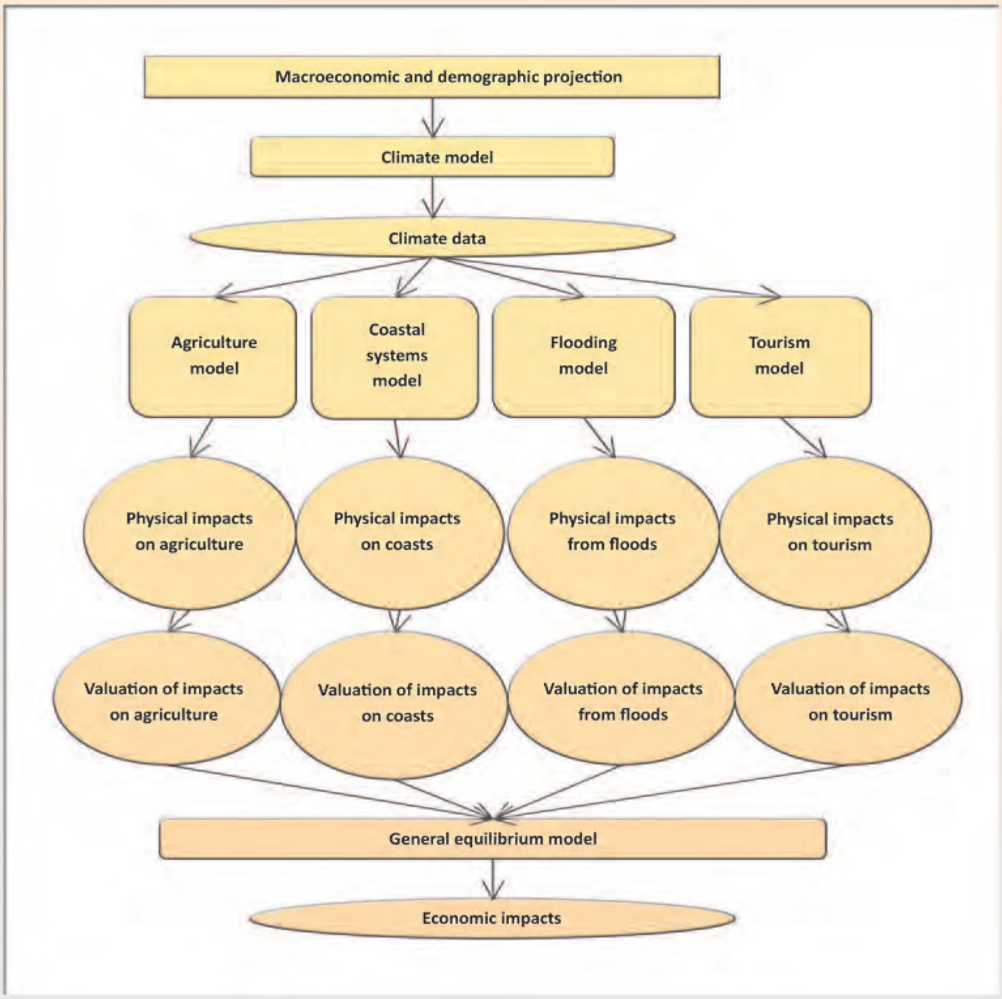
[44] See Fankhauser (1994, 1995), Nordhaus (1994) and Tol (1995, 2002a, 2002b).

[45] For examples, see Tsao et al. (2010) and Barket et al. (2009).

[46] The entire review and all commissioned and supporting material can be found at the official site http://www.garnautreview.org.au/2008-review.html

Figure 3.2 **The PESETA integrated approach**



Source: Ciscar et al. (2009).

3.3 Assessment of the total economic cost of climate change using a general equilibrium model*

3.3.1 Introduction

Chapter 2 assessed the direct economic impacts of climate change on various sectors of the Greek economy. The present sub-chapter examines the overall impact of climate change on the

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* The study for Sub-chapter 3.3 was carried out at the E3MLab laboratory of the NTUA, under the supervision of Prof. Pantelis Capros, by main researchers Marilena Zambara and Dr. Leonidas Paroussos, and by Zoi Vrontisi, Stella Tsani and Maria Papaioannou.

Greek economy, using the GEM-E3 (General Equilibrium Model for Economy, Energy and Environment interactions, Capros et al., 1997). The findings of the sectoral studies presented in Chapter 2 were used as inputs for the macroeconomic analysis presented in this sub-chapter.

Using the general equilibrium model, it is possible to quantitatively assess the overall impacts, both direct and indirect, on the economy. Assuming that climate change will indeed occur, the Greek economy will be affected in its entirety but, more particularly, in certain sectors. By comparing the quantitative assessment of this state against one without climate change, one can deduce the total cost of climate change for the Greek economy. This cost is expressed as a percentage change in Gross Domestic Product (GDP) and in household economic welfare, and is allocated to the different sectors of economic activity.

The general economic equilibrium model is, first, calibrated to replicate the state of the economy in the base year. Then, by introducing changes in the exogenous parameters, the model can compute a new equilibrium state of the economy. The changes to the exogenous parameters can either take place over time (dynamic evolution) or concern only the base year (static change). The conclusions drawn based on general equilibrium models are derived from the comparison of two states of an economy, once they have been quantitatively assessed. A comparison of two dynamic evolutions of the economy is referred to as scenario-based analysis. A comparison of two static states of the economy is referred to as counterfactual analysis. The model simulates the causal link between the introduced changes and their impact on the equilibrium state of the economy.

For the purpose of the present study, the analysis of the economic impacts of climate change was conducted using a comparative static methodology.[47] The reference basis was considered to be the quantitative representation of the economy in the base year, as simulated by the model. The counterfactual assumption was then made that climate change occurs, with direct impacts on different sectors of the economy, as established by the analyses of Chapter 2. A new quantitative representation of the economy was computed by the model, which incorporates those impacts. This new representation, when compared against the representation without climate change, yields differences that enable conclusions to be drawn about the total cost of climate change.

The reasons why the dynamic evolution approach, which involves the comparison of dynamic evolution scenarios, was not chosen are of a practical nature. Such an approach would have required the construction of a dynamic evolution scenario of the Greek economy until 2100, a process that would have been beset by a number of uncertain, but possibly crucial, assumptions for the assessment of climate change costs. The comparative static approach is simpler and has the advantage of being transparent.

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[47] The approach followed in the present study has also been adopted by other studies of the economic impacts of climate change (Ciscar et al., 2010, Fankhauser and Tol, 1996, Halsnaes et al., 2007). Bosello et al. (2007) adopt the alternative, dynamic approach.

Based on the climate scenarios presented in Chapter 1, the climate changes over the time horizon to 2050 are expected to be different from the ones projected for the longer horizon to 2100. The climate changes also depend on the global rate of accumulation of greenhouse gas emissions. Each case of climate change will have different economic impacts, which is why the total cost for the economy needs to be estimated separately for each case.

It is needless to say that the highest total costs are associated with the highest accumulation of GHGs under the Inaction Scenario for reducing global emissions. Even in this case, however, the intensity of climate change is projected to be lower in 2050 than it will be in 2100.

For the valuation of the total costs of climate change with the general equilibrium model, two landmark years —2050 and 2100— were used. Different representations of the economy were obtained depending on whether climate change as at 2050 or at 2100 was factored in, due to the different intensity of climate change in each of these landmark years. It is important to remember that the outcome of the model for 2050 and 2100 should not be taken as representing the state of the economy in 2050 or 2100, but as representing what the state of the economy in the base year would be, if the climate change intensity of 2050 and of 2100, respectively, were to occur in that year.

Similar total cost valuations were also made for the other climate change scenarios, including the Mitigation Scenario, under which drastic GHG emission reduction is achieved worldwide; this mitigation, though not sufficient to prevent all climate change, is nonetheless sufficient to reduce the intensity of climate change.

3.3.2 The general equilibrium model GEM-E3

The GEM-E3[48] (General Equilibrium Model for Energy-Economy-Environment interactions) follows a computable general equilibrium approach, taking into account the individual microeconomic decisions of producers and consumers, the simultaneous equilibrium between supply and demand in all markets for goods, services and production factors, and presuming that the algebraic sum of surpluses or deficits of all economic agents (government, firms, households, banks, external sector) is equal to zero.

Producers are classified according to sectors of economic activity. Each producer is assumed to be representative of all those in his respective sector. Furthermore, in seeking to maximise profits, producers determine the supply of goods and services, as well as the demand for production factors and intermediate goods and services. Households are modelled on one average household, which —motivated by utility maximisation— simultaneously determines the demand for goods and services, the supply of labour, and savings. The behaviour of the government in the areas of public investment, government consumption, taxation and income redistribution (through

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[48] A detailed description of the model can be found on the E3MLab website: http://www.e3mlab.ntua.gr/e3mlab/GEM%20-%20E3%20Manual/Manual%20of%20GEM-E3.pdf

social benefits) is exogenous. The supply and demand for capital are represented in a simplified manner through the balance of payments. The demand for goods and services is met by domestic production and imports, which are not perfect substitutes for each other. Depending on their competitiveness in the international market, part of domestic goods and services are exported. Each economic agent (firms, government, households, external sector) ends up with a cash surplus or deficit, depending on its decisions with regard to consumer spending, investment expenditure and savings. These decisions are interdependent, with the sum of the surpluses or deficits amounting to zero (Walras law). The prices of goods, services and production factors are the result of the interaction between market supply and demand and are determined simultaneously. These prices affect competitiveness in external trade and the decisions of the economic agents. The equilibrium in each market is computed depending on the assumptions made regarding the conditions of competition (perfect, oligopolistic, etc.) governing each one.

For the purposes of the present study, a variation of the GEM-E3 model was used that views the Greek economy as a small, open economy. The activity of the rest of the world economy is regarded as exogenous, but Greece's external trade is considered endogenous, as Greece is seen as not being in a position to influence the international prices of goods and services. As regards the state of competition, it is assumed that all goods and services markets operate under full and perfect competition and that the supply of these goods exhibits constant economies of scale. It is also assumed that the labour market is not characterised by perfect competition, but is in a state of equilibrium, with unemployment determined by an efficient wage mechanism (Shapiro and Stiglitz, 1984).

The model's main data set includes: social accounting matrices, with Input-Output Tables and income distribution tables; household consumption tables; and investment tables by sector and type of good. The nomenclature of production sectors follows a classification of 26 sectors, based on Hellenic Statistical Authority (ELSTAT) data.

3.3.3 Methodology for using the general economic equilibrium model

In order to estimate the cost of climate change using the general equilibrium model, it was first necessary to develop a Baseline Scenario, based on assumptions with regard to demographic trends, global economic developments, labour market participation, government policies (consumption, investment, taxation and income redistribution) and the level of technological progress contained in each production factor for every sector of economic activity. The Baseline Scenario used in the present study is consistent with the GDP and demographic trend projections contained in the "*2009 Ageing Report*" (European Commission, DG ECFIN).[49]

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[49] "The 2009 Ageing Report: Underlying Assumptions and Projection Methodologies for the EU-27 Member States (2007-2060)", in *European Economy* (2008).

Sector	Temperature increase and drought	Sea-level rise	Extreme weather events
1. Agriculture	*		
2. Forests	*		
3. Fisheries	*		
4. Coastal systems		*	
5. Transportation	*	*	*
6. Tourism	*	*	
7. Built environment	*		
8. Water resources	*		

The Baseline Scenario served as a reference only for the Mitigation Scenario, since the dynamic analysis required that the drastic GHG reduction scenario be compared to it (see Chapter 4). The economic assessment of the mitigation costs was based on this dynamic comparison and was expressed as percentage change in GDP. In order to ensure cost assessment comparability across different climate scenarios, the percentage changes in GDP were expressed in terms of base year GDP.

For the other scenarios, a base-year representation was used, as computed with the general equilibrium model, after exogenously changing the parameters to simulate the direct impacts of climate change on different sectors. A dynamic simulation was then performed using the general equilibrium model, to estimate the longer-term impacts.

Direct impact estimates of climate change were mainly drawn from the studies presented in Chapter 2, broken down into sectors and also referred to as “sectors of impact”. The table that follows indicates the sectors of physical impact of climate change, for which costs assessments were made and taken into account in the general equilibrium analysis. It should be noted that sectors with direct impacts on health, biodiversity, ecosystems and the mining/quarrying industry were not included in the analysis.

The direct economic impact of climate change can be a loss of capital or a lower return on capital, variations in productivity (usually lower) in certain sectors of economic activity, variations in expenditure (usually higher) to obtain the same level of services, and changes in labour productivity.

The quantitative assessments from Chapter 2 with regard to the above direct economic impacts were integrated into the GEM-E3 model as changes in the numerical values of the corresponding exogenous parameters. The model was then run to estimate the new state of general (counterfactual) equilibrium corresponding to the economic conditions after the occurrence of climate change. As mentioned above, the analysis was conducted for different levels of climate change intensity, corresponding to landmark years 2050 and 2100 and to different climate change scenarios.

3.3.4 Overview of the climate change scenarios used in the study

The climate scenarios for which total costs were determined in the study are Scenarios B1, B2, A1B and A2 (see Chapter 1).

Each one of the four climate change scenarios incorporates different assumptions with regard to socioeconomic developments, which in turn determine the future level of carbon dioxide emissions and, by extension, the course of the climate change phenomenon.

- Scenario B1: Under this scenario, the carbon dioxide concentrations in the atmosphere increase at a slow rate, given the worldwide shift towards lower carbon-emitting energy sources and towards lower GHG-emitting processes. This is the climate change Mitigation Scenario that comprises a drastic reduction in global emissions. It should be stressed that, under this scenario, climate change is not prevented, but it is mitigated. Therefore, even under this scenario, there is a total economic cost attributable to (albeit limited) climate change.
- Scenario B2: This scenario anticipates moderate economic growth and, by extension, low energy consumption growth. Technological changes are not as intense as in the B1 Scenario; therefore, there is still some increase in GHG concentrations and, consequently, there are economic costs imputable to climate change.
- Scenario A1B: This is the Business-As-Usual (BAU) scenario. Technological advances lead to the use of more efficient energy production technologies, although conventional technologies remain in use. The scenario also projects rapid economic growth and increased consumption. As a result, there is a strong rate of increase in emissions concentrations, and costs definitely arise from climate change. The A1B Scenario can be considered a milder version of the A2 (Inaction) Scenario mentioned immediately below.
- Scenario A2: This is worst-case scenario in terms of emission increases, emission concentration levels, and the overall course of climate change. It anticipates slow technological advances, together with strong population and energy consumption growth. It corresponds to the Inaction Scenario.

3.3.5 Overview of the impacts of climate change on various sectors of the Greek economy

Agriculture is the sector that will suffer the strongest impacts from climate change. Changes in climatic conditions due to the carbon dioxide concentrations in the atmosphere will significantly affect crop growth rates as well as water availability, thereby negatively affecting agricultural productivity. According to the findings of the agriculture study (Sub-chapter 2.4) carried out using the AQUACROP model, crop yield changes will vary, depending on the crop type and the geographic location, from -75% to +26% by 2100.

Also directly dependent upon the climate are the production activities related to forests and water ecosystems. The production of timber will be negatively affected, while predominant drought, combined with higher temperatures, will considerably increase fire frequency.

The impact on the fisheries sector is expected to be negative, but of relatively limited magnitude. As estimated in the sectoral analysis, a 3.3°C rise in sea temperature by 2100 would cause fishing yields to drop by 2.5% (Sub-chapter 2.3).

The coastal systems, where a considerable share of the population and production activities (indicatively, 80% of all industrial activities, 90% of the tourism industry and 35% of agricultural activities; see Sub-chapter 2.2) are concentrated, will suffer from the gradual rise in sea level, as a result of the deterioration to coastal infrastructure and of capital losses. According to the analysis of the coastal systems sector (Sub-chapter 2.2), a 0.5 m rise in sea level would result in land loss (i.e. loss in tourism, residential and agricultural usage land, forests and wetlands) of a total value of €355.76 billion. To this, one would have to add the damage costs to port infrastructure and the cost of gradually relocating the coastal populations.

Tourism will not only suffer from the deterioration of coastal infrastructure, but will be further affected, given that climatic conditions are a decisive factor when people choose a vacation destination. According to the sectoral analysis of tourism (Sub-chapter 2.7), climate change could be of benefit to the sector, as climatic conditions in autumn and winter would improve. Nonetheless, tourist demand in Greece peaks in the summer, when protracted heat waves induced by climate change in the future would make Greece a far less appealing destination. As shown by the study's findings, if the tourism sector does not make the necessary adaptations to attract more tourists in seasons other than the summer, the impact on the demand for tourist services will be negative. For the regions of Crete and the Dodecanese alone, it is estimated that the annual loss of tourism receipts due to climate change would amount to €430 million.

As regards the transport sector, experience to date has shown that extreme weather events cause a lot of damage to networks and infrastructure. Climate change is expected to intensify such damage. The analysis of the transport sector (Sub-chapter 2.9) provides some very telling estimates about the impact of climate change on this sector: by 2100, due to the temperature rise, the cost of maintaining the road and railway networks will have increased by €140-375 million per year, compared to today. The expenditure needed to permanently or temporarily repair the damage caused to networks from flooding would amount to €85-300 million per year. By 2100, the sea level rise will have affected some 3.5% of the road and railway networks. Finally, extreme weather events and fires will cause road traffic delays, which will translate into economic loss due to the late arrival of commuters at work.

The cost imputable to climate change also includes the costs to the built environment (Sub-chapter 2.8). Warmer climate conditions will lead to lower energy demand in winter, but to significantly higher energy demand for air conditioning in the summer. As a result, the demand for oil will drop, but the demand for electricity from the residential and services sector will increase. The temperature rise will have a stronger impact on the microclimate of urban areas (heat island effect). The living conditions in urban areas will deteriorate, causing the value of the built environment in these areas to drop.

This brief overview outlines the climate change impacts taken into account in the study. Cost valuations were carried only for the impacts directly affecting production activities or reducing infrastructure value and translating into capital losses. Not included in the cost valuations was the impact on the natural environment and biodiversity, with the exception of the impact on productivity in the sectors of agriculture, forestry and fisheries. Also not included in the cost valuation was the burden to the health system, as well as the economic implications of increased workforce morbidity, likely to be caused by the temperature rise.

Table 3.1 presents the estimated direct economic impacts of climate change by sector, based on the findings of Chapter 2 and input into the general equilibrium analysis. The last column on the right lists the assumptions made about the adaptation measures and interventions aimed at preventing part of the impacts from climate change. The cost valuation of adaptation is presented later, in Sub-chapter 3.4.

3.3.6 Further processing of the sectoral analysis estimates and linking of these estimates to the parameters of the GEM-E3 model

This section looks at how the economic impact assessments per sector, presented in Table 3.1 were converted into changes in the exogenous parameters of GEM-E3.

As can be seen in Table 3.1, the sectoral analyses did not cover all of the climate scenarios. In order to produce a consistent valuation of sectoral impacts and to examine all the climate scenarios, further estimates were needed to complement the data estimates contained in the above-mentioned table.

More specifically, using data from Chapter 2 and estimates from the international literature,[50] we empirically constructed a function that links the rise in temperature (or in sea level) to the magnitude of economic impacts for each sector.

A non-linear interpolation of constant elasticity was chosen in the form of $y= a \cdot x\theta$, where x is the temperature (or the sea level), y is the level of the corresponding economic impact, and a,θ are empirically assessed numerical parameters. For the coastal systems sector, the rise in sea level was used for x, while for the other sectoral analyses x was the change in temperature.

All estimates given below are in € million, at 2008 prices.

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[50] Whenever needed, further estimates were based on the PESETA study, Ciscar (2009), for Southern Europe.

Table 3.1 Overview of the results of Chapter 2 sectoral analyses taken into account in the analysis based on the general equilibrium model

	Projection periods	Climate scenarios	Physical impacts	Economic impacts	2050				2100					Adaptation			
Water resources	2041-2050, 2091-2100	B2, A1B, A2	Water volume decrease (by up to 19% by2100)	Cost for water supply sector (EUR millions, in 2007 values)	**B1**	**B2**	**A1B**	**A2**	**B1**	**B2**	**A1B**	**A2**		Cost of improving the efficiency of water abstractions: €68.4 million/year, with a benefit of €380 million/year			
					n/a	2,191	2,077	3,070	n/a	4,345	2,795	4,862	/10 years				
	The impacts of water shortage on the water supply sector, including touristic and, in part, industrial uses, are examined. The impacts of reduced availability of irrigation water are taken into account in the examination of agriculture																
Agriculture	2040, 2090	B2, A1B, A2	Overall changes in climate	Percentage change of crop productivity	**B1**	**B2**	**A1B**	**A2**	**B1**	**B2**	**A1B**	**A2**					
					n/a	-4.9	-6.8	-9.0	n/a	-15.8	-17.6	-16.7					
				(more pessimistic estimates taking into account the impact of desertification)													
	Detailed results of the AQUACROP model are given for different crops and different areas. Data from ELSTAT on the distribution and production of various crops by area have been used to derive a mean total change in agriculture yield																
Forests	2050, 2100	B2, A2	Temperature increase		**B1**	**B2**	**A1B**	**A2**	**B1**	**B2**	**A1B**	**A2**			**B2**	**A2**	
				Percentage decrease in timber production	n/a	n/a	n/a	27	n/a	30	n/a	35		Additional management costs (EUR millions, in 2007 values)	30	50	/year
				Percentage decrease in grassland production	n/a	n/a	n/a	n/a	n/a	10	n/a	25		Cost of improving forest fire fighting (EUR millions, in 2007 values)	40	80	/year
				Additional cost of fire fighting and damage from fires (EUR millions, in 2007 values)	n/a	n/a	n/a	n/a	n/a	40	n/a	80	/year	Cost of construction works (EUR millions, in 2007 values)	2,250	4,700	one-off

n/a: non available data from sectoral analyses.

Table 3.1 Overview of the results of Chapter 2 sectoral analyses taken into account in the analysis based on the general equilibrium model *(continued)*

	Projection periods	Climate scenarios	Physical impacts	Economic impacts	2050				2100					Adaptation
Tourism	2070-2100	A1B	Change in the Tourism Climate Index (TCI)	Percentage change in tourism revenue	B1	B2	A1B	A2	B1	B2	A1B	A2		10% additional expenditure on advertising
					n/a	n/a	n/a	n/a	n/a	n/a	5	n/a		
	The decrease in receipts from tourism results from the drop in tourist activity in the regions of Crete and the Dodecanese. Only hotel revenues are taken into account.													
Built environment	2041-2050, 2091-2100	B2, A1B, A2	Overall changes in climate		B1	B2	A1B	A2	B1	B2	A1B	A2		
				Percentage decrease in heating load	n/a	n/a	22	n/a	n/a	36	42	50		
				Percentage increase in cooling load	n/a	n/a	83	n/a	n/a	148	167	248		
Coastal systems	2100		Sea-level rise by 0.5 m, 1 m	Cost per land use type (EUR millions, in 2010 values)				Sea-level rise						Cost of implementing adaptation measures: from €381.6 million to €3,345.6 million
								0.5 m			1 m			
					Housing and touristic			347,738			630,842			
					Wetlands			138			247			
					Forests			0			1			
					Agriculture			7,884			18,253			
Fisheries			Sea surface temperature rise by 3.3 ˚C	Percentage decrease in fish catch	2.5									

n/a: non available data from sectoral analyses.

Table 3.1 **Overview of the results of Chapter 2 sectoral analyses taken into account in the analysis based on the general equilibrium model *(continued)***

	Projection periods	Climate scenarios	Physical impacts	Economic impacts	2050				2100					Adaptation		
					EUR millions, in 2010 values											
					B1	B2	A1B	A2	B1	B2	A1B	A2		Flood protection:		
Trans-portation	2011-2050, 2071-2100	B1, A1B, A2	Rise in temperature	Loss for road transportation	50	n/a	100	150	100	n/a	200	300	/year	The costs of flooding in the adjacent column include the cost of temporary or permanent restoration of flood damages. The two types of cost have been distinguished on the basis of data on flooding in the Prefecture of Magnesia (see the complete text of the study on transportation in the relevant page of the Climate Change Impacts Study Committee (CCISC) on the Bank of Greece website (www.bankofgreece.gr)). The cost of temporary restoration (8%) has been used as the cost of Inaction and the cost of permanent restoration (92%) has been used as the cost of Adaptation.		
				Loss for railway transportation	20	n/a	30	37	40	n/a	55	75	/year			
			Floods	Loss for road transportation	60	n/a	120	200	85	n/a	200	300	/year			
				Loss for railway transportation	–	n/a	n/a	184	n/a	n/a	n/a	276	/year			
			Decreased snowfall	Benefits to road transportation	-15	n/a	-25	-40	-30	n/a	-50	-80	/year	**Protection from sea-level rise (EUR millions, in 2010 values)**		
				Benefits to railway transportation	-0.01	n/a	-0.07	-0.05	-0.1	n/a	-0.15	-0.2	/year	Protection for road transportation	3,000	once
			Extreme weather events	Hours of delay in the road network	103	n/a	154	308	154	n/a	219	513	/year	Protection for railway transportation	300	once
				Hours of delay in the railway network	5	n/a	8	16	8	n/a	12	27	/year	Protection for sea transportation	600	once
					Distance from shoreline (m)											
					25	**50**	**75**	**100**								
			Sea-level rise by 0.5 m, 1 m	Affected percentage of road network	0.72	1.80	2.70	3.47								
				Affected percentage of railway network	0.32	0.83	1.38	1.98								

n/a: non available data from sectoral analyses.

Table 3.2 **Temperature change and sea-level rise in different climate change scenarios**

	B1	B2	A1B	A2
Temperature change				
Climate change intensity in 2050	1.57 °C	1.98 °C	1.95 °C	2 °C
Climate change intensity in 2100	2.41 °C	3.11 °C	3.51 °C	4.46 °C
Sea-level rise				
Climate change intensity in 2050	up to 0.18 m			
Climate change intensity in 2100	up to 0.6 m			

Agriculture

For the agricultural sector, use was made of the results of the AquaCrop model for the sectoral study on agriculture (Sub-chapter 2.4). The sectoral study distinguished two cases, one including and one excluding desertification developments, and estimated the extent of crop yield change due to climate change.

In order to carry out the GEM analysis, we used the upper limits of the range of changes obtained with the AquaCrop model, for the simple reason that AquaCrop does not capture the amplification of desertification induced by climate change. In this sense, the AquaCrop model underestimates the actual impact of climate change on agriculture. To carry out the analysis using the general equilibrium model, we accepted that desertification will take place in parallel with climate change and will intensify because of climatic changes.

The AquaCrop model produced detailed results for four crops and four regions of Greece. Statistics on crop distribution per geographic area from the Hellenic Statistical Authority were used to determine the average total change in the agricultural sector's yield (Table 3.3).[51]

The decline in agricultural yield presented in Table 3.3 was integrated into the GEM-E3 model as an exogenous change in the agricultural sector's total productivity.

Climate change is also expected to lead to reduced availability of irrigation water, due to lower precipitation, on one hand, and to the prolongation of the dry season. This impact was integrated into the GEM-E3 model as an increase in the agricultural sector's expenditure for access to irrigation water (e.g. higher expenditure for land improvement works). This impact was not taken into consideration in the analysis of impacts on agriculture, but instead on the analysis of impacts on water reserves.

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[51] It was necessary to assess the average change in total agricultural productivity, as the GEM-E3 model does not distinguish between different crops.

Table 3.3 **Percentage decrease in crop yield due to climate change, as applied in the GEM-E3 model**

	B1	B2	A1B	A2
Climate change intensity in 2050	1	5	7	10
Climate change intensity in 2100	11	17	19	21

Table 3.4 **Impact of climate change in the tourism sector of Southern Europe**

	2.5 °C	3.9 °C	4.1 °C	5.4 °C
Annual drop in tourism revenue by 2080 in Southern Europe (EUR millions)	1,789	2,599	9,459	12,853

Source: PESETA (2009).

Tourism

As shown by the analysis of impacts on tourism (Sub-chapter 2.7), revenues from tourism (specifically, hotel services) will decrease on account of the new climatic conditions. It is estimated that by 2100 the receipts of the tourism industry in the regions of Crete and the Dodecanese will have declined by €430 million (under Scenario A1B, for the last decades of the 21st century), an amount equivalent to 5% of total tourism receipts. Considering that these two regions account for 40% of total tourism receipts (Sub-chapter 2.7), it was estimated that the total decrease in tourism receipts countrywide would amount to roughly 13%. This impact was integrated into the GEM-E3 model as an exogenous decrease in the demand for tourist services.

In order to determine the impacts on tourism under the other climate scenarios and for the year 2050, use was made of the estimates produced by the PESETA study (Amelung and Moreno, 2009) of the anticipated decrease in tourist demand in Southern Europe[52] (Table 3.4). More specifically, use was made of the PESETA study's correlation of the rise in temperature and the drop in demand for tourist services. The final estimates of the decrease in tourist demand are given in Table 3.5.

In the GEM-E3 model, tourist expenditures form part of households' consumer expenditure. They include both domestic and foreign tourist expenditure, since the Input-Output Tables do

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[52] We maintained Greece's percentage share in the total tourism receipts of Southern Europe (Portugal, Spain, Italy, Greece, Bulgaria), based on World Bank data. http://data.worldbank.org/indicator/ST.INT.RCPT.CD

Table 3.5 **Percentage decrease in tourism revenue due to climate change, as applied in the GEM-E3 model**

	B1	B2	A1B	A2
Climate change intensity in 2050	1	2	2	3
Climate change intensity in 2100	4	9	13	24

not distinguish between Greek and foreign households. Such a distinction in terms of revenue origin is only made in the Social Accounting Matrix, where the expenditures of foreign tourists are recorded as transfer payments from the rest of the world.

In order to simulate the decrease in demand for tourist services from Greek households, the parameters of the model's consumption function were exogenously adjusted, whereas the decrease in demand for tourist services from foreign tourists was simulated by applying a decrease in transfer payments, corresponding to a decrease in the demand for tourist services in Greece from the rest of the world.

Fisheries

As shown by the analysis of fisheries (Sub-chapter 2.3), climate change will have a limited, but definitely negative, impact on fishery production. As estimated, a 3.3°C rise in sea surface temperature would cause the fishery production to drop by 2.5%. This change was assumed to take place under the worst-case climate scenario (A2) for 2100. It was also assumed that there is a linear relationship between the rise in temperature and the drop in fishery production, so that the decrease in production could be calculated for the other climate scenarios and time horizons.

This decrease in fishery production was simulated in the model by applying a corresponding change in the productivity of the fisheries sector.

Table 3.6 **Percentage decrease in the productivity of fisheries, as applied in the GEM-E3 model**

	B1	B2	A1B	A2
Climate change intensity in 2050	0.7	0.8	0.8	0.8
Climate change intensity in 2100	1.0	1.3	1.5	2.5

Table 3.7 **Economic impact of climate change on the forest sector, as applied in the GEM-E3 model**

	B1	B2	A1B	A2
Percentage decrease in the productivity of forests				
Climate change intensity in 2050	21	25	25	27
Climate change intensity in 2100	28	30	34	35
Additional government expenditure to address fires on an annual basis (EUR millions)				
Climate change intensity in 2050	11	17	16	17
Climate change intensity in 2100	24	39	49	78

Forestry

For the forestry sector, the decrease in timber production was simulated by applying a corresponding decrease in the productivity of forestry and logging. The costs of fire outbreaks[53] are considered to be borne entirely by the State and are simulated as increases in government expenditure for forest fire fighting and forest protection.

Coastal systems

As regards coastal systems (Sub-chapter 2.2), the costs from the loss of tourism-related and residential land, wetlands, forests and agricultural land as a result of a sea level rise were estimated as the commercial value of the affected areas, which would obviously yield less than in the event of no climate change. The cost from the loss of forests and wetlands is relatively small and was omitted from the rest of the study.

The value of the losses in tourism-related and residential land was broken down into corresponding categories on the basis of equivalence coefficients established from statistical data.

For tourism and agriculture, the loss of coastal land was integrated into the general equilibrium model as a loss of productive capital. In order to annualise the value of this loss, it was assumed that the capital reserves of these sectors would yield an annual 8% for tourist land and 6% for agricultural land. Based on this assumption, the annual equivalent loss in capital yields in tourism and agriculture ranges between 2% and 4%, depending on the climate scenario and the year to which climate change intensity refers.

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[53] The forestry study group produced estimates of the additional burned areas that would arise from the increased frequency of fires due to climate change, and of the share of forest areas that would be affected by the sea level rise. These forest area losses (which appear to be limited relative to the country's total forest areas, e.g. a burned area of 20,000 hectares is estimated under the B2 Scenario, i.e. 0.3% of the country's total forest areas) could be integrated into the model by applying a decrease to the forestry and logging sector's capital. However, these burned areas do not necessarily constitute productive capital for forestry. For this reason and, also because of their limited size, they were left out of the general equilibrium analysis.

Table 3.8 Value of coastal land loss due to sea-level rise (EUR millions, cumulatively by 2100)

Sea-level rise	0.5 m	1 m
Housing and touristic lands	347,738	630,842
Wetlands	138	247
Forest lands	0	1
Agricultural lands	7,884	18,253

Table 3.9 Percentage decrease in ROC in the sectors of tourism and agriculture on an annual basis, as applied in the GEM-E3 model

	B1	B2	A1B	A2
Tourism services sectors				
Climate change intensity in 2050	2	2	2	2
Climate change intensity in 2100	2	3	3	4
Agricultural sector				
Climate change intensity in 2050	2	2	2	2
Climate change intensity in 2100	2	3	3	4

It was assumed that the loss of coastal residential land brings about a loss of income for households, either directly, in cases where the land and buildings produced a financial yield for their owners, or indirectly, because of the expenses that owners would incur to replace the land or land use services lost. In both cases, the impact was integrated into the general equilibrium model as an additional household expenditure, necessary for households to enjoy the same level of services from their land and buildings as prior to the sea level rise. The cost of the coastal residential land loss was annualised based on the assumption of an annual yield equal to 6% of the land value.

To these costs, it was necessary to add the cost of relocating the coastal populations because of the sea level rise, which was estimated according to the PESETA study (Richards and Nicholls, 2009).

Table 3.10 presents the additional annual household expenditure attributable to the impact of climate change on coastal residential areas. This additional expenditure is incurred without additional income and therefore presupposes a cut-back of other consumer expenses and/or a decrease in savings.

Table 3.10 **Additional expenditure of households as a result of loss of residential land and population movements due to sea-level rise**

	B1	B2	A1B	A2
Increase in household expenditure (EUR millions)				
Climate change intensity in 2050	2,872	3,401	3,379	3,415
Climate change intensity in 2100	6,322	7,471	8,272	10,590

Table 3.11 **Percentage decrease in ROC in sea transportation due to sea-level rise**

	B1	B2	A1B	A2
Loss of capital in sea transportation				
Climate change intensity in 2050	1	2	2	2
Climate change intensity in 2100	3	5	7	15

Port infrastructure

The analysis of the transport sector (Sub-chapter 2.9) comprises an assessment of the cost of protecting port infrastructure, which —because of its preventive nature— is included in the cost of adaptation to climate change. However, an estimate of the cost corresponding to the loss of port infrastructure due to the sea level rise must be envisaged for the Inaction Scenario. It was assumed that the loss of port infrastructure under the Inaction Scenario (Scenario A2) would amount to 30% of the infrastructure value. This loss was integrated into the general equilibrium model as a loss of capital in the sea transport sector.

The built environment

For the built environment sector, an estimate was made of the cost arising from changes in heating and cooling needs, as analysed in Sub-chapter 2.8. The analysis projects a decline in the heating load, which will affect the consumption of oil and natural gas, and an increase in the cooling load, which will affect the extent of air conditioner use and, thereby, electricity consumption.

The changes studied in Sub-chapter 2.8 were further analysed using the PRIMES energy model (see Chapter 4), which made it possible to estimate the total reduction in heating need-related oil and natural gas consumption, as well as the total increase in electricity consumption in the residential and services sector. The impact of the Inaction Scenario on the structure of the total energy consumption of this dual sector is significant, as shown in Table 3.12.

Table 3.12 **Changes in energy consumption in the built environment due to climate change, as calculated with the PRIMES model**

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Percentage change in total energy consumption by households for residences and passenger cars								
Oil	-8	-10	-9	-10	-12	-15	-18	-21
Electric power	4	7	6	7	9	12	14	21
Natural gas	-16	-20	-19	-20	-24	-31	-36	-43
Change in total energy consumption in the services sectors								
Oil	-16	-20	-19	-20	-24	-31	-36	-43
Electric power	6	10	10	10	13	18	21	31
Natural gas	-19	-23	-22	-24	-28	-36	-42	-50

Table 3.13 **Additional expenditure to compensate for the loss of value of the built environment in urban heat islands (EUR millions, on an annual basis)**

	B1	B2	A1B	A2
Climate change intensity in 2050	28	50	48	51
Climate change intensity in 2100	81	154	228	400

These estimates were integrated into the general equilibrium model as exogenous changes in household and service sector consumption. The impact on energy purchase expenditure is calculated by the general equilibrium model, but the total impact is small (and, in some cases, even yields a small benefit), because the additional expenditure for air conditioning electricity is offset by reduced expenditure for heating oil and natural gas.

A significant economic impact on the built environment is expected to be exerted by the climate change-induced intensification of the heat island effect in urban centres. Such a phenomenon would bring about an important decrease in house and service building value in those parts of urban centres that would experience high temperature increases. For the Inaction Scenario, it was assumed that some 20% of houses and buildings in urban centres will lose value, which translates into a decline of about 3% in total house and building value by 2100. This cost was annualised by assuming an annual return on capital of 6%. The corresponding loss of income from the return on capital was integrated into the general equilibrium model as an additional expenditure to be borne by households and the services sectors. This expenditure corresponds to the cost of making up for the loss of capital, so that services rendered by such real estate remain unchanged.

Water reserves

Climate change will lead to reduced water availability in the future. Based on the analysis of the water reserves sector (Sub-chapter 2.1), it was estimated that the water supply will not suffice to meet part of the demand. This strain on the water supply sector was simulated in the general equilibrium model assuming a corresponding decrease in the sector's productivity.

Along with the water supply sector, reduced water availability will also significantly affect irrigation and, by extension, agriculture. The analysis of the agricultural sector (Sub-chapter 2.4) comprises an assessment of the impact of reduced water availability on crop yields. However, it does not take into account the increased irrigation costs needed to meet irrigation needs (e.g. drilling to greater depths, additional land improvement works, etc.). In the present analysis, it was assumed that, under the worst-case scenario (Scenario A2), irrigation costs will increase by as much as 120% by 2100. The simulation of this increase in irrigation costs was achieved by applying an appropriate change (increase) in the unit cost of the agricultural sector production factors corresponding to irrigation.

Table 3.14 **Percentage decrease in the productivity of the water supply sector, as applied in the GEM-E3 model**

	B1	B2	A1B	A2
Climate change intensity in 2050	13	16	16	16
Climate change intensity in 2100	20	26	30	39

Table 3.15 **Percentage change in irrigation costs in the agricultural sector**

	B1	B2	A1B	A2
Climate change intensity in 2050	39	50	49	51
Climate change intensity in 2100	62	81	93	120

Table 3.16 **Economic impacts in the transportation sector, as applied in the GEM-E3**

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Additional government expenditure on infrastructure (EUR millions, on an annual basis)	46	68	66	69	95	149	186	288
Drop in government expenditure on snow removal operations (EUR millions,on an annual basis)	-9	-14	-13	-14	-19	-30	-37	-58
Loss of work hours due to delays (annual number of hours per employee)	36	57	54	108	54	67	77	180
Percentage loss of capital in the land transportation sector due to SLR	0.01	0.01	0.01	0.01	0.01	0.05	0.08	0.11

Transport

Climate change will have significant consequences on transport sector infrastructure. Higher expenditures will be required for road surface maintenance on account of the rise in temperature, as well as extraordinary expenditure to repair flood-induced damage. These additional outlays were integrated into the general equilibrium model as additional public works expenditure for the state, to be carried out by the construction sector. The analysis for the transport sector identified a small benefit arising from the reduced expenditure for snow clearing, which was integrated into the general equilibrium model as a decrease in the corresponding State expenditure.

The impacts of the sea level rise on port infrastructure are examined together with the impacts on the coastal systems.

As regards the impacts of the sea level rise on land transport infrastructure, the sectoral analysis provides data concerning the sections of the road and railroad networks located within 25 to 100 metres of the coastline and expected to be affected by the rise in sea level. These data made it possible to estimate the extent of the damage to land transport infrastructure attributable to the rise in sea level. The value of this damage was then integrated into the general equilibrium model as loss of capital for the land transport sector.[54]

The sectoral analysis for transport also estimated the number of delay hours for commuters, as a result of the impact of extreme weather events on their transport routes to work.

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[54] The damage levels estimated by the work group on transport have not taken into account data relevant to the network's altitude. In the general equilibrium model, it was assumed that part of this estimate corresponds to a loss of capital.

For a number of reasons, it would be incorrect to consider the sum of these hours as a loss of labour productivity. For the analysis with the general equilibrium model, it was assumed that part of these hours (about 1/3) corresponds to a definite inability to provide work. This loss was integrated into the general equilibrium model as a decrease in the available workforce.

3.3.7 The total cost of climate change per climate scenario

As mentioned in the introduction to the present sub-chapter, the costs of climate change for the Greek economy were estimated using the GEM-E3 model, into which estimates concerning the direct economic impact of climate change on various sectors of activity were entered as exogenous changes. Table 3.17 summarises the numerical values of the exogenous changes introduced into the GEM-E3 model.

The general equilibrium model was used to calculate the costs for the Greek economy under different scenarios with regard to the intensity of climate change and the relative intensity of climate change in years 2050 and 2100.

The costs of climate change for the Greek economy were estimated by applying the exogenous changes to the state of the economy in a base year, as represented by the general equilibrium model for that specific year. Therefore, the cost assessments refer to the size of the base year economy, and not to the size that the economy could have in 2050 or 2100. In other words, the euro-denominated costs should be assessed against the present size of the economy.

The cost assessments for the economy were performed in a time-dynamic manner. In other words, the exogenous changes were applied to the base year, so that the general equilibrium model simulated the dynamic evolution of the economy (over ten years), as affected by these changes, e.g. by factoring in changes in investment and capital accumulation. The assessment of the costs of climate change is based on a comparison between this simulation and the simulation in which no exogenous changes attributable to climate change are introduced. The comparison is performed both for the base year (corresponding to static costs) and the last year of the dynamic simulation (corresponding, in this case, to long-term costs). The period of simulation does not refer to the years 2050 or 2100, for which only the intensity of climate change is of interest.

The exercise using the general equilibrium model provides an answer to what the static and the long-term impact on Greek economy would be, if the climate change intensity of 2050 or of 2100 (for different climate scenarios) was to occur in the present state of the economy.

The costs for the Greek economy were estimated both for the economy as a whole and separately per sector. Using the general equilibrium model, the costs were measured as the change in Gross Domestic Product (GDP) at constant prices and as the welfare equivalent variation. The general equilibrium model also provides detailed estimates of the impact of climate change per sector of economic activity, as well as the impact on investment, consumption, prices, the labour market and foreign trade.

Table 3.17 Consolidated table of exogenous assumptions entered in the GEM-E3 general equilibrium model to assess the cost of climate change scenarios

	2050				2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Agriculture	Percentage decrease in crop yield (productivity)							
	1	5	7	10	11	17	19	21
Tourism	Percentage decrease in tourism revenue							
	1	2	2	3	4	9	13	24
Fisheries	Percentage decrease in the productivity of fisheries							
	0.7	0.8	0.8	0.8	1.0	1.3	1.5	2.5
Forests	Percentage decrease in the productivity of forests							
	21	25	25	27	28	30	34	35
	Additional government expenditure to address fires on an annual basis (EUR millions)							
	11	17	16	17	24	39	49	78
Coastal areas	Percentage decrease in ROC in the tourism sector due to sea-level rise							
	2	2	2	2	2	3	3	4
	Percentage decrease in ROC in the agricultural sector due to sea-level rise							
	2	2	2	2	2	3	3	4
	Additional expenditure of households as a result of loss of residential land and population movements due to sea-level rise (EUR millions, on an annual basis)							
	2,872	3,401	3,379	3,415	6,322	7,471	8,272	10,590
	Percentage decrease in ROC in the sea transportation sector due to sea-level rise							
	1	2	2	2	3	5	7	15
Water resources	Percentage decrease in the productivity of the water supply sector							
	13	16	16	16	20	26	30	39
	Percentage increase in irrigation costs in the agricultural sector							
	39	50	49	51	62	81	93	120

Table 3.17 Consolidated table of exogenous assumptions entered in the GEM-E3 general equilibrium model to assess the cost of climate change scenarios *(continued)*

	2050				2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Built environment								
	Percentage change in total consumption of energy by households for residences and passenger cars							
Oil	-8	-10	-9	-10	-12	-15	-18	-21
Electric power	4	7	6	7	9	12	14	21
Natural gas	-16	-20	-19	-20	-24	-31	-36	-43
	Percentage change in total consumption of energy in the services sectors							
Oil	-16	-20	-19	-20	-24	-31	-36	-43
Electric power	6	10	10	10	13	18	21	31
Natural gas	-19	-23	-22	-24	-28	-36	-42	-50
Built environment	Additional expenditure to compensate for the loss of value of the built environment in urban heat islands (EUR millions, on an annual basis)							
	28	50	48	51	81	154	228	400
Transportation sector	Additional government expenditure on infrastructures (EUR millions, on an annual basis)							
	46	68	66	69	95	149	186	288
	Decrease in government expenditure on snow removal operations (EUR millions, on an annual basis)							
	-9	-14	-13	-14	-19	-30	-37	-58
	Loss of work hours due to delays (annual number of works per employee)							
	36	57	54	108	54	67	77	180
	Percentage loss of capital in land transportation due to sea-level rise							
	0.01	0.01	0.01	0.01	0.01	0.05	0.08	0.11

Table 3.18 **Annual impact of climate change on GDP and prosperity**

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Impact in the baseline year								
Percentage change in GDP	-0.90	-1.56	-1.77	-2.03	-2.69	-4.03	-4.77	-6.50
Welfare equivalent variation (EUR millions, on an annual basis)	-1,696	-2,831	-3,072	-3,409	-4,888	-7,638	-9,404	-14,207
Impact in the final year of the dynamic simulation								
Percentage change in GDP	-0.90	-1.53	-1.74	-2.00	-2.67	-3.92	-4.57	-6.01
Welfare equivalent variation (EUR millions, on an annual basis)	-2,963	-4,803	-5,144	-5,666	-8,391	-13,002	-16,018	-24,435

The welfare equivalent variation is estimated, using the model, as the income that would need to be taken away from or given to consumers (households) so that consumer utility under the climate change scenario would be equal to that of the Baseline Scenario, based on the price levels of goods under the Baseline Scenario. A negative equivalent variation means that the prices of goods under the climate change scenario cause consumer utility to fall below that of the Baseline Scenario, a situation equivalent to a decline in household income, if the prices of goods in the Baseline Scenario were to apply. It should be noted that, in general equilibrium models such as the GEM-E3, welfare variation is a measure that enables total impact to be assessed, given that the model is structured in such a way as to optimise consumer utility.

According to the general equilibrium analysis, the GDP losses range from -0.9% to -2% for the climate change conditions of 2050, and from -2.7% to -6% for the climate change conditions of 2100. The welfare equivalent variation of households ranges from €3 billion to €5.7 billion for the climate change conditions of 2050 and from €8.4 billion to €24.4 billion for the climate change conditions of 2100. The upper limits of these ranges correspond to the Inaction Scenario, the total cost of which was estimated at €5.7 billion per annum for the climate change intensity of 2050 and at €24.4 billion per annum for the climate change intensity of 2100.

The impact of climate change was found to be more adverse on household consumption than on investment. The unavoidable expenses that not only households, but also the State, will incur to counter losses caused by climate change are mainly investment expenditures. However, the decrease in capital yields and the decline in productivity in various sectors, coupled with reduced demand for tourist services, lead to slower growth and to reduced real household income, which in turn causes a greater decline in consumption than in investment. Another factor behind the slowdown in economic activity is the structure of the investments made necessary because of climate change, which have to be directed towards sectors with a smaller multiplier effect on the economy. The negative impact on economic activity is strongest in the sectors of services, agriculture and consumer goods. These variations lead to a small increase in real interest rates and a decrease in real wages.

3.3.8 The total cost of climate change per impacted sector

The analysis using the general equilibrium model was also conducted separately for each of the respective sectors of impact, i.e. for each sector found to suffer a direct impact from climate change. The results presented in Table 3.19 and in Figure 3.3 express the impact from climate change in terms of percentage change in GDP. The results presented in Figure 3.4 express the impact of climate change in terms of welfare equivalent variation.

These results indicate what the impact on the economy would be if climate change were only to affect one sector at a time.

The general equilibrium results per sector show that the most negative effects on the economy are caused by the impact of climate change on agriculture and coastal systems. The negative effects on the economy as a result of the impact on tourism were also found to be considerable, though only with regard to the climate change intensity of 2100 (the effects associated with the climate change intensity of 2050 were definitively on a smaller scale, compared with the effects projected for 2100 and with the effects on other sectors). Similar differences in the magnitude of the effects were also observed with regard to the economic effect on the transportation and built environment sectors. This is due to the non-linearity of impacts: climate change intensity by 2100, especially under the worst-case scenarios, such as the A2 Inaction Scenario, corresponds to temperature and sea levels with a greater than proportional impact on the corresponding sectors and, consequently, on the economy.

Agriculture, the productive sector most vulnerable to climate change, will, in the long run, account for the largest loss in GDP. The decline in the sector's productivity will lead to a steep rise in production costs, resulting in a large decrease in exports, a decrease in domestic consumption and an increase in agricultural imports.

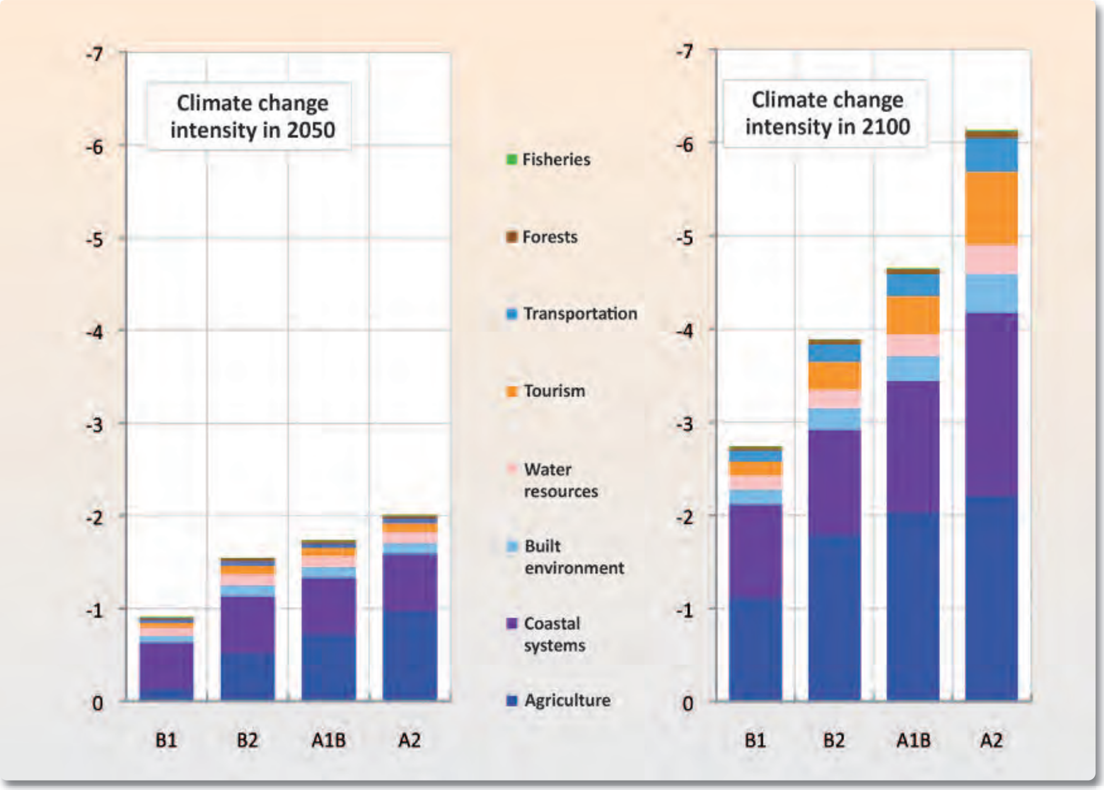
The impact on the tourism sector becomes more pronounced when considered in terms of welfare equivalent variation. The drop in the demand for tourist services leads to decreases in employment, real wages and household income.

The impact on coastal systems, in terms of capital losses, does, on the one hand, generate an increase in investment, but the losses in terms of residential land have negative effects on household income and lead to a drop in consumption. The impact from the rise in sea level is negative across all sectors of economic activity, with the exception of the construction sector, where activity increases slightly due to the investment expenditure for damage restoration. Similar effects were also found within the transportation sector, with transportation-related

Table 3.19 Annual impact of climate change on GDP and prosperity

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Sector	**Percentage change in GDP**							
Agriculture	-0.13	-0.52	-0.72	-0.97	-1.11	-1.79	-2.03	-2.21
Forests	-0.02	-0.03	-0.03	-0.03	-0.03	-0.04	-0.05	-0.06
Fisheries	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02
Coastal systems	-0.50	-0.61	-0.61	-0.62	-1.01	-1.12	-1.41	-1.97
Transportation	-0.04	-0.05	-0.05	-0.05	-0.12	-0.19	-0.24	-0.37
Tourism	-0.05	-0.09	-0.09	-0.09	-0.15	-0.30	-0.41	-0.78
Built environment	-0.07	-0.12	-0.11	-0.12	-0.16	-0.23	-0.27	-0.41
Water resources	-0.09	-0.12	-0.12	-0.12	-0.15	-0.20	-0.23	-0.32
All sectors	**-0.90**	**-1.53**	**-1.74**	**-2.00**	**-2.67**	**-3.92**	**-4.57**	**-6.01**
Sector	**Welfare equivalent variation (EUR millions, on an annual basis)**							
Agriculture	-173	-701	-983	-1,324	-1,517	-2,485	-2,821	-3,077
Forests	-28	-35	-35	-38	-42	-51	-60	-75
Fisheries	-7	-8	-8	-8	-10	-13	-15	-26
Coastal systems	-1,287	-1,553	-1,541	-1,560	-2,637	-3,020	-3,623	-4,939
Transportaiton	-63	-94	-91	-96	-180	-284	-354	-548
Tourism	-616	-1,129	-1,085	-1,160	-1,888	-3,683	-5,063	-9,548
Built environment	25	-30	-35	-33	-80	-162	-210	-476
Water resources	-192	-247	-243	-249	-308	-413	-477	-639
All sectors	**-2,963**	**-4,803**	**-5,144**	**-5,666**	**-8,391**	**-13,002**	**-16,018**	**-24,435**

Figure 3.3 Percentage GDP change as a result of climate change by sector affected

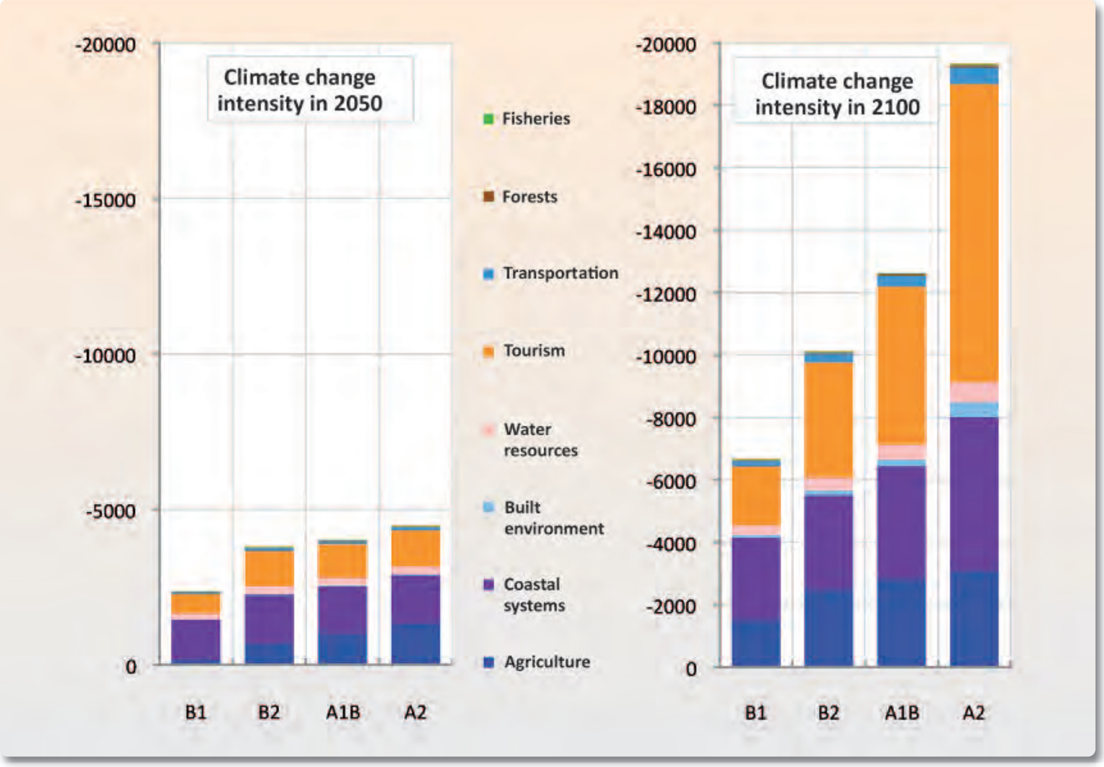


construction increasing slightly due to the increased need to restore damage caused to the transportation network by floods and the temperature rise.

The impact on the built environment has a relatively limited negative effect on the economy, as part of the capital loss costs caused by heat islands is offset by the (small) energy cost savings for households, as a result of the decrease in fuel consumption for heating, given the smaller increase in the use of electricity for air-conditioning purposes, made possible by the improved performance of heat pumps.

Smaller negative effects on the economy were attributed to the impact of climate change on forest ecosystems and fisheries. The impact of climate change on these sectors will obviously have serious repercussions on biodiversity and ecosystems, the cost of which has not been included in the general equilibrium analysis (similarly, the additional cost to the health sector has also been excluded). These repercussions are presented in detail in the relevant chapters of the present volume; however, due to the considerable uncertainty surrounding the economic implications of this impact per sector of activity, they were not incorporated into the general equilibrium analysis.

Figure 3.4 Welfare equivalent variation in million euro on an annual basis as a result of climate change by sector affected



3.3.9 The total cost of the Inaction Scenario

By applying the percentage change in GDP to the level of GDP in the base year (2008), it is possible to calculate the total costs of climate change with respect to the various climate change intensity cases reflected in the different scenarios, as well as with respect to the climate change intensity projected for the years 2050 and 2100. These total cost estimates are presented in Table 3.20.

Based on the results of the general equilibrium analysis, the costs of climate change under the Inaction Scenario (Scenario A2), relative to base year GDP (2008), amount to an annual €5.9 billion for climate change intensity of year 2050 and to €17.8 billion for climate change intensity of year 2100.

In spite of the drastic reduction in greenhouse gas (GHG) emissions under the Mitigation Scenario (emissions reduction achieved at the global level), climate change does occur, though of clearly lesser intensity than under the Inaction Scenario. The total costs (in base year GDP values) attributable exclusively to climate change under the Mitigation Scenario (mean temperature increase maintained at 2°C beyond 2100), was estimated, using the general equilibrium analysis, at an annual €2.7 billion for the climate change intensity of 2050 and at an annual €5.9 billion for the climate change intensity of 2100.

Table 3.20 **Total cost of climate change in relation to GDP level in the baseline year (2008)**

	Climate change intensity in 2050				Climate change intensity in 2100			
	B1	B2	A1B	A2	B1	B2	A1B	A2
Impact in the baseline year								
GDP fall (EUR millions, in 2008 values, on an annual basis)	-2,133	-3,703	-4,191	-4,816	-6,364	-9,556	-11,302	-15,403
Impact in the final year of the dynamic simulation (10 years later)								
GDP fall (EUR millions, in 2008 values, on an annual basis)	-2,671	-4,536	-5,143	-5,919	-7,919	-11,605	-13,535	-17,805

In other words, the Mitigation Scenario achieves annual cost savings from climate change (in base year 2008 GDP terms) of €3.2 billion per annum for the climate change intensity of 2050 and of €11.9 billion per annum for the climate change intensity of 2100.

Based on estimates concerning the total costs of climate change relative to the climate change intensities of years 2050 and 2100, an attempt was then made to estimate the total cumulative costs through 2100. Given that the analysis presented in earlier sections of this sub-chapter only concerned years 2050 and 2100, it was necessary to estimate the rates of decline in GDP for the entire time period. This was done using a sigmoid function for interpolation, the parameters of which were determined empirically. The percentage changes in GDP were applied to the base year GDP. Consequently, the total cost estimates for the Greek economy refer to base year GDP values. In order to calculate the cumulative costs and convert these estimates into present value terms, a discount rate of 0% was used. Table 3.21 also shows the cumulative costs using a non-zero discount rate.

Table 3.21 presents the total cumulative costs of the Mitigation Scenario (attributable exclusively to climate change, without taking into account the cost for the economy of implementing GHG emission reduction measures),[55] which, from a climatic viewpoint, corresponds to a variation of the B1 Scenario, in which the mean temperature increase remains at 2°C until —but also beyond— 2100, thanks to the global reduction in GHG emissions. The cost of climate change under the Mitigation Scenario is lower than that of the B1 Scenario, which corresponds to a slightly higher rise in temperature.

The total cumulative costs of the Inaction Scenario were estimated (using a discount rate of 0%) at €701 billion (in 2008 terms) for the period 2011-2100. The Mitigation Scenario ensures cumulative cost savings of €407 billion over the period extending till 2100, relative to the

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[55] See Chapter 4 and Sub-chapter 5.3 for an analysis of the full costs of the Mitigation Scenario.

Table 3.21 **Total cumulative cost of climate change**

	Cumulative cost (EUR billions, in 2008 values)				
Period	B1	B2	A1B	A2	Mitigation Scenario (2 °C)
	Discount rate 0%				
2011-2050	21	59	68	79	17
2051-2100	343	444	509	622	277
2011-2100	363	503	577	701	294
	Discount rate 2%				
2011-2050	10	30	35	41	8
2051-2100	90	117	133	161	75
2011-2100	101	147	168	202	83

Inaction Scenario. Using a discount rate of 2%, the cumulative cost savings achieved over the period extending till 2100 by the Mitigation Scenario amount to €119 billion (in 2008 terms).

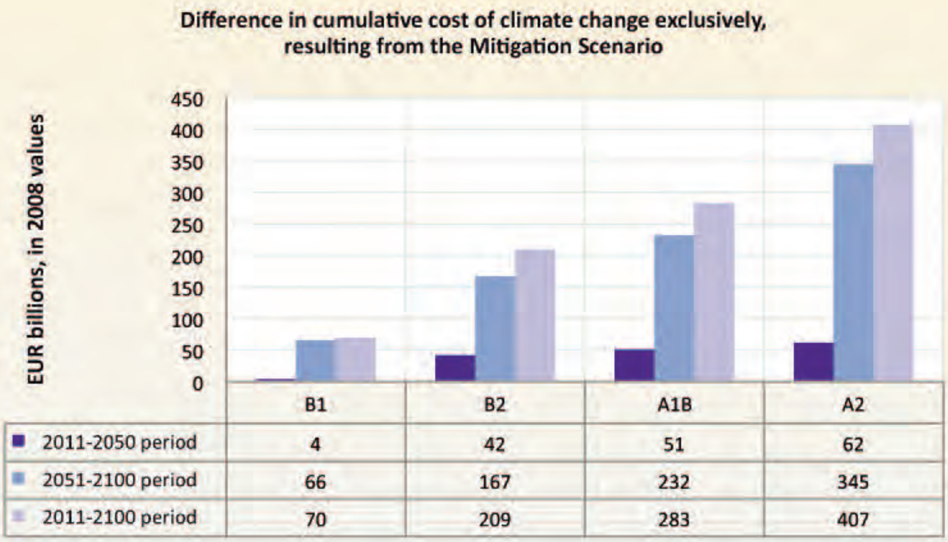
As the figures of Table 3.21 clearly show, the total costs of climate change escalate for the most part after 2050. These costs are therefore particularly low in present value terms when a non-zero discount rate is used.

It is important to stress that the cost of climate change will continue to rise beyond 2100, given that, under all the climate scenarios except for the Mitigation Scenario, climatic conditions will continue to deteriorate beyond that point. Only under the Mitigation Scenario are the climatic conditions presumed to remain unchanged after 2100. The additional costs incurred after 2100 have not been included in the estimates given in Table 3.21.

As is well known, the impacts of climate change are surrounded by considerable uncertainty. The more extreme the climate scenarios become, the higher the degree of uncertainty about the precise magnitude of climate change impacts. Under the extreme climate scenarios, such as the Inaction Scenario (A2, but also A1B), the occurrence of extreme impacts, such as high-frequency extreme weather events, is considered likely, impacts which, under today's conditions, would be catastrophic. In other words, there is a non-zero probability of occurrence of unpredictable natural events with profoundly catastrophic and irreversible, non-linear impacts. The economic costs of such "catastrophic" impacts have not been included in the general equilibrium model analysis (see Sub-chapter 3.1).

Consequently, given that the costs of climate change beyond 2100, the costs of possible catastrophic climate events and some of the impacted sectors (e.g. biodiversity, health) have not

Figure 3.5 **Reduction in cumulative cost of climate change by 2100 achieved by the Mitigation Scenario (Discount rate 0%)**



	B1	B2	A1B	A2
■ 2011-2050 period	4	42	51	62
■ 2051-2100 period	66	167	232	345
■ 2011-2100 period	70	209	283	407

been included in the analysis, the estimated costs of the Inaction Scenarios presented in the present sub-chapter should be seen as a lower bound of the real costs for the economy.

3.4 Policies and cost of adaptation to climate change*

3.4.1 Introduction

From a country point of view, it is not judicious to associate the mitigation of climate change impact exclusively with emissions reduction, since mitigation can only be achieved if all countries, the world over, combine their efforts to drastically cut back on emissions, starting immediately and over a long period of time. Such an alignment of all countries on an aggressive and immediate plan of action is desirable, but highly uncertain. In the event that such a global effort should fail, even if only partially, then, as shown by the relevant analyses, some sort of climate change will occur.

It is therefore in a country's own interest to include future climate change in its contingency planning and to take protective measures in good time to reduce the harshness, for the country,

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* The study for this sub-chapter was carried out at the E3MLab laboratory of the NTUA under the supervision of Prof. Pantelis Capros by main researchers Marilena Zambara and Dr. Leonidas Paroussos, and with the participation of researchers Zoi Vrontisi, Stella Tsani, and Maria Papaioannou. The text on the adaptation measures was written by Prof. Anastasios Xepapadeas.

of the climate change impacts. A clear distinction must be made between policies aimed at mitigating the impact of climate change, referred to as adaptation policies, and policies aimed at reducing the possibility of a climate change occurrence, examined in Chapter 4.

Even if climate change mitigation is achieved through global action to reduce emissions, climate change will still occur to some extent. In the best-case scenario, this change will involve a temperature increase of just 2°C, but if global action is delayed or only partly successful, the temperature increase is likely to be higher. Such an eventuality is considered under Scenarios B1 and B2 (see Section 3.3 above). It is therefore crucial for a country to arm itself against this uncertainty with a range of adaptation policies to possible climate change developments.

Climate change adaptation policies consist in taking appropriate action to address the damages and negative effects considered most likely to arise from climate change.

These adaptation policies need to target the sectors of activity most vulnerable to climate change. Because of their preventive nature, these policies obviously need to be developed prior to the actual occurrence of climate change effects. Furthermore, in order to reduce their costs, such adaptation policies need to be developed gradually and not under tight time constraints. Since adaptation policies depend on the State's initiative and intervention for their implementation, their effectiveness can be maximised if formulation and planning is based on analytical studies and if the relevant decisions are made in close cooperation with the parties concerned.

The overall intensity of the adaptation policies will depend on the expected intensity of climate change. At the same time, though, the more intensified and successful mitigation measures are at the global level, the less the adaptation policies will cost. It is therefore difficult to determine beforehand what the optimal strategy would be in terms of adaptation policy intensity for a given country.

The adaptation measures should, first of all, be selected conservatively, giving strict priority to identifying which adaptation measures would be indispensable under all cases of climate change (even if mitigation succeeds). These measures are usually of an institutional nature, involving e.g. the incorporation of appropriate provisions and specifications in legislation, and do not require specific works or costly interventions. If, as time goes by, there are delays in global mitigation action, then additional adaptation measures would have to be adopted in time. Such additional measures would entail costs and require special works, and would need to be implemented well before the uncertainties about the expected intensity of climate change can be resolved. Nevertheless, these expenditures should be perceived as a safeguard against future dangers from climate change.

Adaptation is therefore a long and ongoing process that concerns all sectors of the economy and society and calls for close cooperation and coordination between all parties concerned. The efficient adoption of adaptation measures presupposes timely planning and a strategic approach.

It is up to policy-makers to determine what the consequences of climate change are likely to be, and to develop and implement policy forms that ensure the best possible levels of adaptation.

3.4.2 Adaptation categories and measures

Adaptation to climate change can take on numerous forms. It is important to distinguish between spontaneous and planned adaptation. Spontaneous adaptation is the adaptation made at an individual level by economic agents, consumers and producers, without any State intervention, in response to climate change and to the ecological changes in natural systems. Planned adaptation, on the other hand, is the result of deliberate policy decisions and involves State intervention, in the form either of regulation enactments, direct public investment, or incentives and disincentives.

Both types of adaptation aim to mitigate the negative impacts of climate change and take place before climate change actually manifests itself on a wide scale.

It is obvious that priority in adaptation must be given to those sectors expected to be most negatively affected by climate change, and to averting those impacts that would entail the highest costs for the economy. According to the analyses presented in Chapter 2 and the general equilibrium analysis presented in Sub-chapter 3.3, agriculture would be the sector in Greece most affected by climate change, while household incomes and the economy as a whole would be most seriously affected by the impact on agriculture, tourism and coastal systems. The water reserves sector is of special importance, because of its repercussions on both agriculture and the water supply. The adaptation policies must therefore be focused on the above sectors and the implementation of appropriate actions must be properly planned time-wise, so as to mitigate the likely negative impacts.

Immediately below is a list of indicative climate change adaptation measures, chosen from among relevant studies in the international literature.

Table 3.22 **Types of adaptation**

Types of adaptation		Decision making level
Spontaneous	Decisions taken individually by producers and consumers without any intervention by the State (e.g. the manner in which farmers would try to enhance their crops by differentiating cultivation techniques or households' choice of location for their summer residence).	Individual
Planned	Adaptation measures taken by the government (legislation, investments, incentives and disincentives), including investment in the protection or preservation of resources (e.g. water storage), definition of policy on saving natural resources (e.g. water pricing), changing national standards (e.g. building code).	National and local

1. Agriculture and forests

1.1 Measures designed to improve crop yields:

- Measures to control and reduce soil erosion;
- Expanding the use of appropriate fertilisers;
- Introduction of new crops;
- Development of "resistant" crops (to drought, higher temperatures, salt, insects, pests, etc.);
- Soil enrichment so as to preserve or improve soil fertility;
- Adjusting the times of farm operations (sowing, spraying, harvesting, etc.);
- Recourse to crop rotation and land fallowing systems;
- Recourse to no-till farming practices, which help to contain erosion, etc.

1.2 Public works:

- Dam construction, extensive land reclamation, grey-water reuse systems, etc., as means to improve irrigation systems;
- Protection of forest biodiversity, as a means to enhance the resilience of ecosystems to climate change;
- Reinforcement of forest protection infrastructure, as a means to prevent forest fires.

1.3 Protection mechanisms:

- Development of early warning systems (to mitigate the effects of unexpected and extreme weather variations and to facilitate fire protection);
- Prolongation of the forest protection period, due to the increased number of days with a high risk for forest fire occurrence;
- Improvement of forest fire-fighting infrastructure and methods for a faster and more effective response to forest fires.

2. Water supply

2.1. Measures to increase water resource availability:

- Better management and maintenance of the existing water supply systems and relevant infrastructure;
- Watershed protection and water loss control;
- Protection of groundwater sources;
- Groundwater/rainwater collection and desalination;
- Promotion of rainwater collection systems (e.g. for watering);
- Reuse of treated wastewater in non-potable uses (e.g. toilet flushing, landscape irrigation, production of concrete for construction projects);
- Public works to access remote water sources;
- Seawater desalination (preferably using renewable energy sources).

2.2 Measures for rational water use:

- Modifications to relevant policies, such as water pricing and irrigation regulations;
- Installation of water-saving fixtures (e.g. low-flow water taps and shower heads, water metres to control consumption, infrared sensor water taps, etc.);
- Replacing plants in public spaces and streetscaping with low water-consuming plants;
- Setting of strict water-saving requirements for all new infrastructure.

3. Protection against floods

3.1 Public works:

- Infrastructure and housing protection works in riverside areas;
- Reinforcement and protection of ground areas serving as natural barriers against flooding.

3.2 Protection mechanisms:

- Planning for the participation of individuals in risk management;
- Specification of criteria for granting compensation to the flood-afflicted;
- Institutional measures;
- Flood forecasting and early warning systems.

4. Biodiversity and ecosystems

4.1 Management and protection systems:

- Improvement of ecosystem management systems, including deforestation control and reforestation;
- Promotion of agro-forestry;
- Identification and development of species resilient to climate change;
- Development and proper management of seed banks;
- Reinforcement or restoration of affected ecosystems (e.g. artificial dispersal of seeds, protection of pollinations, use of pesticides);
- Reinforcement of the ecosystems' natural resistance to climate changes, by reducing overexploitation, eutrophication, pollution, alien species invasion, etc.

4.2 Public works:

- Creation of parks, protected areas and biodiversity zones;
- Development/improvement of fire protection systems.

5. Coastal areas

5.1 Public works:

- Construction of dikes/flood defence systems to protect productive activities and residential areas situated along the coast;

- Transfer of economic activities away from the coastal areas (especially in cases where their protection cannot be ensured);
- Beach nourishment;
- Protection of vulnerable marine ecosystems (coral reefs, mangroves, seagrass, coastal vegetation).

5.2 Institutional measures:

- Incentives, spatial planning interventions and institutional measures to facilitate the transfer of economic, tourist and residential activities and investments away from the coastal zones. The departure of economic activities from the coast will in the long run enable the regeneration of the natural coastal ecosystems, which provide natural protection by dissipating much of the energy of storm waves, and help contain soil erosion in coastal areas, etc.

6. Transport and industry infrastructure

6.1 Public works:

- Relocation and reinforcement of port infrastructure;
- Airport relocation or protection works;
- Road relocation or protection works;
- Works for network infrastructure protection (electricity, telecommunications);
- Works for the protection of industrial and mining facilities against floods and extreme weather events.

6.2 Maintenance works:

- Use of maintenance materials and methods to protect road surfaces and other infrastructure against extended drought and extreme weather events;
- Use of suitable materials and methods for the maintenance of industrial and mining facilities.

7. Tourism

7.1 Private sector investment:

- Investment in existing tourism infrastructure to counter the physical consequences of climate change, such as higher temperatures and the shortage of drinking water;
- Preparation by the tourism industry of a shift of the tourist season from summer to autumn and spring.

7.2 Public works:

- Works to protect tourism facilities against floods and extreme weather events.
- Works to protect or relocate tourism facilities in vulnerable coastal areas.

8. The built environment

8.1 Public works:

- Creation and protection of "urban green spaces" that can mitigate the heat island effect, provide shade, improve the air quality, etc.

9. Energy-saving interventions in buildings through incentives, institutional measures and funding schemes. Indicatively:

- Use of building materials that naturally enhance the thermal insulation of buildings;
- Construction of air circulation as well as natural ventilation and cooling systems that help maintain a steady indoor temperature and save energy;
- Equipping building façades with special shading systems that produce a cooling effect;
- Promotion of the installation of ground-water heat pumps (GWHPs) which, apart from meeting thermal needs, also provide cooling;
- Creation of "green roofs" that provide cooling in the summer and insulation in the winter, thus saving energy.

10. Human health

- Improvements and changes to the health system infrastructure (e.g. air-conditioning in hospitals, improvement in equipment needed to treat specific diseases likely to spread on account of climate change);
- Disease monitoring (setting-up of suitable infrastructure, laboratories, etc., specialised training for new recruits in the healthcare sector, etc.);
- Investment in research on diseases likely to become more frequent on account of climate change, as well as in ways of prevention;
- Improving the quality of the living environment (e.g. air, water supply);
- Adjustment of conditions in the workplace, so as to minimise workforce productivity losses due to the temperature rise, and/or an adjustment of working hours/periods;
- Closer medical surveillance of workers/provision of medical assistance at the workplace;
- Development of early warning systems (to mitigate the effects of unexpected and extreme weather changes, e.g. heat waves).

The sectoral analyses in Chapter 2 provide more information and outline additional sector-specific adaptation measures.

3.4.3 Assessment of the costs of adaptation using the GEM-E3 general equilibrium model

The present section provides a quantitative assessment of the total costs — for the Greek economy — of adapting to high-intensity climate changes, as described in Scenario A2.

The considerable uncertainty surrounding the future intensity of climate change and the fact that the adaptation measures would need to be adopted beforehand make it very difficult to propose an optimal adaptation policy. Excessive adaptation measures could be judged a posteriori to have been unnecessary and therefore responsible for the squandering of financial resources. However, even small-scale adaptation measures may prove a posteriori to have been ineffective, thereby requiring the adoption of ad hoc and costly 'last-minute' measures.

In the light of these difficulties, we have chosen not to perform a full quantitative assessment of all the adaptation policy options available, but to focus solely on the case of high-intensity climate change (Scenario A2).

This quantitative assessment will also enable us to perform a cost-benefit analysis, and to compare the cost of adaptation (present section) with the cost of mitigation (Chapter 4) and the cost of inaction (Sub-chapter 3.3).

The Adaptation Scenario was drawn up based on the sectoral analyses (Chapter 2) and on the report "*Assessing the costs of adaptation to climate change*" (Parry et al., 2009). This report provides an overview of all the studies made by the United Nations Framework Convention on Climate Change (UNFCCC) on the subject of adaptation to climate change.

According to the report, adaptation to climate change would be very worthwhile, with a mean benefit/cost ratio of 20 in the aggressive abatement scenario and 60 in the business-as-usual A2 Scenario. After adaptation, the impacts of climate change would be reduced by 28% to 33%, compared to the case of no action either for mitigation or for adaptation.

The methodology used in the present section to assess the cost implications of the Adaptation Scenario for the Greek economy can be summarised as the following steps:

- The total cost of adaptation for the Greek economy was taken as the costs of adaptation measures plus the costs attributable to climate change.
- The costs of the adaptation measures were first estimated as direct expenditure for adaptation works and interventions; the total costs or benefits that these expenditures entail for the Greek economy were then estimated, taking into account all the indirect impacts on the economy, as simulated using the general equilibrium model GEM-E3.
- The direct costs of the adaptation measures were estimated either with data from the sectoral analyses presented in Chapter 2 or —whenever such quantitative assessments were not provided by the said analyses— with data from the international literature.
- The costs attributable to climate change were estimated, first, by assessing the extent to which the adaptation measures will succeed in mitigating the negative impacts of climate change in various sectors.
- The containment of the climate change effects, achieved thanks to adaptation, was then subtracted, on a sector-by-sector basis, from the direct cost estimates of climate change presented in Sub-chapter 3.3.

- The general equilibrium model was then used to estimate the total costs for the Greek economy of the reduced, thanks to the adaptation measures, climate change impacts.
- Lastly, the total cost of the Adaptation Scenario was obtained from the combined application, in the general equilibrium model, of the direct costs of the adaptation measures and the reduced impacts of climate change.

Only planned adaptation measures (Table 3.22), i.e. those involving actions and works undertaken by the State, are exogenously taken into consideration as adaptation measures. Spontaneous adaptation measures taken by consumers and producers are not represented as exogenous changes in the parameters of the general equilibrium model. However, it should be considered that part of these spontaneous measures are indirectly included in the analysis through the endogenous change in behaviours, as simulated by the consumption and production functions incorporated in the general equilibrium model.

Estimates of the direct cost of adaptation measures were drawn from the data of Chapter 2 only for the sectors of water reserves, forests, transport, tourism, the built environment and coastal systems. These estimates, schematically presented in Table 3.1 (Sub-chapter 3.3), are detailed in Table 3.23. For the sectors of agriculture and fisheries, data was used from the international literature. The sectors of biodiversity, ecosystems and health have been excluded from the analysis of adaptation costs. Part of the expected expenditure for protection against extreme weather events and floods, especially in the industry, mining activities and network infrastructure sectors, has also been excluded from in the analysis.

The assumption was made that the adaptation measures will for the most part be implemented during the period 2025-2050 (1st phase of adaptation). The assumption was also made that additional expenditure for adaptation measures will be required during the period 2050-2070 (2nd phase of adaptation), but that these additional expenditures will not be as extensive, i.e. about 50% lower than in the 1st phase. An exception was made for the transport sector, for which the exact adaptation cost provided by the analysis in Sub-chapter 2.9 was taken.

Despite the adaptation measures, some negative climate change impacts will still occur. The magnitude of these impacts will, however, be smaller than under the Inaction Scenario (i.e. Scenario A2, as analysed in Sub-chapter 3.3). Different assumptions were accepted for each sector regarding the reduction of the direct impacts achieved thanks to the adaptation measures, with the percentage reduction of the direct costs of climate change ranging from 30% to 70% depending on the sector. More details are provided in Table 3.23.

For the agriculture sector, estimates of the direct costs of adaptation measures were mainly based on "*Adaptation Options for Agriculture, Forestry and Fisheries*" by McCarl (2007), a study which refers to the A1B Scenario and assesses that adaptation measures would amount to a 2% increase in the sector's capital formation (along with an increase in research). The assumption was also made that the current expenditure in the agricultural sector for purposes such as addressing desertification and promoting soil denitrification and land reclamation works will increase in the future, in the context of adaptation measures implementation.

In the tourism sector, the cost estimates of adaptation measures are somewhat uncertain. For one, the costs of measures for protection and relocation away from coastal areas are recorded under the coastal systems sector. Secondly, any additional adaptation measures specific to the tourism sector would primarily need to be taken by the private sector, thereby leading to an increase in the non-labour costs of provided tourist services. The available international literature on the subject of tourism adaptation options focuses mainly on the potential offered by winter tourism, with its greater elasticity and room for adaptation. Summer tourism, in cases such as Greece's, offers far fewer possibilities for adaptation, because of its direct dependence on coastal areas vulnerable to climate change, where most of the sector's infrastructure is concentrated (Fischer, 2007). Expenditure will, however, be needed to promote tourism and extend the tourist season into the shoulder periods, as well as to upgrade buildings, with a view in particular to adjusting facilities to warmer temperature conditions.

As can be clearly seen from Table 3.23, the greater part of the cost of adaptation involves public expenditure. This expenditure was entered into the general equilibrium model as additional public investment and consumption in the sectors corresponding to each adaptation measure (public works for transport, expenditure for agriculture, forests, etc.). Some of the adaptation measures, e.g. in the tourism sector, involve private sector funding, which, after being annualised, was entered into the model as an increase in the non-labour unit costs of provided tourist services. Other adaptation measures involve investment expenditure by publicly controlled production sectors, such as in the case of the water supply. For these sectors, the costs of the adaptation measures were entered into the model as an additional public expenditure.

As regards the cost of adaptation measures concerning the energy efficiency upgrading of homes and buildings in urban centres, the assumption was made that the additional costs will be covered out of higher indirect taxes levied on energy products. It was ensured in the model that additional revenue from energy taxation covered exactly the additional expenses for the energy upgrading of homes and buildings. This, of course, ultimately places the cost of the energy upgrade on households. However, these same households are the ones that will benefit from the relevant expense avoidance (for the purchase of energy products).

The estimates of the direct cost of the adaptation measures were entered into the general equilibrium model as exogenous changes to parameter values.

Given that a large part of the adaptation measures corresponds to public expenditure, the additional budgetary cost will have macroeconomic implications for the Greek economy. It was assumed in the analysis using the general equilibrium model that the budgetary burden will occur in the future by which time the current public debt crisis will have been addressed and

Table 3.23 **Consolidated table of estimates of the direct cost of adaptation measures (EUR millions, in 2010 values, unless otherwise stated)**

Sector	Adaptation measures	1st adaptation stage, 2025-2050	2nd adaptation stage, 2050-2070	Unavoided impacts of climate change
Transportation	Expenditure for removing a part of the road and railway network at a greater distance from the shoreline	3,300	–	The cost of maintenance of the road network due to the temperature rise is not avoided.
	Expenditure for the protection of the land transportation network from flooding	184 on an annual basis	276 on an annual basis	The cost resulting from the sea-level rise and extreme weather events is avoided.
Coastal systems	Expenditure for the protection of coastal systems (except ports)	1,864	1,482	60-70% of the impact of climate change is avoided.
	Expenditure for raising the level of breakwaters in ports	600	–	
Water resources	Expenditure on works and interventions intended to restore resources and ensure the rational use of resources	70* on an annual basis	42 on an annual basis	A total cost of €390 million is avoided.
Forests	Additional management cost	50 on an annual basis	30 on an annual basis	The bulk of the impacts on forests is avoided.
	Expenditure for the improvement of forest fire fighting	80 on an annual basis	46 on an annual basis	
	Cost of protection works	4,700	2,800	
Tourism	Percentage increase in the cost of tourism services, excluding labour costs	10%	10%	20-30% of the loss of tourism receipts is avoided.
Agriculture and fisheries	Expenditure on irrigation works and protection works	72 on an annual basis	42 on an annual basis	The bulk of impacts on fisheries is avoided.
	Cost of the promotion of improved production practices and of the protection of wetlands systems	100 on an annual basis	60 on an annual basis	The decline in the productivity of the agricultural sector would reach 6% by 2050 (30% improvement) and 15% by 2100 (21% improvement).
Built environment	Cost of energy upgrade of building stock and of developing green islands	20,000	–	Reduction of energy consumption for cooling purposes by 20% compared to the Inaction Scenario.

* The analysis of the water resources sector stresses that this cost does not fully reflect the cost of realising this particular policy. However, in the absence of further information, the present analysis used this partial cost.

therefore that the financing of the public expenditure for adaptation measures at competitive market rates will be possible.

On the basis of this assumption, the general equilibrium model simulates the future path of the real interest rate as a shadow price of the balance of payments constraint, considering that the balance of payments will be burdened, in the first place, by this public expenditure. One of the impacts of the adaptation measures will therefore be an increase in the real interest rate. The results of the model showed this increase to be of 1 percentage point, at most.

The increase in the real interest rate has an adverse effect on private investment. In other words, the additional public expenditure for adaptation measures has a partial crowding-out effect on private investment, which in turn has a negative impact on economic growth. This impact is simulated in the model through the setting of the real interest rate.

At the same time, though, the increase in public expenditure for adaptation measures also has a boosting effect on different branches of economic activity and, thereby, on private investment. The additional public expenditure translates into an increased demand for goods and services needed to carry out public works and to implement the relevant expenditure for protection against climatic impacts. The additional demand for such goods and services has a multiplier effect on the economy and is simulated in the model by the Leontief multiplier. The additional economic activity resulting from the public expenditure for adaptation has a positive impact on employment which, through labour market equilibrium, has an increasing effect on real wages. Moreover, the sectors of activity that benefit from the sectoral allocation of the additional public expenditure invest more, as compared to the situation without this additional expenditure. Greater pressure is therefore exerted on the capital market, something which translates into trends towards a further increase in the real interest rate. As a result of the pressure exerted on the capital and labour markets, the model simulates an upward trend in the prices of goods and services.

These changes, however, namely the increased economic activity stemming from additional public expenditure, as well as the upward trend in prices of goods and services, have a negative impact on the trade balance, which is burdened by the increase in imports and the decline in exports. Increased domestic activity has a crowding-out effect on export activities. Since the model simulates the maintenance of the trade balance at the same level as in the situation without adaptation measures, the real interest rate is redetermined by the model and has a negative effect on consumption.

Private spending and investment associated with some of the adaptation measures have further adverse impacts on the economy. The relevant branches, as well as private consumption, transfer funds to pay for adaptation measures at the expense of other expenditures with a greater multiplier effect for the economy. The simulation by the model shows that the negative consequences of this crowding-out effect outweigh the positive effects for the economy of the additional demand for goods and services needed to carry out the corresponding adaptation measures.

The simulation with the general equilibrium model reveals that the impact from the increase in public expenditure through the crowding-out of investments and exports is greater than the impact with a multiplier effect on economic activity; this, as estimated by the model, will lead to an eventual decline in GDP, compared to the situation without adaptation measures, as well as to declines in private consumption and (to a lesser extent) in private investment and to a marginal change in employment. As mentioned above, private adaptation measures are accountable for part of the decline in GDP.

The impact is not uniform across the sectors of economic activity considered. The expenditure for adaptation has a positive impact on such sectors as construction, the production of non-metallic minerals and construction materials, the production of ferrous and non-ferrous metals, and banking services. However, the impact on the other productive sectors of the economy is negative.

In the course of time, the economy will also suffer the negative impacts of climate change. Thanks to the adaptation measures taken, however, the intensity of these impacts will be limited, compared to the ones envisaged under of the Inaction Scenario. The macroeconomic mechanism of these impacts is the same as the one described in Sub-chapter 3.3.

3.4.4 Assessment of the total costs of adaptation

The analysis of adaptation using the general equilibrium model presents several limitations, as it does not capture the full range of adaptation measure options and because the assessment of the benefits arising from the reduction of climate change impacts is quite uncertain.

In spite of these drawbacks, the GEM-E3 general equilibrium model, using the data and the assumptions mentioned in the previous section, makes it possible to assess the economic (macroeconomic and sectoral) effects of the combined application of adaptation measures and of the (lesser) damage arising from climate change. Separate assessments were made for the total costs of adaptation measures and for the lesser damage from climate change. By comparing this last cost figure to the total cost of the Inaction Scenario (A2, see Sub-chapter 3.3), one can deduce the total benefit of the adaptation measures for the Greek economy.

For this simulation, the limited-intensity climate change corresponding to the years 2050, 2070 and 2100, as well as the range of adaptation measures corresponding to those three years, were applied to the state of the economy in the base year. The reason why three reference years were chosen was to better capture the different dynamics of the adaptation measures and damages from climate change.

Using the abovementioned assumptions with regard to the adaptation measures and the ensuing benefits from the reduction of the climate change damage corresponding to Scenario A2, the simulation with the general equilibrium model yielded the following conclusions:

The adoption of adaptation measures over the period 2025-2050 corresponds to an annual expenditure of roughly 1.5% of GDP, on top of the expenditure under the Baseline Scenario. The expenditure for adaptation measures subsequently decreases, to 0.9% of GDP during the period 2051-2070 and to 0.1% of GDP during the period beyond 2070.

Table 3.24 **Total cost of the Adaptation Scenario for the Greek economy, in accordance with the results of the GEM-E3 general equilibrium model**

		Climate change intensity in 2050	Climate change intensity in2070	Climate change intensity in 2100
Percentage GDP change				
Implementation of adaptation measures only	initial simulation year	-0.92	-0.55	-0.07
	final simulation year	-1.10	-0.66	-0.08
Unavoided climate change impacts	initial simulation year	-0.96	-2.16	-3.96
	final simulation year	-0.97	-1.99	-3.59
Combined adaptation measures and climate impacts	initial simulation year	-2.11	-3.02	-4.03
	final simulation year	-2.30	-2.96	-3.67
Change in the level of baseline year GDP (EUR millions, in 2008 values, annually)				
Implementation of adaptation measures only	initial simulation year	-2,177	-1,303	-174
	final simulation year	-3,249	-1,952	-250
Unavoided climate change impacts	initial simulation year	-2,272	-5,125	-9,393
	final simulation year	-2,863	-5,897	-10,646
Combined adaptation measures and climate impacts	initial simulation year	-4,989	-7,156	-9,553
	final simulation year	-6,804	-8,764	-10,883
Welfare equivalent variation of the baseline year (EUR millions, in 2008 values, annually)				
Implementation of adaptation measures only	initial simulation year	-857	-513	-72
	final simulation year	-1,689	-1,013	-135
Unavoided climate change impacts	initial simulation year	-1,132	-3,618	-7,246
	final simulation year	-1,922	-6,136	-12,504
Combined adaptation measures and climate impacts	initial simulation year	-2,278	-4,431	-7,311
	final simulation year	-4,056	-7,656	-12,627

These additional expenditures, in the end, have a negative impact on the economy, as explained in the previous section, and lead to a decline in GDP that is smaller in absolute terms than the expenditure for adaptation measures.

Despite the adaptation measures, the economy still suffers losses from climate change, which evolves according to Scenario A2. The residual (unavoided) damage from climate change is small at the start and middle of the simulation period, but becomes more important later on, i.e. 2070-2100. According to the model's results, the decline in GDP caused by these losses is, however, definitely smaller, in absolute terms, than the one calculated under Scenario A2 (Inaction) in Sub-chapter 3.2. Expressed in terms of their contribution to the change in GDP, the residual (unavoided) climatic impacts on the economy, after implementation of the adaptation measures, amount to 48% of the loss in GDP projected for year 2050 under Scenario A2 and to 60% of the loss in GDP projected for year 2100.

Nevertheless, the expenditure for adaptation measures combined with the, albeit lesser, climatic impact has a cumulative GDP-reducing effect on the economy. According to the model's results, the total decline in GDP corresponding to the Adaptation Scenario amounts to -2.3% for the year 2050, -2.96% for the year 2070 and -3.67% for the year 2100.

Figure 3.6 **Total annual cost for the Greek economy on the basis of the Adaptation Scenario and the Inaction Scenario, according to the results of GEM-E3 general equilibrium model**

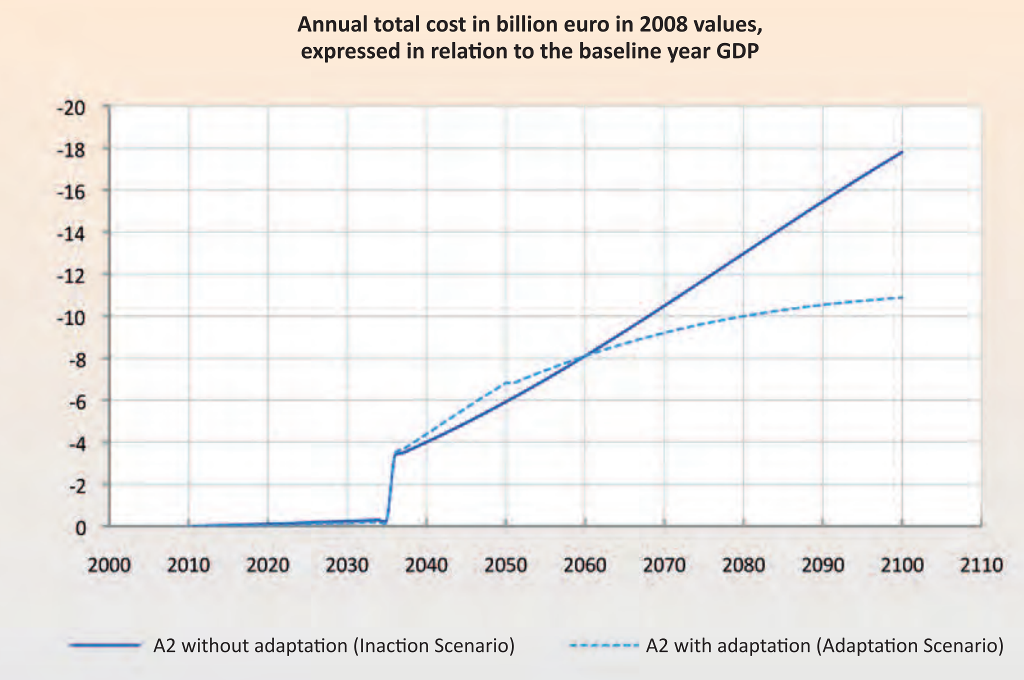

Table 3.25

Cumulative cost for the Greek economy on the basis of the Adaptation Scenario and the Inaction Scenario, according to the results of the GEM-E3 general equilibrium model (EUR billions, in 2008 values)

Period	A2 without adaptation (Inaction)	A2 with adaptation (Adaptation Scenario)	Cost differential between Adaptation and Inaction
Discount rate 0%			
2011-2050	78.9	85.7	-6.8
2051-2070	182.3	177.5	4.7
2071-2100	439.4	314.4	125.0
2011-2100	700.5	577.7	122.8
Discount rate 2%			
2011-2050	40.5	43.6	-3.0
2051-2070	65.0	63.8	1.2
2071-2100	96.1	70.0	26.1
2011-2100	201.6	177.3	24.3

The results of the model point to a decline in welfare equivalent variation, of the same scale as the changes in GDP.

As mentioned earlier, the impacts differ across sectors of the economy, with sectors such as construction and construction materials suffering a small-scale contraction in output, whereas agriculture and tourism suffer a larger-scale negative change.

An attempt was also made to calculate the cumulative costs for the Greek economy, according to the methodology described in Sub-chapter 3.2, using an interpolation based on a sigmoid function.

Given that the timing of the expenditure for adaptation measures does not coincide with the time at which the economic impacts induced by climate change take place (see Figure 3.6) and, more specifically, that the relevant expenditure precedes climate-induced damage, the cumulative costs of the Adaptation Scenario are similar to those of the Inaction Scenario during the period up to 2070. However, from 2070 onwards, the cumulative costs of Inaction are far greater than the costs of Adaptation.

The Adaptation Scenario (in terms of the cumulative decline in GDP over the entire period until 2100) would cost the Greek economy €123 billion less than the Inaction Scenario (at constant prices of 2008). This result was obtained using a zero discount rate, relative to base year GDP. However, even when an annual discount rate of 2% was used, the

Adaptation Scenario, on a cumulative basis, still cost the Greek economy some €24 billion less than the Inaction Scenario.

Despite the uncertainty surrounding the adaptation measures and their cost implications for the Greek economy, the results of the cost-benefit analysis on the basis of the general equilibrium model should be considered safe. What this means in practical terms is that it is possible to draw up a suitable adaptation programme that would cost less than the cost savings to be achieved, for the simple reason that adaptation reduces the economic impacts of climate change. This analysis did not take into account the benefit arising from the fact that adaptation, as a preventive policy, serves as a safeguard against climate change-induced extreme implications for the economy. It is, once again, necessary to underscore the great difficulty involved in determining the optimal mix and time planning of adaptation measures. The State should therefore ensure that the adaptation strategy is supported by systematic and proper consultation procedures. This would allow for the strategy to be fine-tuned along the way.

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Chapter 4
Towards a low emissions economy*

4.1 Emissions reduction targets at the global, European and national level

4.1.1 The international and the European framework on climate change

At the 2009 United Nations Climate Change Conference, commonly known as the Copenhagen Summit, held in December 2009, the need to ensure that the temperature rise, relative to the pre-industrial era, does not exceed 2ºC was widely recognised. Such a target can only be achieved if the concentrations of greenhouse gases (GHGs) in the atmosphere are stabilised at 450 ppm.[1] This means that emissions worldwide must be drastically reduced by 2050 to about 50% of their corresponding levels of 1990.

The various countries and regions of the world cannot be held equally responsible for curbing greenhouse gas emissions. Given that emissions from developing economies (China, India, etc.) are likely to increase substantially, the analysis using global energy models —Prometheus (NTUA-E3MLab), POLES (IPTS) and WEO (IEA)— showed that emissions from the OECD countries must be reduced by 80%, relative to 1990 levels, by 2050. In order for this target to be achieved, developing countries will, on their part, have to reduce their emission levels by 25%, relative to 1990, by 2050, a target roughly corresponding to an 80% reduction of their emissions by 2050 given their current growth trends.

The target, therefore, for the European Union is to reduce its greenhouse gas emissions by 80% by 2050, relative to 1990 levels. As an intermediate target, GHG emissions would have to be reduced by 40% by 2030, once again relative to 1990 levels. Both reduction targets must be achieved within Europe. Using the PRIMES energy model (E3MLab), the European Commission in 2010 adopted the so-called "Effort Sharing Decision" which aims to distribute the emission reduction effort fairly among the Member States. Under this distribution, the national target for Greece is for emissions to have been reduced by 70-75% by 2050, relative to 1990.

Given that the energy sector accounts for roughly 80% of all greenhouse gas emissions, and that the drastic reduction of emissions (such as methane) in certain sectors (e.g. agriculture) is

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* This chapter was drawn up by the E3MLab of the National Technical University of Athens, under the scientific supervision of Prof. Pantelis Capros, by researchers Nikolaos Tasios, Xenia Chanioti and Nikolaos Kouvaritakis.

[1] Parts per million.

particularly difficult, meeting the emissions reduction target in the energy sector alone would be sufficient to enable the EU to achieve its overall target, i.e. -80% by 2050 and -40% by 2030.

Therefore, as the emphasis of the challenge of reducing GHG emissions is placed on the energy sector, important changes will be required both on the energy consumption and the energy generation sides.

4.1.2 Global hydrocarbon market trends

In order to formulate assumptions about the future prices of hydrocarbons on the international energy market, an analysis was conducted of the dynamic evolution of global energy supply and demand, using the Prometheus model (NTUA-E3MLab).

The effort to drastically reduce carbon emissions will have repercussions on the international prices of hydrocarbons. These repercussions were therefore also taken into account in the modelling process.

Based on an analysis of the world's oil reserves, along with the trend in global demand, it can easily be concluded that there is likely to be a lot of tension in the oil market in the medium term, if today's trends continue. The decline in oil reserves and the prospect of oil depletion over the next 30-40 years are distinct possibilities. Without an intensive exploitation of unconventional oil reserves, the global oil market will not be able to find its equilibrium in the long term, unless global oil prices increase considerably. Meanwhile, dependence on geopolitically sensitive regions is expected to be high. This reinforces the prospects of a significant and continued rise in oil prices in the medium and the long term.

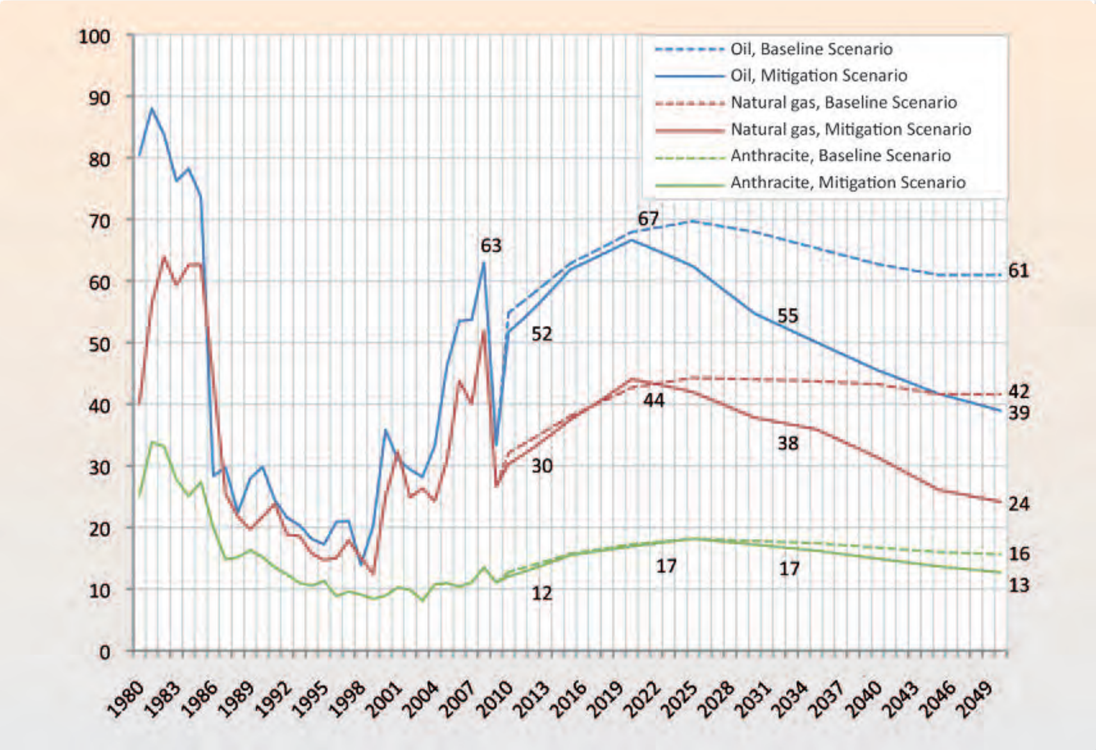
All of these considerations point to the need to achieve oil independence as a major priority of energy strategy. What is more, the pursuit of such a target could be combined with the effort to drastically reduce carbon emissions from the energy sector. By systematically reducing emissions, we can reduce the global demand for oil, thereby easing market pressures and causing global oil prices to drop.

The outlook regarding the world's natural gas reserves seems more favourable, since the production capacity will most likely decline much later than in the case of oil. The prospects of exploiting unconventional natural gas sources, both in the US and elsewhere, substantially improve the outlook for natural gas adequacy and explain why natural gas prices stabilise over the long term.

Nevertheless, in spite of pressure from the market for liquefied natural gas (LNG), the prices of which become particularly competitive in the short term, though not in the long term, the prices of natural gas, according to the analysis, remain linked to those of oil. Consequently, the increases in medium- and long-term oil prices anticipated under current growth trends would lead to a similar increase in natural gas prices.

Europe has been shown to be geopolitically vulnerable in terms of its natural gas supply, due to an insufficient diversification of import sources and delivery routes, combined with a sharp

Figure 4.1 **Projected international hydrocarbon prices (€ per barrel of oil equivalent, 2008 prices)**



Source: PROMETHEUS.

drop in its own reserves. Securing natural gas supply security will remain a top priority of energy strategy, especially in the move to a low-emissions energy system: the demand for natural gas, with its comparatively lower rate of carbon dioxide emissions, is projected to grow.

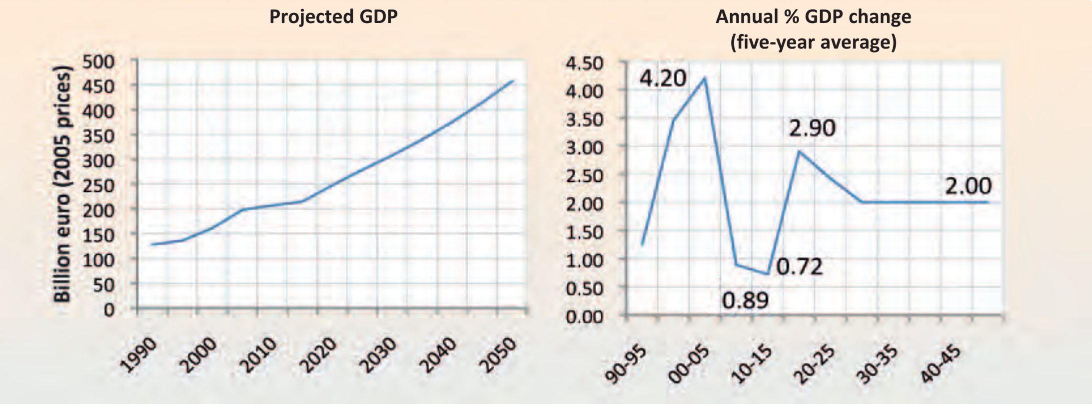
The outlook for the global coal market seems to be one of sufficient global supply, with a fairly low risk of price increases. However, the pursuit of a drastic emissions reduction target would leave no room for coal as a major energy source or as an answer to such issues as supply security and competitive energy costs.

The global price assumptions made for hydrocarbons in the Baseline Scenario and in the Mitigation Scenario (drastic emissions reduction at the global level) are presented in Figure 4.1. As can be seen, the global effort to reduce emissions has a definite depressive effect on the global hydrocarbons markets, causing substantial drops in prices over the long term, relative to the Baseline Scenario.

4.1.3 The future course of the Greek economy

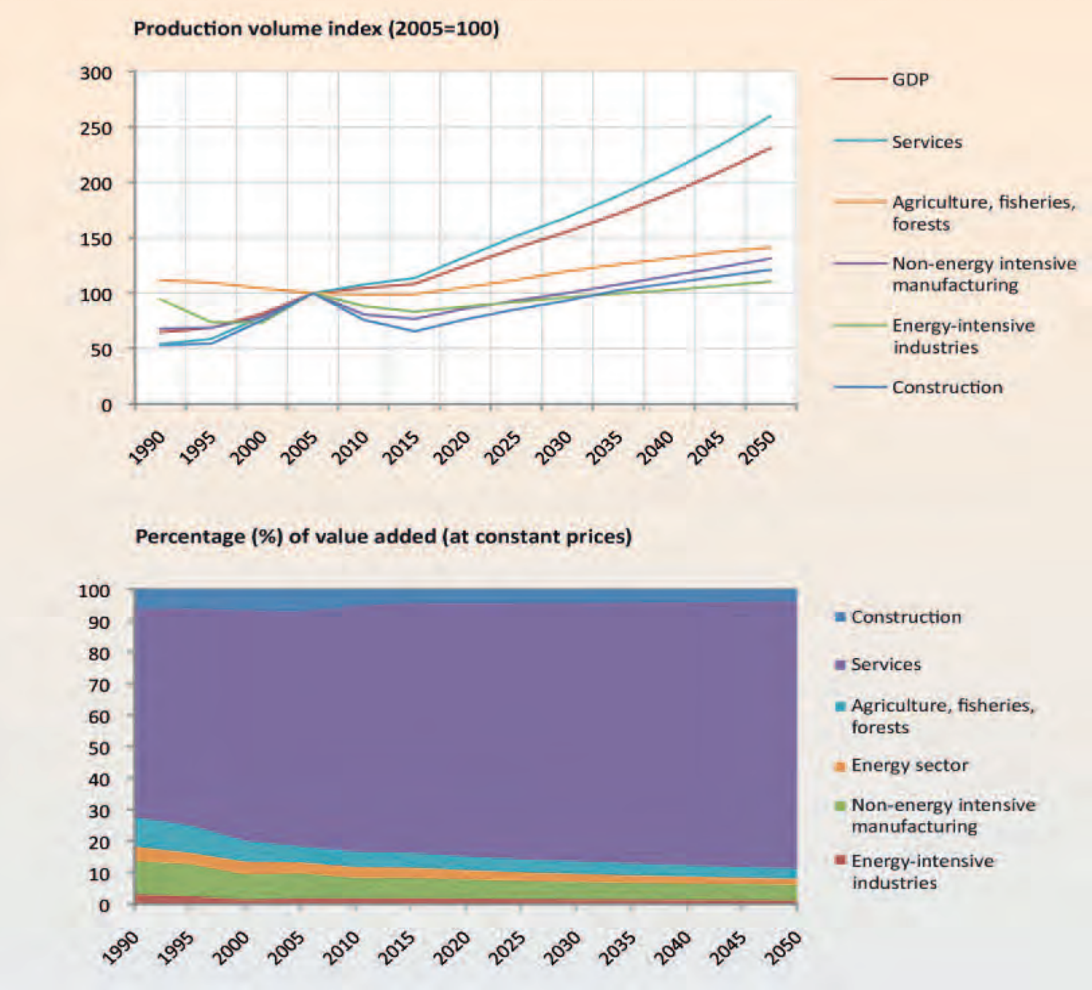
The present analysis involved making quantitative projections about the outlook for the Greek economy, both as a whole (GDP) and per sector of economic activity, using the general equilibrium model GEM-E3 (NTUA-E3MLab).

Figure 4.2 **Projected GDP growth**



Source: GEM-E3.

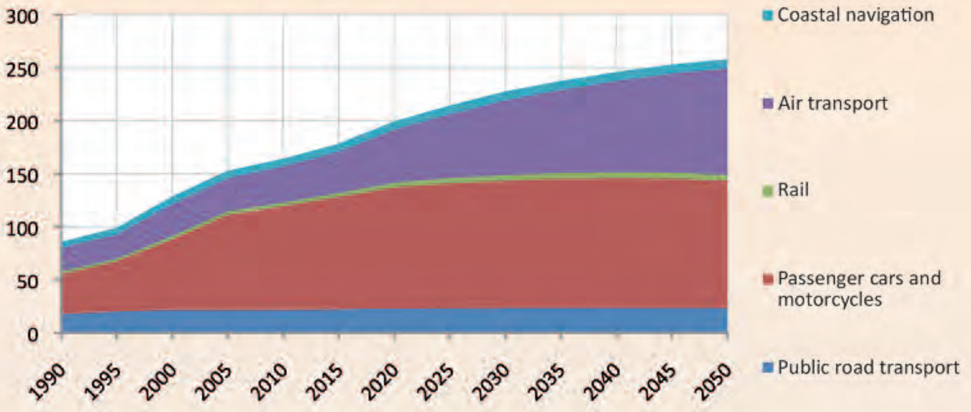
Figure 4.3 **Projected GDP by sector**



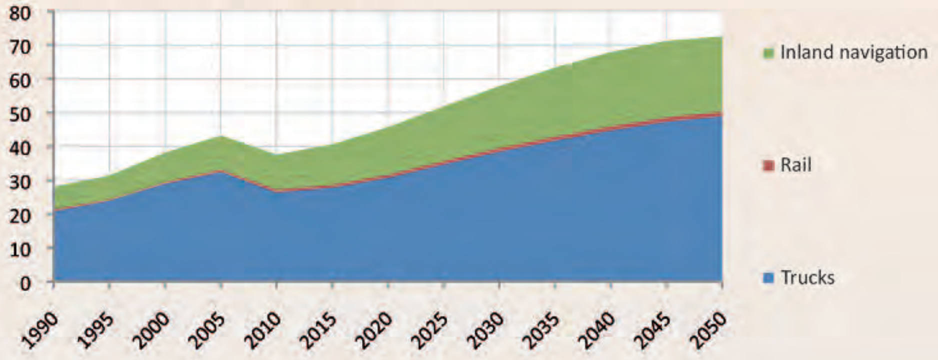
Source: GEM-E3.

Figure 4.4 **Projection of transport activity**

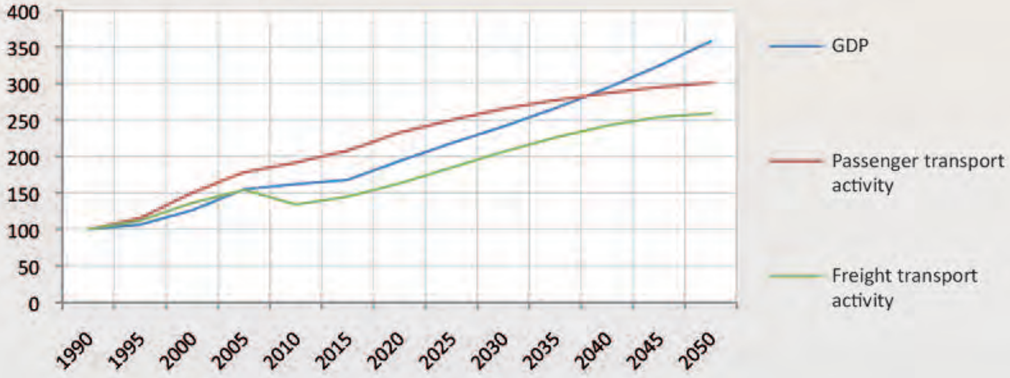
Passenger transport activity (Gpkm)



Freight transport activity (Gtkm)



Activity indices (1990=100)



Source: PRIMES.

The main aspects of these projections (Figures 4.2 and 4.3) can be summarised as follows:

- The economic recession of 2009-2011 has been incorporated in the projections.
- A period of limited growth lasts until end-2013, followed by a protracted period of recovery beginning in 2014 and continuing until the end of the projection horizon.
- Growth in the long term stabilises at 2% per year, after a small slowdown during the period 2020-2030.
- Population growth continues at first, halting in 2030. Thereafter, the population gradually declines.
- Highly energy-intensive industries remain present in Greece.
- Growth is mainly driven by services and low energy-intensive manufacturing.

The projections of transport sector activity (Figure 4.4), made using the mathematical model PRIMES, were based on the assumption of a gradual decoupling of transport activity from GDP and private consumption. It is assumed, in other words, that there will be gradual saturation in transport activity, as compared with economic activity, a trend already observed in other EU countries.

4.1.4 The European framework for energy

The European Union has already adopted a binding set of measures and targets for 2020, which include:

- the EU Emission Trading Scheme (EU ETS) covering emissions from installations such as power generation, large industries and, starting in 2012, the airline industry;
- targets for each Member State regarding the reduction of emissions in sectors outside the EU ETS; and
- targets for each Member State regarding the increase in the overall share of energy from renewable energy sources (RES).

In the same context, the European Union has adopted binding legislation on the energy efficiency of electrical appliances, buildings and houses, as well as on the carbon emissions from transportation.

The targets for 2020 are rather moderate, compared with the effort needed from the EU (and Greece) to avoid a temperature rise of more than 2ºC. The drastic reduction of emissions in the longer term (2050) would obviously require reinforcement of the initial targets and, by extension, of the policy for 2020.

Another major priority for European policy is the completion of the single energy market in Europe, for both electricity and natural gas, which would have indisputable benefits: better management of the EU’s energy dependence on third countries, better quality of services and better prices as a result of enhanced competition, better resource management as a result of inter-regional cooperation (e.g. better incorporation of RES via joint load balancing).

The EU “Climate and Energy” package

In January 2008 the European Commission proposed binding legislation to implement the 20-20-20 targets. This ‘climate and energy package’ was agreed by the European Parliament and Council in December 2008 and became law in June 2009.

The core of the package comprises four pieces of complementary legislation:

1. A revision and strengthening of the Emissions Trading System (ETS), including: a) a single EU-wide cap on emission allowances, to apply as of 2013 and to be reduced annually (by 1.74%), thereby reducing the number of allowances available to businesses to 21% below the 2005 level in 2020; b) the free allocation of allowances will be progressively replaced by auctioning; c) the EU ETS will be expanded to include aviation as from 1 January 2012; and d) beyond 2020, the total number of allowances will continue to be reduced by 1.74% each year.
2. Binding national emissions limitation targets for 2020, which reflect each Member State’s relative wealth.
3. Binding national targets for renewable energy, which collectively will lift the average renewable share across the EU to 20% by 2020.
4. A legal framework to promote the development and safe use of carbon capture and storage (CCS). The EU therefore plans to set up a network of 12 CCS demonstration plants by 2015, with the aim of commercial update of CCS by around 2020.

4.1.5 Evaluation of the current situation in Greece

Compared with other EU countries, Greece’s energy sector is considered to be both less efficient and high emission generating. The transportation sector, both urban and long-distance, is particularly problematic, due to a long list of problems, such as inadequacy of the rail transit system, excessive use of air transport, the low levels of public transport usage, the inefficient expansion of road merchandise delivery, etc.

The only real progress in the energy supply sector achieved so far has been the introduction of natural gas, both for direct use and for power generation. Even so, the introduction of natural gas for direct use has advanced at a slow pace and thus remains limited.

The modernisation of power generation technology has been limited to gas-fired combined-cycle power plants, while outdated, polluting and inefficient plants (solid fuel-fired and oil-fired) remain in operation.

The Greek energy market is also faced with a series of other problems that need to be addressed, such as overdue island interconnection projects, slow development of RES, incomplete competition in the energy market and limited inter-regional cooperation.

If the current trends are allowed to continue, Greece will miss its targets and commitments by a widening margin in all sectors. The negative implications will be considerable, e.g. sizable increases in electricity prices to cover the emissions costs set by the EU ETS.

The Greek government recently submitted to the European Union a binding and rather ambitious programme for the development of RES by 2020. In the present analysis, the implementation of this programme was taken as part of the national effort to overhaul the energy system in line with a drastic reduction in carbon emissions.

4.1.6 The challenges for Greek energy policy

The challenges that Greece's energy policy must meet, both under the mandatory targets set by the EU and as part of its energy sector overhauling effort, are in summary the following:

- a continued and increasingly drastic reduction of carbon emissions from the energy sector, in a move towards an economy of particularly low emissions by 2050,
- a gradual shift away from oil dependence,
- enhancement of the security of the natural gas supply,
- a wide-scale development of renewable energy sources as clean and domestic energy sources,
- a reliable and adequate supply —to all consumers— of energy and energy services,
- achieving the most competitive energy prices and costs possible, and
- reducing access inequality to energy services.

4.2 Policy for emissions reduction per sector

In order to meet the obligations arising from its ratification of the Kyoto protocol and from respective commitments to the EU, Greece drew up a "National Action Programme"[2] for the abatement of GHG emissions over the period 2000-2010. This programme included measures to reduce emissions from the residential and tertiary sector, electricity generation, transport, agriculture, industry and industrial processes.

The need for further drastic emissions reduction by 2050 in the fight against climate change makes the reinforcement and expansion of these measures imperative.

The residential and tertiary sector

There is considerable room for energy saving in this dual sector, considering the old age of many buildings, the low level of RES penetration achieved so far, the low efficiency of energy-hungry appliances, and the irrationality of energy consumption patterns.

The policy for GHG reduction is mainly targeted at saving energy by improving the sector's energy consumption efficiency. This is an indirect way of reducing the emissions from power generation. The main lines of action which the GHG reduction policy has adopted are the following:

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[2] http://www.ypeka.gr/Default.aspx?tabid=431&language=el-GR

- Measures to improve the external envelope of existing buildings, e.g. by insulating the roof or installing double-pane windows to minimise heat loss.
- Measures to improve heating and cooling equipment efficiency, such as the proper maintenance of central heating boilers (or their replacement whenever improvement measures would be ineffective) in order to increase heating efficiency; the use of solar protection techniques (sun shades, ceiling fans, night ventilation) to reduce the buildings' cooling load; the use of more efficient climatisation units, etc.
- Measures to improve electrical appliance and lighting efficiency, such as the use of more efficient appliances, especially domestic (washing machines, television and audio systems, etc.), the use of energy-saving compact fluorescent lamps (with only 25% of the energy consumption of incandescent ones), the installation of automatic lighting control systems (with occupancy sensors, light intensity meters that also take natural lighting into consideration to achieve optimal lighting, etc.). These measures also involve the usage –for lighting purposes– of (freely available) solar energy, as a way to avoid artificial lighting.
- RES penetration in both heating and electrical installations. With the exception of solar panel usage, the degree of RES exploitation still remains low, despite the abundant RES potential present in Greece's natural environment. As part of the effort to reduce emissions, measures should be taken to: increase the share of water heating needs met by solar-powered systems, expand the use of solar energy to space heating (as an auxiliary or back-up system to conventional main heating systems), develop biomass-fired district heating systems (with one central boiler instead of several individual ones), etc. Other measures include simplifying and standardising procedures for the installation and grid-connection of photovoltaic systems, in cases where high costs are not a deterrent (for instance, if alternative energy supplies are even more expensive).
- Expansion of the use of heat pumps, which are not only highly efficient but also use RES, for such purposes as heat recovery, the use of low-enthalpy geothermal energy, etc.
- Increase of the use of natural gas (provided that the distribution network is completed) by promoting a faster rate of natural gas penetration in space heating, as well as the installation of special gas-fired cooling systems.

Transport

The transport sector is responsible for a large part of Greece's CO_2 emissions (27% of total CO_2 emissions in 2010). This is a sector that –with the exception of electric powered means (trolleybuses, urban railway, tram, trains)– is predominantly dependent on liquid fuels, mostly refined from petroleum, and that till now did not have many alternatives to the internal combustion engine.

In the context of emissions reduction, the use of alternative technologies in the transport sector is recommended, especially in land transport, given that there is not much potential for the use of alternative technologies in sea and air transport.

Efforts to reduce emissions from air transport are taking shape with the inclusion of the sector in the Emissions Trading Scheme (ETS).

The scenarios developed in the present study anticipate that oil consumption in the road transport sector will be substituted for by electricity, which in the long term will be produced CO_2-free. The sector's use of electrical energy will increase as plug-in hybrid electric vehicles become more widespread.

Renewable energy sources can play an important role, as biofuels (mainly biodiesel and bioethanol) can be admixed with conventional fuels, thereby limiting emissions considerably as they are produced with second- and third-generation technologies, which reduce emissions along the entire biofuel production chain.

A plethora of other technologies, still at a trial stage and which research is trying to make more competitive, may be available in the future, such as hydrogen fuel cells.

Overall, the implemented measures for reducing emissions in the transport sector can be divided into the following categories:

- Vehicle-related interventions, involving the maintenance of cars and trucks (maintenance of the engine combustion, transmission and breaking systems),
- Measures involving transport system management, e.g. the promotion of urban transport usage, the use of gas-fired buses, better traffic lighting, as well as mild emissions reduction interventions,
- The use of new fuels (more specifically by expanding the use of biofuels) and the promotion of alternative, clean technologies with an emphasis on electricity and, in the longer term, on hydrogen, and
- The implementation of more stringent standards for CO_2 emissions per vehicle kilometre travelled, as well as for vehicle energy efficiency (this measure is expected to be crucial to the future reduction of emissions).

EU policy for reducing transport sector emissions

In 2007, the EU proposed (proposal COM (2007)/856) a Community strategy to reduce emissions from light-duty vehicles (passenger cars and light-commercial vehicles), having as an overall objective that by 2012 the average new car fleet should achieve CO_2 emissions of 120g CO_2/km (corresponding to a 25% reduction of emissions, relative to 2006). The purpose of this strategy is to mitigate emissions from both the production and the consumption side.

On the production side, the strategy provides for the adoption of legislation that will give car manufacturers incentives to reduce the emission levels of new vehicles and to increase the efficiency of vehicle components largely responsible for high fuel consumption, such as air-conditioning systems, special tires, etc. At the same time, fiscal incentives were considered to motivate consumers to purchase fuel-efficient vehicles and save energy.

In April 2009 (Regulation No. 443/2009) the target for average CO_2 emissions from the new car fleet in the Community was set at 130g CO_2/km, to be achieved by means of improvements in vehicle motor technology, while a further 10g CO_2/km reduction should be achieved by additional measures. In the longer-term, i.e. by 2020, the average CO_2 emissions target from the new car fleet should be lowered to 95g CO_2/km.

Industry

The measures taken to reduce the emissions from the industrial sector include:

- Promoting the use of natural gas, mainly as a substitute for crude and diesel oils. This substitution should not be limited to energy-hungry plants with high thermal needs, but should also be promoted in other manufacturing units and diesel-fired operations, while new distribution networks should be developed.
- Promoting the use of RES and heat pumps for the recovery of thermal energy in low- and middle-enthalpy uses.
- Expanding electricity and heat cogeneration to medium- and high-enthalpy applications.
- Promoting the use of biomass in thermal energy applications and in co-combustion furnaces.
- Adopting various energy-saving measures (energy management optimisation and modernisation interventions to reduce heat losses and to re-use the heat discarded by furnaces).

Electricity generation

Any drastic emissions abatement effort must first and foremost involve a total restructuring of electric energy generation. This sector is responsible for the largest part of CO_2 emissions (45% in 2010), but at the same time has the greatest room for emissions reduction, now that a plethora of alternative, clean and sustainable technologies can replace conventional solid fuel-fired stations, predominant today in Greece's electricity generation.

The target, in the fight against climate change, is to achieve almost carbon-free electricity generation. This will make electrical energy a suitable substitute for fossil fuels in final energy uses (through heat pumps in stationary energy plants and transport electrification).

The policy promoted today is focused in this direction and seeks to establish a legal framework that will pave the way to the gradual development of an electricity generation system totally free of carbon emissions. The key lines of this policy involve:

- Promoting wind farm installations, on land and at sea,
- Promoting small hydroelectric plant installations,
- Setting up central and decentralised photovoltaic plants,

- Developing the high-enthalpy geothermal potential,
- Promoting biomass and waste use in electricity generation and cogeneration,
- Enhancing and expanding electrical energy storage systems (pumped storage, in the long term hydrogen storage) and
- Expanding the operation of natural gas plants.

Waste management

In the waste management sector, there is room to reduce methane (CH_4) emissions. It should be noted that methane has an atmosphere warming potential 21 times more potent than CO_2 for a period of 100 years. Actions for the abatement of CH_4 emissions, though of limited potential relative to actions for the reduction of CO_2 emissions, are therefore deemed necessary to address climate change.

Agriculture

Agricultural activity is mainly associated with the emissions of nitrous oxide (N_2O), widely used as a fertiliser. The heat capacity of nitrous oxide is up to 300 times that of CO_2, while the largest part of N_2O emissions results from natural processes occurring in the soil. Biological cultures are being promoted, in order to reduce the use of nitrogen fertilisers and thereby to curb N_2O emissions.

Other policies for this sector involve using animal waste management systems, so as to limit CH_4 emissions from animal husbandry.

Industrial processes

Industrial processes (chemical processing, cooling sprays, aluminium electrolysis, etc.) are all associated with the emissions of fluorinated greenhouse gases, more simply known as f-gases (hydrofluorocarbons-HFCs, perfluorocarbons-PFCs, sulfur hexafluoride-SF_6). In 2000, emissions of these gases in Greece came to 3,744 kilotonnes of CO_2 equivalent. It is also worth noting that the sector of production, use, maintenance and final disposal of refrigeration, air-conditioning equipment, etc. makes up the most dynamic source of emissions, with an average annual growth rate of 20% over the period 2000-2010. In order to reduce these emissions, efforts are being made to: a) redesign the operation of chemical industries (high f-gas emitting plants) and b) recover HFCs from refrigerating and air-conditioning equipment.

4.3 Road map for a transition to a low-emissions economy

The road map for Greece's energy policy to meet the emissions reduction targets was quantified using the PRIMES energy model (E3MLab/NTUA). The model points out the optimal cost-effective way of achieving these targets by simulating the economic and technical decisions of energy producers and consumers, as well as their interactions with the energy markets. The results of the simulation include the optimal mix of energy forms, the penetration of new technologies, the extent of energy saving, the optimal investment programmes broken down per technology and per sector, as well as energy price and cost estimates.

4.3.1 The future course of Greece's energy system: assumptions and constraints

Scenario formulation for the PRIMES model

The scenarios developed using the PRIMES model reflect the optimal course toward a low emissions economy, by means of a near elimination of CO_2 emissions from power generation by 2050. These scenarios are consistent with the targets of reducing emissions at the European level by 40% in 2030 and 80% in 2050, relative to 1990.

In developing these scenarios, the following assumptions and constraints were adopted with regard to energy policy:

- Until 2020, the energy system evolves in such a way as to at least meet the targets and commitments set by the European Union[3] in 2008 and further elaborated by Greece's Ministry of Energy and Climate Change in its action plan for RES. The model simulates the behavioural patterns of energy producers and consumers, taking it as given that emission reduction targets will become more stringent after 2020, for instance by 40% in 2030, thus explaining why producers opt to make certain investments and decisions before 2030.
- For the period beyond 2020, the assumption was made that the pricing of CO_2 emissions is generalised to the entire economy. It was also assumed that the price of CO_2 is the same across all sectors and all EU Member States. Using the PRIMES model, a price for CO_2 was set at a pan-European level that helps achieve the targeted CO_2 emission reductions. It was then considered that Greece, as a small country within the EU, is not in a position to influence CO_2 price levels. These prices are presented in Table 4.1. It should be reminded that polluters subject to the EU ETS scheme will pay the State for their emission allowances, while it was assumed that other polluters (not subject to the EU ETS scheme) will take the price of emissions into account when making decisions, without actually incurring a fine if they don't reduce their emissions.
- Increasing energy consumption efficiency continues to be promoted through the implementation of a package of policy measures for energy saving and the promotion of more efficient appliances and equipment in all sectors. Particular emphasis is placed on energy saving in buildings through a large-scale programme specially devised for the energy

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[3] The EU climate and energy package, http://ec.europa.eu/clima/policies/package/index_en.htm

Table 4.1 **CO_2 price (Euro/t CO_2, 2008 prices)**

		2020	2030	2050
Mitigation Scenarios	ETS sectors	25.0	60.0	190.0
	Non-ETS sectors	25.0	60.0	190.0
Baseline Scenario	ETS sectors	16.5	36.0	50.0
	Non-ETS sectors	5.3	5.3	5.3

Source: PRIMES.

upgrading of houses and buildings. In compliance with EU Directives, tight energy efficiency standards are implemented for a wide range of appliances and industrial equipment, as well as for means of transport.

- The road transport sector undergoes a dynamic penetration of alternative technologies and biofuels, as the result of a specially devised policy, with e.g. strict emission limits per vehicle, mandatory admixture rates for second generation biofuels and mass transport improvement measures. The admixture of biofuels is extended to fuels used by airplanes and ships. In the long term, electricity gradually becomes the main source of energy, as a result of these measures and of advances in battery technology. The road map thus includes the large-scale development of vehicle charging stations immediately after 2020, the use of 'smart' meters and recourse to incentives to recharge during hours of low system load. Responsibility for the development of the system lies with the Network Operator and the costs are covered by a special tax.
- No binding targets are set for energy generation from RES beyond 2020. The support mechanisms for renewable energy sources remain as they are until 2020 and are gradually phased out in the following decade (2020-2030). However, due to the wide scope of the emission reduction targets and to emission pricing, RES continue to expand dynamically beyond 2020 and largely overshoot the 2020 target levels. On a longer horizon, low- and medium-voltage 'smart' grids are developed and thereby facilitate the development of very small-scale RES-fired power generation. In addition, electrical energy storage systems are developed, thanks mainly to pump systems with reservoirs and, in the long term, to hydrogen technologies. The assumption is made that hydrogen could be produced in small quantities in the long term via water electrolysis and mixed with natural gas to fire electricity-generating gas turbines. This way, hydrogen indirectly supports the development of large-scale RES in power generation, while at the same time serving as a storage medium.

The prices of CO_2 emission allowances were determined using the PRIMES model, just as they had been determined in earlier studies of all the EU Member States for the European Commission (2010). This was necessary, given that the auctioning of emission allowances will apply across the EU and its equilibrium will therefore lead to uniform CO_2 prices across the EU.

Given the uncertainty surrounding the future structure of the power generation system, which in any case will have to eliminate emissions in the long term, variations of the 'conducive to a particularly low GHG emissions economy' energy scenario were developed (corresponding to variations of the Mitigation Scenario).

This uncertainty concerns:

a) the upper limits of RES contribution to power generation on condition that an acceptable level of system reliability can be maintained, given that RES production depends on primary energy availability and is therefore stochastic;

b) the capacity to store CO_2 in geological formations, after its capture in large fossil fuel-fired plants (mainly for power generation), given the uncertainty about Greece's geological potential but also about public acceptance of the corresponding storage projects; and

c) the possibility of developing nuclear plants in Greece, which raises highly complex economic and organisational matters, as well as waste management issues.

It is not within the scope of the present study to resolve these technical and policy-related uncertainties. Instead of advocating specific options, we chose to investigate what the impact of the alternative scenarios would be —in terms of power generation costs and structure— assuming in each case that the relevant uncertainty has been resolved.

Three different Mitigation Scenarios were developed for Greece. Their difference, as detailed below, lies in how the country's almost emission-free power generation will be structured in the future:

I. The ***"RES" Mitigation Scenario***, which envisages high RES penetration in power generation and the development of storage techniques. Nuclear energy and carbon capture and storage (CCS) technologies remain absent.

II. The ***"RES and CCS" Mitigation Scenario***, which envisages the development of CCS technologies with carbon dioxide storage in geological formations in Greece. Once again, nuclear energy is absent, but CCS technologies and CO_2 transmission and storage systems are assumed to be available on the market from 2025 onward.

III. The ***"RES and nuclear energy" Mitigation Scenario***, which assumes that nuclear energy can be developed in Greece after 2030, whereas CO_2 storage sites (from CCS projects) are not available.

A ***Baseline Scenario*** was also developed, which assumes that the "20-20-20" policy is fully implemented through 2020, but that no further decisions are made, apart from the implementation of the emission allowances purchase scheme, which basically applies to power generation, large combustion facilities and aviation. The scenario extends until 2050 and can be summarised as follows:

- The Emission Trading Scheme (EU ETS) is implemented, under the further assumptions that: (a) the total number of emission permits issued is progressively reduced by 2050; (b) EU ETS regulations are extended to power generation, heavy industry and aviation; and (c) all emission permits are auctioned as of 2013. Non-ETS sectors are subject to certain emission caps as of 2015 (less stringent than under the EU ETS and constant through 2050).
- Greece's announced policy for RES is simulated by assuming that renewables account for close to 40% of power generation until 2020. Beyond 2020, however, no further binding targets are set, while subsidies for RES technologies are gradually phased out, particularly in cases where know-how is limited. The contribution of these technologies nonetheless remains high.
- The EU directives and regulations aimed at improving the energy efficiency of buildings, houses, electrical appliances and transport are adopted, but implementation is assumed to enjoy limited financial support and to be of moderate intensity, in contrast with the Mitigation Scenarios, under which financial support policies are developed to the maximum extent possible.
- With the exception of nuclear and CCS technologies, all other power generation technologies are considered to be available to Greece and eligible for investment.

To allow for comparability and for assessments of the policy contained in the Mitigation Scenarios, another scenario, the ***"No Policy" Scenario***, was developed which assumes that no emission reduction policies (including RES penetration and energy efficiency improvement) are implemented. This scenario is purely market-based, without any state intervention or policy targets.

Scenarios developed using the PRIMES model for the period 2010-2050

Baseline Scenario: the policy in effect in Greece and the EU remains in place until 2020 and is extended until 2050, without any ambitious emission abatement targets set. The EU ETS mechanism also remains in effect until 2050.

Mitigation Scenarios: CO_2 emission reductions by 2050 of 80% at the European level and of 75% for Greece. Alternative scenarios are envisaged with regard to the future structure of power generation:

- The *"RES"* Mitigation Scenario
- The *"RES and CCS"* Mitigation Scenario
- The *"RES and nuclear energy"* Mitigation Scenario

4.3.2 Scenarios concerning the evolution of the Greek energy system in response to the mitigation targets

Findings of the study using the PRIMES energy model

The quantification of the Mitigation Scenarios using the PRIMES model outlines a road map for achieving the target of an 80% reduction of greenhouse gas emissions by 2050. This road map includes:

- energy efficiency enhancement in buildings, electrical appliances, industrial processes, etc.;
- energy savings of 20% by 2030 and of 50% by 2050, relative to the “No Policy” Scenario;
- RES participation in final energy consumption above 20% by 2030 and 35% by 2050, against 13% in 2010,
- Participation of RES in power generation (14.5% in 2010) as follows:
  - 66% by 2030 and 83% by 2050 under the *“RES” Mitigation Scenario,*
  - 47% by 2030 and 43% by 2050 under the *“RES and CCS” Mitigation Scenario,*
  - 49% by 2030 and 51% by 2050 under the *“RES and nuclear energy” Mitigation Scenario,*
- Road transport electrification of 25% by 2030 and 85% by 2050,
- Production of 500,000 tonnes (of oil equivalent) biofuels by 2030 and 2,65 million tonnes by 2050 for admixture with diesel oil products, against 135,000 tonnes in 2010, and
- Infrastructure upgrading and expansion to ensure island interconnection, transport electrification and the connection of very small scale RES to low-voltage grids.

The methodology used for the simulation of the emissions reduction effort

The pricing of CO_2 can serve as a key incentive tool in promoting the transition to a low-emissions economy.

By steadily increasing CO_2 prices, energy producers are compelled to pay increasingly more for emission allowances, a cost which they pass on to consumers by charging higher prices for energy. Energy producers are thus motivated to “reconsider” their energy generation mix as a way of cutting back on costs and thus deliberately choose to spend more on energy forms that are more capital-intensive, but less carbon-intensive. This restructuring also benefits consumers, as the impact on energy prices is mitigated.

Consumers, on their side, are faced not only with higher energy prices, but also with higher costs from their own direct emissions. They are therefore motivated to “reconsider” their energy consumption mix, in favour of less carbon-intensive energy forms, while also proceeding to energy saving investments and purchases of electrical appliances, equipment and vehicles that cost more to purchase, but less to operate because of their greater energy efficiency and fewer emissions.

All energy market participants spend more on capital and less on operating costs, in comparison with the Baseline Scenario.

CO_2 pricing can thus serve as a motivational tool for substituting existing technologies with lower-emission technologies. Such a substitution cannot be perfect, which explains why total energy costs are higher under the Mitigation Scenario than under the Baseline Scenario.

The impact of the Mitigation Scenarios on GHG emissions

As shown by the results presented in Table 4.2, if no policy is adopted, Greece's greenhouse gas emissions would continuously increase and by 2050 would exceed 1990 levels by 55%, an outcome totally incompatible with a global effort to avert climate change.

Table 4.2 also gives a projection of current policies, reflected in the Baseline Scenario. In spite of the ambitious policies contained in this scenario, especially for the 2020 time horizon, the absence of additional climate policies makes this scenario insufficient in the context of the effort to avert climate change. In the Baseline Scenario, greenhouse gas emissions by 2050 are reduced by a mere 6% relative to 1990 levels, against the reduction target of 'minus 70-80%' adopted by the EU. Additional large-scale climate policies are thus required, particularly in the period beyond 2020, so as to bring Greece's emissions into line with the target for limiting the increase in the Earth's temperature to 2ºC.

These additional policies are outlined in the three variations of the Mitigation Scenarios that achieve a reduction in Greece's greenhouse gas emissions by between 58% and 63% in 2050, relative to 1990 levels, and equivalent to a reduction by about 70%, relative to the emission levels of 2005.

Using the mathematical model, we determined the optimal cost-effective distribution of the greenhouse gas emissions reduction among the sectors of economic activity (Table 4.3), taking into account each sector's emissions reduction potential through various actions. The model considered that the costs of each action increase in a non-linear manner depending on how it has developed relative to its potential. This way, the optimal distribution of the emissions reduction effort among the sectors includes all actions as well all sectors, without exhausting the potential. When trying to ensure maximum adaptation flexibility as well as a reduction in total costs, it is important that no actions be omitted, especially in the power generation sector. This is why, as mentioned above, alternative scenarios were examined.

The drastic abatement of greenhouse gas emissions was found to be similar in all three variations of the Mitigation Scenario (Figure 4.5).

Figure 4.6 illustrates how the reduction of CO_2 emissions from the energy sector, relative to 2005 emission levels, is achieved, by distributing this reduction among the different ways of achieving it, according to the modelling results for each Mitigation Scenario.

Of all the ways of reducing emissions, energy saving consistently makes the largest contribution, as it accounts, cumulatively over the period 2005-2050, for more than 40% of the total reduction. RES account for a share of 48% under the "RES" Mitigation Scenario and for 30% and 39%, respectively, under the other two Mitigation Scenarios. CO_2 capture and storage accounts for 19% of total emissions reduction, but is only developed under the "RES and CS" Mitigation Scenario. The contribution of nuclear energy, only envisaged under the "RES and nuclear energy" Mitigation Scenario, is small. Natural gas, as a substitute for other fossil fuels, accounts for between 9% and 12% of total emissions reduction.

Table 4.2 Greenhouse gas emissions by scenario derived with the PRIMES model in million tonnes of CO_2 equivalent

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
No Policy Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	90.2	91.8	100.2	103.8	107.7	110.9	117.2	123.1	132.8
Industry	9.3	9.8	9.9	8.2	6.1	5.7	6.0	5.4	5.6	5.7	6.0	6.2	6.5
Household sector	4.6	4.8	7.5	9.7	9.8	9.7	10.6	11.9	12.6	12.9	13.0	13.0	12.8
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.7	1.9	1.9	2.0	2.1	2.1	2.2
Agriculture	2.7	2.6	2.6	2.7	2.7	2.6	2.7	2.7	2.7	2.8	2.9	3.1	3.2
Transport	17.2	19.1	21.3	23.9	23.4	24.8	27.4	28.8	30.2	31.3	32.6	33.8	35.2
Electricity generation	34.1	39.0	43.9	46.3	44.0	44.9	49.0	50.0	51.5	53.1	57.6	61.7	70.0
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.7	2.9	3.1	3.2	3.1	3.1	3.2	3.1
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	22.7	22.8	23.0	23.1	22.2	22.7	23.5	24.2
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.4	6.8	7.1	7.6	8.0
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	17.4	17.1	16.8	16.4	15.2	15.3	15.7	15.9
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	115.1	114.5	123.0	126.8	130.8	133.1	139.9	146.6	157.1
Baseline Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	84.4	74.6	76.2	79.1	74.7	68.8	69.7	70.8	73.5
Industry	9.3	9.8	9.9	8.2	6.0	5.0	4.1	4.0	3.9	3.9	4.0	4.2	4.5
Household sector	4.6	4.8	7.5	9.7	9.7	9.3	9.8	10.4	10.7	10.4	10.0	9.6	8.9
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.6	1.5	1.5	1.6	1.6	1.7	1.7
Agriculture	2.7	2.6	2.6	2.7	2.7	2.6	2.6	2.5	2.5	2.6	2.7	2.8	2.9
Transport	17.2	19.1	21.3	23.9	23.0	23.3	23.9	24.9	25.0	25.2	25.9	26.7	27.7
Electricity generation	34.1	39.0	43.9	46.3	38.7	30.4	31.9	33.4	28.6	22.8	23.2	23.5	25.5
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.6	2.4	2.4	2.4	2.3	2.3	2.3	2.3
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	22.2	21.0	21.2	20.5	20.3	20.6	21.2	21.7
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.3	6.6	6.7	7.0	7.2
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	16.9	15.3	15.1	14.1	13.6	13.7	14.1	14.3
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	109.3	96.7	97.3	100.4	95.2	89.1	90.2	92.0	95.1

Source: PRIMES.

Table 4.2 Greenhouse gas emissions by scenario derived with the PRIMES model in million tonnes of CO_2 equivalent *(continued)*

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
RES Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	84.3	73.1	68.6	64.0	54.3	46.3	38.0	30.8	24.9
Industry	9.3	9.8	9.9	8.2	6.0	5.1	4.0	3.8	3.8	3.5	3.2	2.6	2.0
Household sector	4.6	4.8	7.5	9.7	9.7	9.1	9.3	9.8	9.9	9.0	7.5	6.0	3.9
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.5	1.4	1.3	1.2	0.8	0.5	0.3
Agriculture	2.7	2.6	2.6	2.7	2.7	2.5	2.4	2.4	2.3	2.1	1.8	1.0	0.3
Transport	17.2	19.1	21.3	23.9	23.0	23.3	23.4	23.5	23.6	20.2	17.4	13.1	11.1
Electricity generation	34.1	39.0	43.9	46.3	38.7	29.2	25.6	21.0	11.2	8.5	5.8	6.2	6.2
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.6	2.3	2.2	2.1	1.8	1.6	1.3	1.2
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	20.6	20.4	20.4	19.1	17.7	15.9	13.3	12.7
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.0	5.1	3.5	0.9	0.6
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0	0.0
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	15.4	14.7	14.4	13.0	12.6	12.3	12.3	12.1
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	109.3	93.7	88.9	84.5	73.4	64.1	53.9	44.1	37.5
Combined RES and CCS Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	84.3	73.0	70.2	50.7	51.6	46.7	41.6	33.9	26.6
Industry	9.3	9.8	9.9	8.2	6.0	5.1	4.0	3.8	3.8	3.5	3.2	2.6	2.0
Household sector	4.6	4.8	7.5	9.7	9.7	9.1	9.3	9.8	10.0	9.1	7.6	6.1	4.0
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.5	1.4	1.3	1.2	0.8	0.5	0.3
Agriculture	2.7	2.6	2.6	2.7	2.7	2.5	2.4	2.4	2.3	2.2	2.0	1.6	0.7
Transport	17.2	19.1	21.3	23.9	23.0	23.3	23.4	23.5	23.6	20.2	17.4	13.1	11.1
Electricity generation	34.1	39.0	43.9	46.3	38.7	29.2	27.2	7.6	8.5	8.8	9.1	8.6	7.4
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.6	2.3	2.2	2.1	1.8	1.6	1.4	1.2
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	20.6	20.4	20.4	19.1	17.7	15.9	13.3	12.7
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.0	5.1	3.5	0.9	0.6
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	15.4	14.7	14.4	13.0	12.6	12.3	12.3	12.1
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	109.3	93.7	90.6	71.1	70.7	64.5	57.5	47.2	39.3

Source: PRIMES.

Table 4.2 **Greenhouse gas emissions by scenario derived with the PRIMES model in million tonnes of CO_2 equivalent *(continued)***

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Combined RES and Nuclear Energy Scenario													
Emissions from fossil fuel combustion	71.1	78.0	88.9	95.8	84.3	73.0	70.1	69.5	60.0	49.4	44.1	35.9	30.4
Industry	9.3	9.8	9.9	8.2	6.0	5.1	4.0	3.8	3.8	3.5	3.1	2.6	2.0
Household sector	4.6	4.8	7.5	9.7	9.7	9.1	9.3	9.8	10.0	9.1	7.6	6.1	4.0
Services	0.6	0.6	0.8	1.5	1.4	1.3	1.5	1.4	1.3	1.2	0.8	0.5	0.3
Agriculture	2.7	2.6	2.6	2.7	2.7	2.5	2.4	2.4	2.3	2.2	2.0	1.6	0.7
Transport	17.2	19.1	21.3	23.9	23.0	23.3	23.4	23.5	23.6	20.2	17.4	13.1	11.1
Electricity generation	34.1	39.0	43.9	46.3	38.7	29.2	27.1	26.4	16.9	11.4	11.6	10.7	11.2
Other energy industries	2.4	2.2	3.1	3.5	2.8	2.6	2.3	2.2	2.2	1.8	1.6	1.4	1.2
Emissions from non-energy related activities	30.3	30.8	31.6	31.8	25.0	20.6	20.4	20.4	19.1	17.8	15.9	13.3	12.7
CO_2 emissions from industrial processes	6.9	7.5	7.9	8.0	6.1	5.0	5.5	5.9	6.0	5.1	3.5	0.9	0.6
Other CO_2 emissions	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0
Emissions of other greenhouse gases	23.1	23.2	23.5	23.5	18.7	15.4	14.7	14.4	13.0	12.6	12.3	12.3	12.1
Total greenhouse gas emissions	101.4	108.9	120.5	127.5	109.3	93.7	90.4	89.9	79.1	67.1	60.0	49.2	43.1

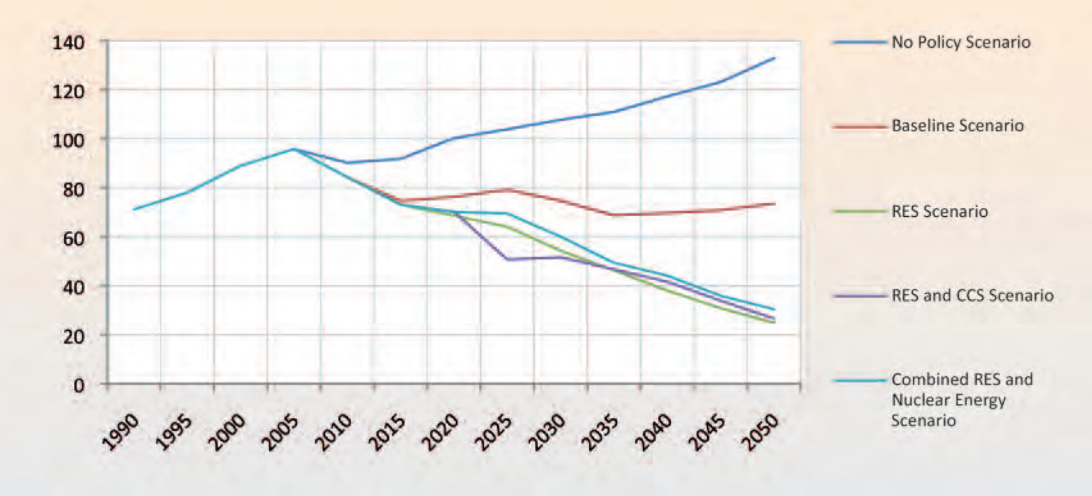
Source: PRIMES.

Table 4.3 **Reduction of greenhouse gas emissions under the Mitigation Scenario**

RES Scenario	Percentage change relative to the Baseline Scenario 2020			Percentage change relative to the No Policy Scenario		
	2020	2030	2050	2020	2030	2050
Emissions from fossil fuel combustion	-10.1	-27.3	-66.2	-31.6	-49.6	-81.3
Industry	-2.4	-3.6	-55.9	-33.6	-33.0	-69.6
Household sector	-4.5	-7.8	-56.9	-11.8	-21.5	-69.9
Services	-5.8	-13.1	-83.6	-11.6	-28.6	-87.0
Agriculture	-4.3	-8.9	-90.7	-7.6	-14.6	-91.5
Transport	-2.3	-5.5	-59.9	-14.7	-21.8	-68.4
Electricity generation	-19.7	-60.8	-75.7	-47.7	-78.3	-91.1
Other energy industries	-3.4	-10.5	-48.2	-18.1	-33.1	-62.1
Emissions from non-energy related activities	-3.2	-7.0	-41.4	-10.7	-17.1	-47.6
CO_2 emissions from industrial processes	-0.3	-5.2	-91.6	-0.5	-6.2	-92.5
Other CO_2 emissions	-7.0	-18.6	-77.9	-25.9	-47.8	-88.7
Other greenhouse gas emissions	-4.2	-7.6	-15.7	-13.8	-20.9	-24.4
Total greenhouse gas emissions	-8.6	-22.9	-60.5	-27.7	-43.9	-76.1

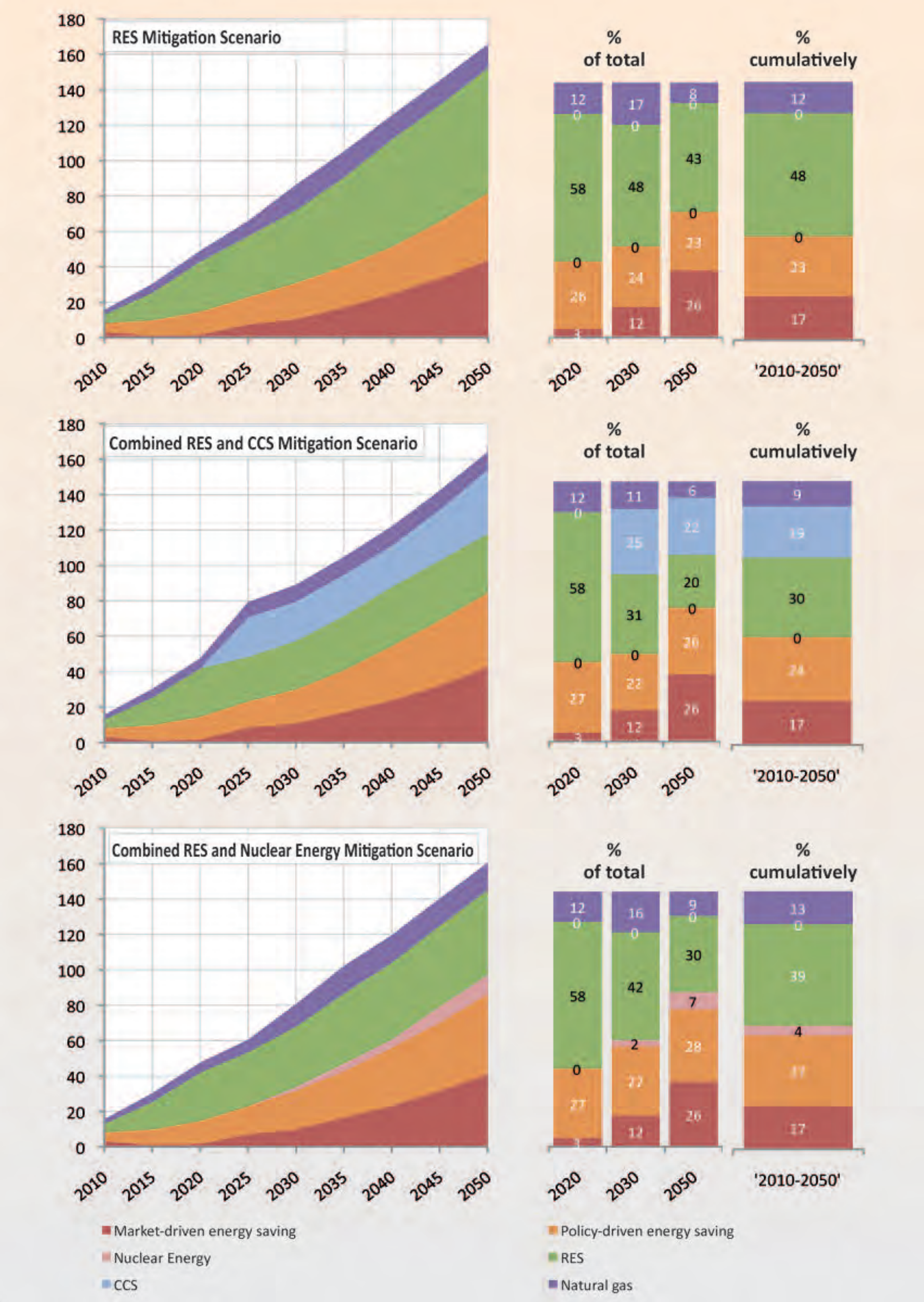
Source: PRIMES.

Figure 4.5 **Total greenhouse gas emissions in million tonnes of CO_2 equivalent**



Source: PRIMES.

Figure 4.6 Breakdown of emission reduction options in the energy sector relative to 2005 levels in million tonnes of CO_2



Source: PRIMES.

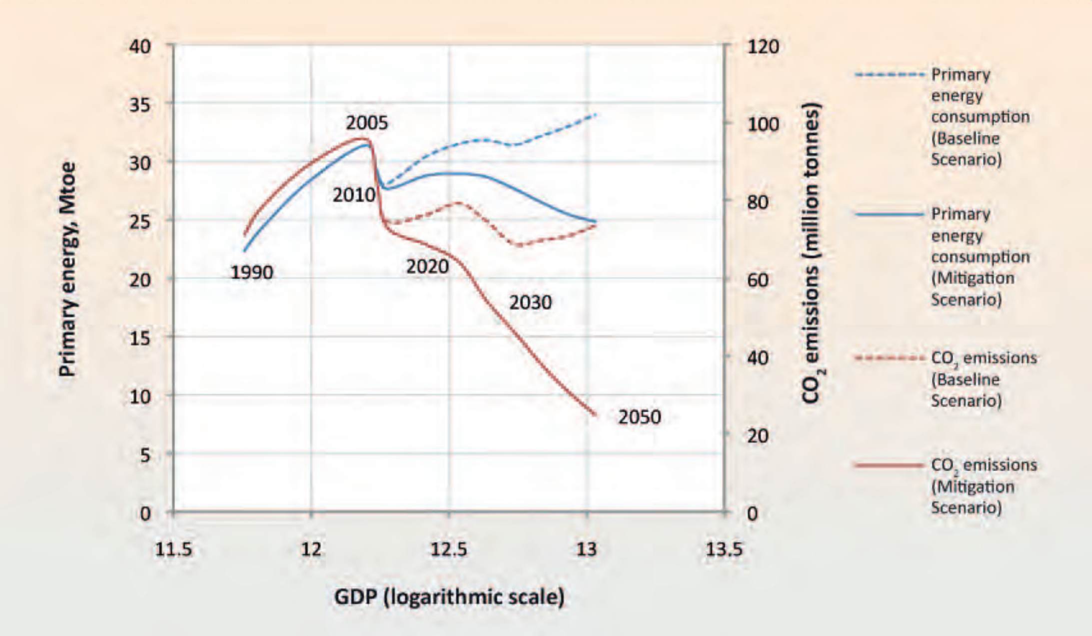
The importance of energy saving

Improving energy efficiency together with energy saving is probably the most important category of actions for reducing emissions: any decrease in energy demand produces the effect of reducing emissions both directly, i.e. in final consumption, and indirectly, i.e. in energy generation. It is also the most economical means of reducing emissions. There are, however, numerous obstacles to the adoption of extensive action for energy saving, which ensue from the fact that such decisions fall to individuals and small-scale businesses.

Energy saving is achieved whenever a consumer decides, for instance, to spend more on equipment or on a home upgrade with the expectation of having to paying less from that point on for the operation of such equipment. Such decisions are based on subjective criteria, usually including high discount rates (definitely higher than the ones used by large businesses or the state) and a risk factor resulting from inadequate information about new technologies and their efficiency. As a result of these factors, energy saving decisions, found to be efficient by feasibility studies, end up being rejected in practice.

To eliminate such obstacles, the state needs to take a decisive course of action with a series of policy measures that include: enforcing strict standards and regulations, launching extensive information campaigns, developing third party-financing mechanisms involving Energy Service Companies (ESCOs), and setting up a certificate trading scheme for energy saving projects, such as white certificates.

Figure 4.7 **Decoupling of GDP from CO_2 emissions and energy consumption**



Source: PRIMES.

Table 4.4 **Energy intensity and CO_2 emissions intensity indexes for the Greek economy under the Mitigation Scenarios**

	2010	2020	2030	2050
RES Mitigation Scenario				
CO_2 emissions (Mt)	84.36	68.58	54.26	24.85
Energy intensity (toe/M€05)	141.05	116.42	93.22	54.31
Correlation between emissions and GDP (t CO_2/M€05)	408.22	277.60	176.49	54.40
Carbon intensity of energy (t CO_2/toe of primary energy)	2.89	2.38	1.89	1.43
Combined RES and CCS Mitigation Scenario				
CO_2 emissions (Mt)	84.36	70.20	51.59	26.61
Energy intensity (toe/M€05)	141.05	117.59	102.72	62.71
Correlation between emissions and GDP (t CO_2/M€05)	408.22	284.16	167.84	58.25
Carbon intensity of energy (t CO_2/toe of primary energy)	2.89	2.42	1.63	0.93
Combined RES and Nuclear Energy Mitigation Scenario				
CO_2 emissions (Mt)	84.36	70.07	60.02	30.38
Energy intensity (toe/M€05)	141.05	117.46	96.63	57.93
Correlation between emissions and GDP (t CO_2/M€05)	408.22	283.61	195.24	66.50
Carbon intensity of energy (t CO_2/toe of primary energy)	2.89	2.41	2.02	1.15

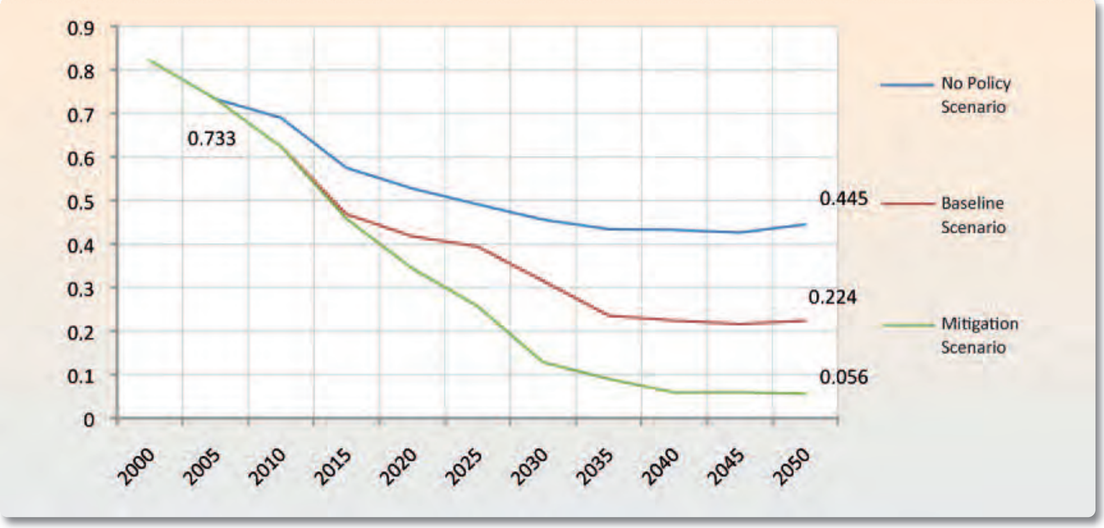
Source: PRIMES.

In pursuing the effort to reduce climate change-inducing emissions, as shown by the analysis, it is of the utmost importance that economic recovery and GDP growth take place in conjunction with a restructuring of the energy system that decouples GDP growth from an increase in emissions. Under the Mitigation Scenario, energy saving and increased energy efficiency in all sectors needs to reach levels such that total energy consumption is fully decoupled from GDP growth and total energy consumption is continuously reduced in absolute terms, relative to the levels of 2010. This decoupling from GDP in the Mitigation Scenario is immediately visible from Figure 4.7, which also illustrates that current policies (Baseline Scenario) are not sufficient to drive total energy consumption down to levels compatible with the Mitigation Scenario targets.

The pivotal role of electrical energy in the Mitigation Scenarios

As shown by the model analysis, electrical energy crucially affects the reduction of emissions to targeted levels, in three different manners: via the near elimination of CO_2 emissions from power generation; via the expansion of electrical energy to other final energy uses, thanks mainly to heat pumps and other methods; and via generalised road transport electrifi-

Figure 4.8 **Carbon intensity of electricity generation ($t\ CO_2/MWh$)**



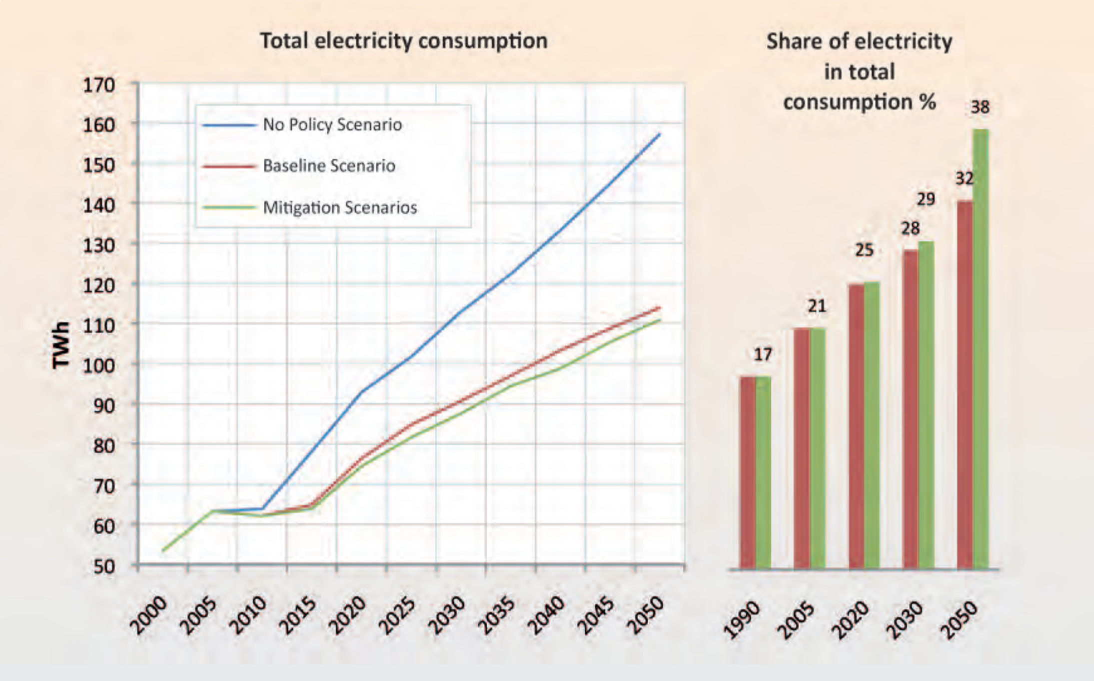
Source: PRIMES.

cation. The analysis also showed that the use of electrical energy in final energy uses leads to a spectacular improvement in energy efficiency across all sectors, including road transport. Expanding the use of electrical energy to final uses will require policy measures as well as new infrastructures, and would be pointless if not coordinated with a drastic reduction of emissions in power generation.

The carbon intensity of power generation (Figure 4.8) drops impressively in the Mitigation Scenarios, making electrical energy almost emission-free in the long run and therefore a suitable substitute for fossil fuels in final energy uses. The corresponding carbon intensity reduction in the Baseline Scenario (relative to the "No Policy" Scenario), though important, is not sufficient to drastically reduce total emissions in the energy system.

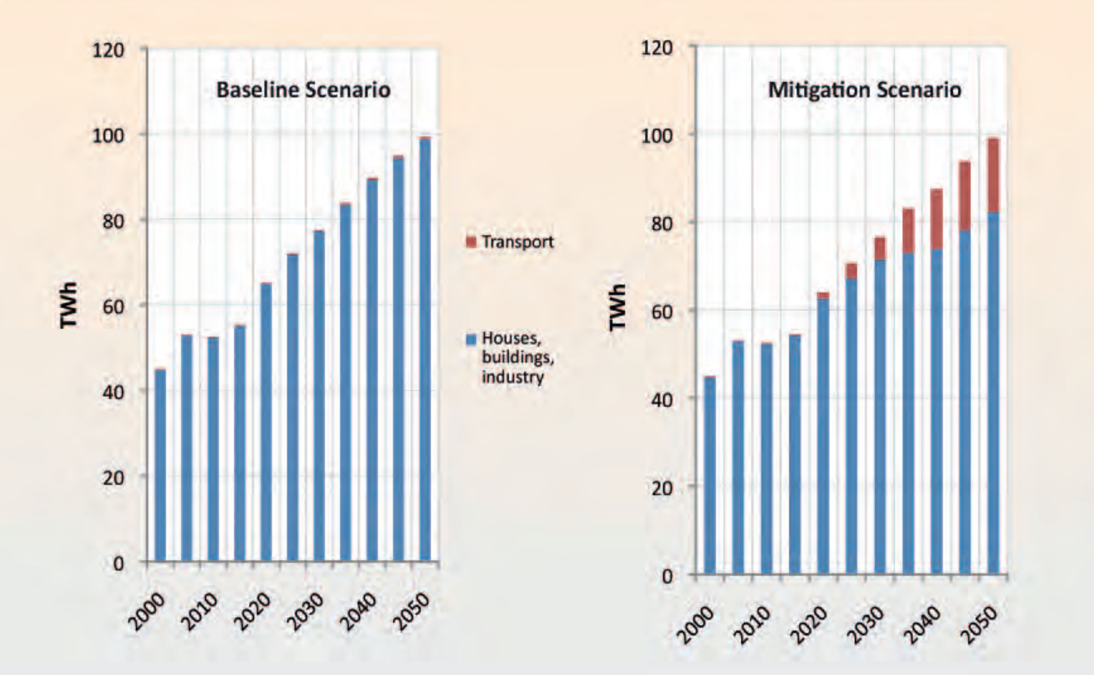
As shown by the results of Figure 4.9, electrical energy accounts for a larger share of total final energy consumption in all the variations of the Mitigation Scenario than in the Baseline Scenario. At the same time though, electrical energy consumption in absolute figures is lower in the Mitigation Scenarios than in the Baseline Scenario, and much lower than in the "No Policy" Scenario, on account of the greater effort under the Mitigation Scenarios to save energy and improve energy efficiency. Thanks to energy saving, energy consumption (including electrical energy consumption) decreases under the Mitigation Scenarios in the residential, buildings and industrial sectors, relative to the other scenarios. This decrease counterbalances the same-sized increase in electricity consumption in transport, which is spectacular under the Mitigation Scenarios, whereas under the other scenarios road transport electrification is not developed. Without the energy savings achieved under the Mitigation Scenarios, any additional

Figure 4.9 **Electricity consumption and share in final energy consumption**



Source: PRIMES

Figure 4.10 **Electricity consumption by sector**



Source: PRIMES.

energy consumption in transport would burden power generation and make the decoupling from CO_2 emissions more difficult (see Figure 4.10).

The Mitigation Scenario shows precisely what the results of a “systemic” approach in energy and environmental policy would be, when actions are coordinated across energy production and consumption sectors.

The decision to restructure power generation in the direction of a drastic reduction of emissions is, therefore, of pivotal importance, but will require time and perseverance to avoid any unwanted impacts on supply security and reliability. Apart from securing the right conditions for the realisation of the necessary investments in power generation, grid and interconnection infrastructure will have to be painstakingly developed over a number of years. Expenditure levels would therefore increase multifold, relative to today’s levels.

Shifting away from fossil fuel dependence is a long and complex process, which needs to be tackled early on. The target of achieving near-zero carbon emissions in power generation proves to be feasible, but nonetheless hinges upon crucial strategic decision-making during the period 2015-2030. If such strategy adjustments are not made in time, the cost of achieving the Mitigation Scenario targets (in the form of cumulative greenhouse gas emissions in the period 2010-2050) will be considerably higher.

RES development is central to all the Mitigation Scenarios

Because of Greece’s sizeable renewable energy source potential, all variations of the Mitigation Scenario assume a notable development of RES usage, particularly in power generation. Even the current policies, reflected in the Baseline Scenario, are centred on substantial RES development, relative to today’s particularly low levels.

Table 4.5 presents the RES indicators, estimated in the same way as Eurostat’s energy indicators, according to the modelling results obtained for the various scenarios. The European Commission uses these ratios to monitor Member State compliance with what is known as the “RES Directive”.

The Baseline Scenario attains the RES-related targets by 2020 (see “overall RES indicator”) and further improves them in the long term. All three variations of the Mitigation Scenario achieve considerably higher RES indicators relative to the Baseline Scenario, due, on one hand, to lower energy consumption as a result of extensive energy saving in these scenarios (consumption is part of the RES indicator denominator) and, on the other hand, to the drastic reduction of CO_2 emissions. Worth noting is the spectacular increase in the RES indicator in heating and cooling in the Mitigation Scenarios, as compared with the Baseline Scenario, as well as the strong increase in the RES indicator in transport, attributable in part to biofuels, but mostly to transport electrification in conjunction with the large share of RES in power generation.

Table 4.5 **Renewable energy indicators (by Eurostat) as a percentage of gross final energy consumption under the different scenarios**

	2000	2010	2020	2030	2040	2050
Baseline Scenario						
RES for heating-cooling	13.7	13.0	22.9	16.9	17.2	17.6
RES for electricity generation	7.1	14.8	38.7	45.6	48.3	44.4
RES for transport	0.0	2.2	8.1	9.0	9.6	9.5
General RES indicator	7.2	9.3	21.5	22.8	24.9	24.4
RES Mitigation Scenario						
RES for heating-cooling	13.7	13.0	23.8	19.6	23.3	34.8
RES for electricity generation	7.1	14.8	45.7	62.8	78.2	77.4
RES for transport	0.0	2.2	9.1	16.4	46.8	64.2
General RES indicator	7.2	9.3	23.8	29.3	45.4	61.6
Combined RES and CCS Mitigation Scenario						
RES for heating-cooling	13.7	13.0	23.8	19.1	21.8	32.6
RES for electricity generation	7.1	14.8	43.7	44.6	44.8	40.5
RES for transport	0.0	2.2	9.1	13.9	36.6	51.5
General RES indicator	7.2	9.3	23.3	23.8	31.5	41.1
Combined RES and Nuclear Energy Mitigation Scenario						
RES for heating-cooling	13.7	13.0	23.8	19.0	21.8	32.6
RES for electricity generation	7.1	14.8	43.8	49.9	51.7	46.1
RES for transport	0.0	2.2	9.1	14.7	38.9	53.7
General RES indicator	7.2	9.3	23.3	25.1	34.1	44.3

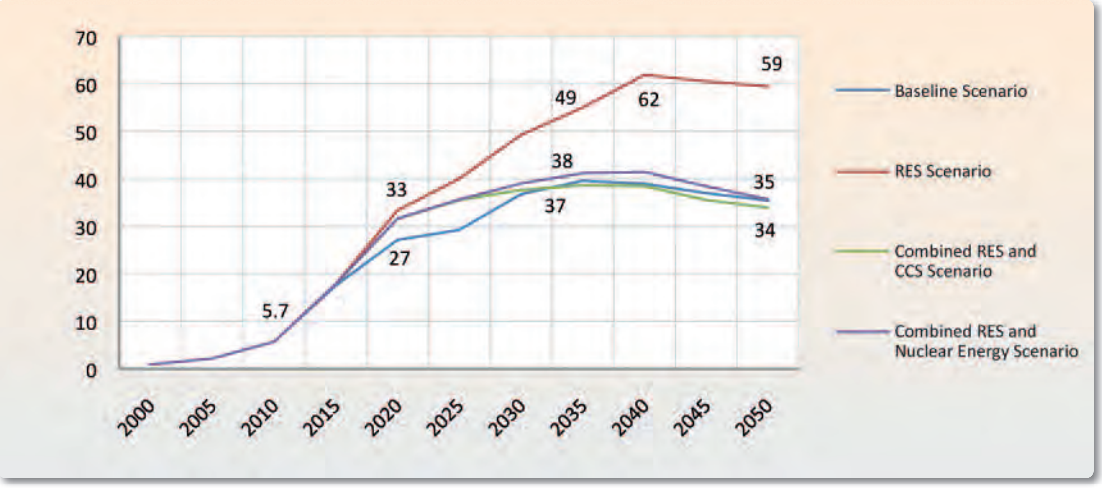
Source: PRIMES.

Organising Greece's future power generation system around a large participation of RES is a major economic and technical challenge. Stochastic RES generation (with wind turbines and solar panels) is determined by primary energy availability, and not by System Operator decision-making. A system with a high share of stochastic RES will require a large back-up thermal capacity or large storage systems. Insufficient storage capacity would mean that, during low load periods, stochastic RES generation would have to be cut back. Market organisation would also be different from today's, given that energy producers would be paid pre-determined feed-in tariffs.

These particular matters also apply to the Baseline Scenario, particularly for the 2020 time horizon, with 30% of generation projected to come from stochastic RES.

Under the *"RES" Mitigation Scenario*, the share of stochastic RES must be increased further to roughly 60% after 2035. Serious technical and financing matters will need to be resolved

Figure 4.11 **Stochastic RES in electricity generation (in percentages)**



Source: PRIMES

to ensure the reliability and cost-effectiveness of the electric system's operation. Our simulation with the mathematical model was based on the assumption that hydroelectric and hydrogen storage systems will be developed, in combination with 'smart' grids.

The alternative Mitigation Scenarios envisage lower shares of stochastic RES (below 40% over the entire period) and, from a technical and system operation standpoint, are therefore easier to implement. However, other types of uncertainty, associated e.g. with CO_2 storage or nuclear energy, come into play. The strategic problem surrounding generation development stems from the fact that conventional base load thermal generation, with its carbon emissions, is not sustainable under the Mitigation Scenario, even if lignite-fired generation were to be entirely substituted for by gas-fired generation. The near elimination of emissions from power generation is the deciding factor that will determine whether or not electricity can be used as a substitute for fossil fuels in final consumption, especially transport.

In the *"RES and CCS" Mitigation Scenario*, RES development is once again important, but base load generation is ensured by solid fuel-fired plants with CO_2 capture. There is much less uncertainty here concerning the system's reliability than under the "RES" Mitigation Scenario, because of the smaller share of stochastic RES in the generation mix. The use of CCS technologies, however, poses other problems that need to be addressed: public opposition (already voiced) to the location of future CO_2 storage sites and technical problems regarding geological storage.

Under the *"RES and nuclear energy" Mitigation Scenario*, base load generation is provided by nuclear energy (developed after 2030) and marked RES development. Although the system's reliability is ensured, the development of nuclear energy in Greece remains clouded in considerable uncertainty, due to a wide range of issues extending from radioactive waste management, safety standards throughout the entire process, additional construction costs (given Greece's lack of relevant know-how and the need for anti-seismic reinforcement) to the question of public acceptance, especially in areas close to the power plants. As things stand today, it is deemed that, in the case of Greece, the uncertainty surrounding nuclear energy largely outweighs the benefits that would arise from its use. In order to ensure the integrity of the present study, the relevant scenario was nevertheless quantified and assumed that the high uncertainty surrounding nuclear energy is dealt with successfully.

The strategic importance of natural gas in power generation

It is necessary to stress that the mathematical modelling results for all the variations of the Mitigation Scenario, without exception and for the entire projection horizon, point to the continued particular importance of natural gas in power generation (but also in final energy consumption).

Gas-fired power generation is maintained and expanded in all the Mitigation Scenarios. Natural gas does not account for a large share of total electrical energy generation, but gas-fired capacity accounts for a large share of total installed capacity. The reason for this is that gas-fired plants (especially those with flexibility to load increases) are a particularly suitable option for meeting back-up needs and ensuring system reliability, both under the scenario with the largest RES development and under the other variations of the Mitigation Scenario. All of these scenarios envisage large scale RES, heat or nuclear generation that can meet base load demands, but cannot respond to fluctuating loads. A large gas-fired capacity will therefore have to be maintained in all cases. One advantage to this is that —of all the conventional power generation plants— gas-fired plants are the lowest CO_2 emitters.

The importance of regional market integration

To ensure system reliability, greater flexibility will be needed with electrical energy imports so that the system of the wider region can help with load balancing.

The coordination of System Operators and the creation of a permanent mechanism for joint load balancing within the regional market of South-Eastern Europe are provided for under the current policy for the single European energy market, as well as by the Energy Community. Regional market integration takes on even greater importance in view of the restructuring of the electric systems in the context of drastic emission reduction and large-scale RES development. Our simulation by mathematical modelling was based on the assumption that load balancing at a regional level will be possible in the future, thereby reducing the cost of developing back-up systems in Greece. In spite of the joint load balancing, the Mitigation Scenario does not envisage a significant change in total imports of electrical energy to Greece.

Large-scale investments in energy infrastructure

Infrastructure investments in all energy sectors are both large-scale and of crucial importance to the restructuring of the energy system. The new infrastructures will be required to: ensure the interconnection of Greece's islands with the mainland grid; support the widespread development of small-scale RES at the end-consumer level with connections to the low- and medium-voltage grids; supply electrical energy to means of transport; be equipped with 'smart' grids so as to respond quickly to load and RES generation fluctuations; store energy; ensure a flexible and reliable gas supply; and, finally, have large flexible stand-by power generation plants in place.

From an economic standpoint, a major issue will be how to finance and attract capital for such large-scale infrastructure investments required under the Mitigation Scenario.

The part of the energy sector operating under conditions of natural monopoly and regulated prices will grow, while, given that RES will be under a mandatory purchase regime, the competitive part of the energy market will shrink considerably.

State intervention and regulation will thus be of great importance to maintaining the cost-effectiveness and reliability of the energy supply to consumers.

The evolution of final energy consumption

The model analysis confirms that there is ample room for reducing energy consumed, through energy saving measures in buildings and homes, promotion of more energy efficient appliance and equipment use by consumers, the dynamic penetration of new technologies in the transport sector and the substitution of more energy-efficient electricity for fossil fuels in all consumption sectors, especially transport.

A comparison with the results of the *"No Policy" Scenario* shows that a considerable reduction in final energy consumption is achieved under the *Mitigation Scenarios*, and, to some extent, under the *Baseline Scenario* (Table 4.6).

Energy saving involves shifting to more efficient heating and cooling in office buildings and homes, but also the use of more efficient electrical appliances in all sectors, including lighting. Heat pumps play an important role in meeting the heating, cooling and low-enthalpy heating needs in buildings, homes and industry. Heat pumps use air and/or low-enthalpy geothermal energy to extract renewable energy.

Despite the fact that roughly the same energy saving measures are adopted in the Baseline Scenario as well as in the Mitigation Scenarios, higher energy savings was recorded under the Mitigation Scenarios, in all sectors. The lower levels of energy consumption in industry, households and the tertiary sector under the Mitigation Scenarios were mainly the result of higher CO_2 prices imposed across all economic sectors. The lower levels of energy consumption observed in the transport sector are attributed to the more dynamic penetration of electricity, which is more energy-efficient than conventional or hybrid vehicle technologies.

Table 4.6

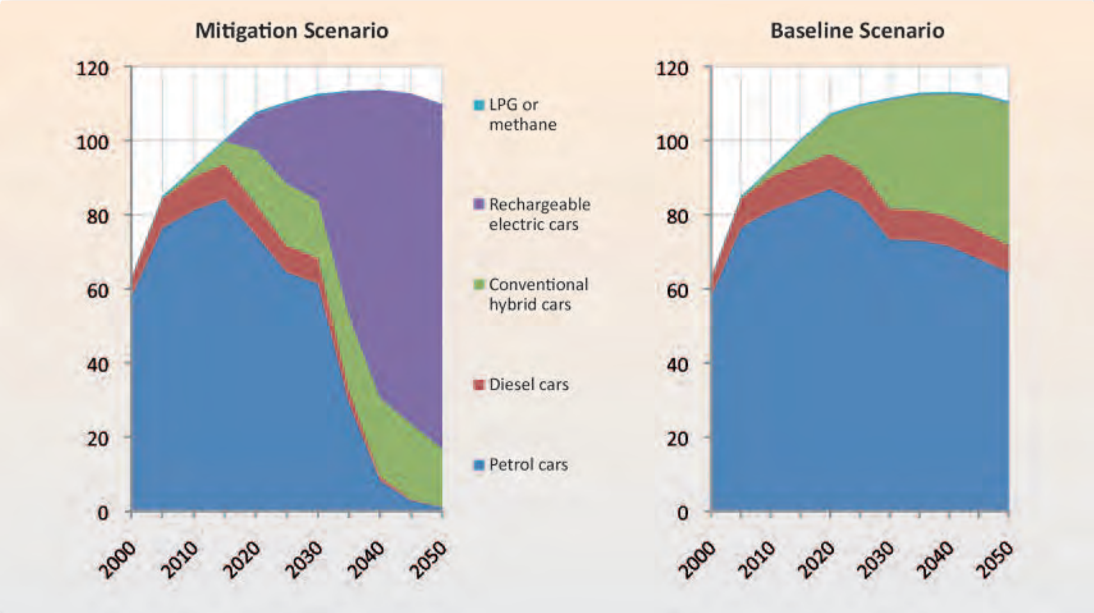
Energy saving by sector: percentage change compared to the No Policy Scenario

	RES Mitigation Scenario			Baseline Scenario		
	2020	2030	2050	2020	2030	2050
Final energy consumption						
Energy-intensive industry	-8	-15	-35	-8	-14	-19
Non-energy intensive manufacturing	-10	-13	-36	-10	-13	-12
Household sector	-11	-17	-43	-8	-15	-26
Tertiary sector	-16	-25	-62	-11	-17	-24
Transport	-12	-18	-45	-11	-16	-20
Houses and service buildings						
Heating/cooling	-10	-19	-50	-7	-14	-26
Electric uses	-21	-25	-55	-17	-20	-26
Energy intensity indexes						
Energy per m^2 in buildings	-7	-16	-48	-4	-12	-27
Energy consumption by cars per 100 km	-17	-20	-46	-13	-15	-20
Energy consumption by airplanes per 100 km	-10	-14	-38	-10	-14	-14
Specific energy consumption indicator for industry	-9	-14	-35	-8	-14	-16

Source: PRIMES.

Figure 4.12

Structure of car fleet by technology (Million pkm)



Source: PRIMES

Table 4.7 **Biomass consumption in various forms and sectors in ktoe**

		RES Mitigation Scenario			Baseline Scenario		
	2000	2020	2030	2050	2020	2030	2050
Transport fuel	136	477	501	2664	529	590	632
Biogasoline	59	269	269	476	312	356	359
Biodiesel	77	208	199	709	216	234	274
Biokerosene	0	0	9	632	0	0	0
Marine biofuel	0	0	24	846	0	0	0
Biofuel for electricity and steam	140	1001	1426	2174	962	1034	1240
Solid biomass	75	766	994	1638	740	606	803
Waste	29	100	246	321	100	246	226
Biogas	36	135	185	215	122	181	211
Biomass in other sectors	848	1214	844	1203	1181	762	517
Total biomass	1123	2693	2771	6040	2671	2386	2390
Share of biofuel in liquid transport fuel		4.3	4.5	33.0	4.7	4.9	4.7

Source: PRIMES.

Extensive changes are envisaged especially for the transport sector. In the short term, new ‘conventional’ cars will be required to have engines that meet EU emission requirements. In the medium term, hybrid vehicles take centre stage, with accumulator batteries that can be charged at low voltage. Finally, in the longer term, electric vehicles prevail (see Figure 4.12). Energy efficiency is also projected to improve in other means of transport, in particular heavy-duty vehicles, ships and airplanes. Also envisaged is the admixture of biofuels to petroleum fuels (Table 4.7).

Table 4.7 outlines the importance that biomass would assume under the Mitigation Scenario. New biomass and waste conversion technologies (e.g. the Fischer–Tropsch process) are expected to have reached commercial maturity before 2020 and to be implemented on an industrial scale. This means that ligno-cellulosic crops, which Greece’s agriculture is capable of supporting on a large scale without adverse impacts on food production and without entailing serious emissions during the collection and processing stages, could become an important new sector of activity, boosting both agriculture and job creation.

The fuel mix of final energy consumption can be broken down as follows (Table 4.8):

- In the long term, the dynamic penetration of electricity use in the Mitigation Scenarios leads to major changes in the energy consumption mix. Electricity is a substitute mainly for oil, as a result of transport electrification.

Table 4.8 **Final energy consumption by type of fuel in Mtoe**

		RES Mitigation Scenario		Percentage change compared to Baseline Scenario		Difference in percentage shares compared to the Baseline Scenario	
	2010	2030	2050	2030	2050	2030	2050
Solid fuels	0.23	0.20	0.00	-6	-98	0	-1
Oil	13.31	11.32	4.50	-9	-66	-3	-25
Gas	0.86	2.66	1.69	13	-31	2	0
Electricity	4.37	6.44	6.80	-1	-19	1	6
Steam distribution	0.19	0.08	0.28	3	3	0	1
RES	1.13	1.81	4.45	2	171	0	19
Total	20.10	22.52	17.73	-4	-32		

Source: PRIMES.

- The use of RES increases considerably relative to the Baseline Scenario, mainly in the energy consumption of industry, households and the tertiary sector, e.g. through the use of solar systems or biomass combustion in heating and other uses.
- Biofuel consumption increases in the transport sector, both in an effort to attain the targets for 2020 and afterward, with its consumption reaching 33% of the final energy consumption of the transport sector in 2050.
- Natural gas accounts for a large share of final energy consumption, although its upward trend is halted in the long term by the dynamic penetration of electricity.

Electricity becomes the dominant energy form in the Mitigation Scenarios. As substitution progresses in parallel with impressive improvements in energy efficiency, major savings in energy and electricity are achieved, especially in the energy consumptions of industry, residential and tertiary sector. In the transport sector, electricity penetration is rapid, reaching 5.4 TWh[4] in 2030 and 17 TWh in 2050. This penetration considerably improves the transport sector's energy efficiency and is counterbalanced by electricity-saving in other sectors, as analysed above.

The evolution of power generation

The Baseline Scenario

In order for "20-20-20" targets to be met, the Baseline Scenario envisages a spectacular development of RES, particularly in the period up to 2020, and a decrease in the share of fossil fuel-fired plants in total power generation from 82% today to 60% in 2020 and further down

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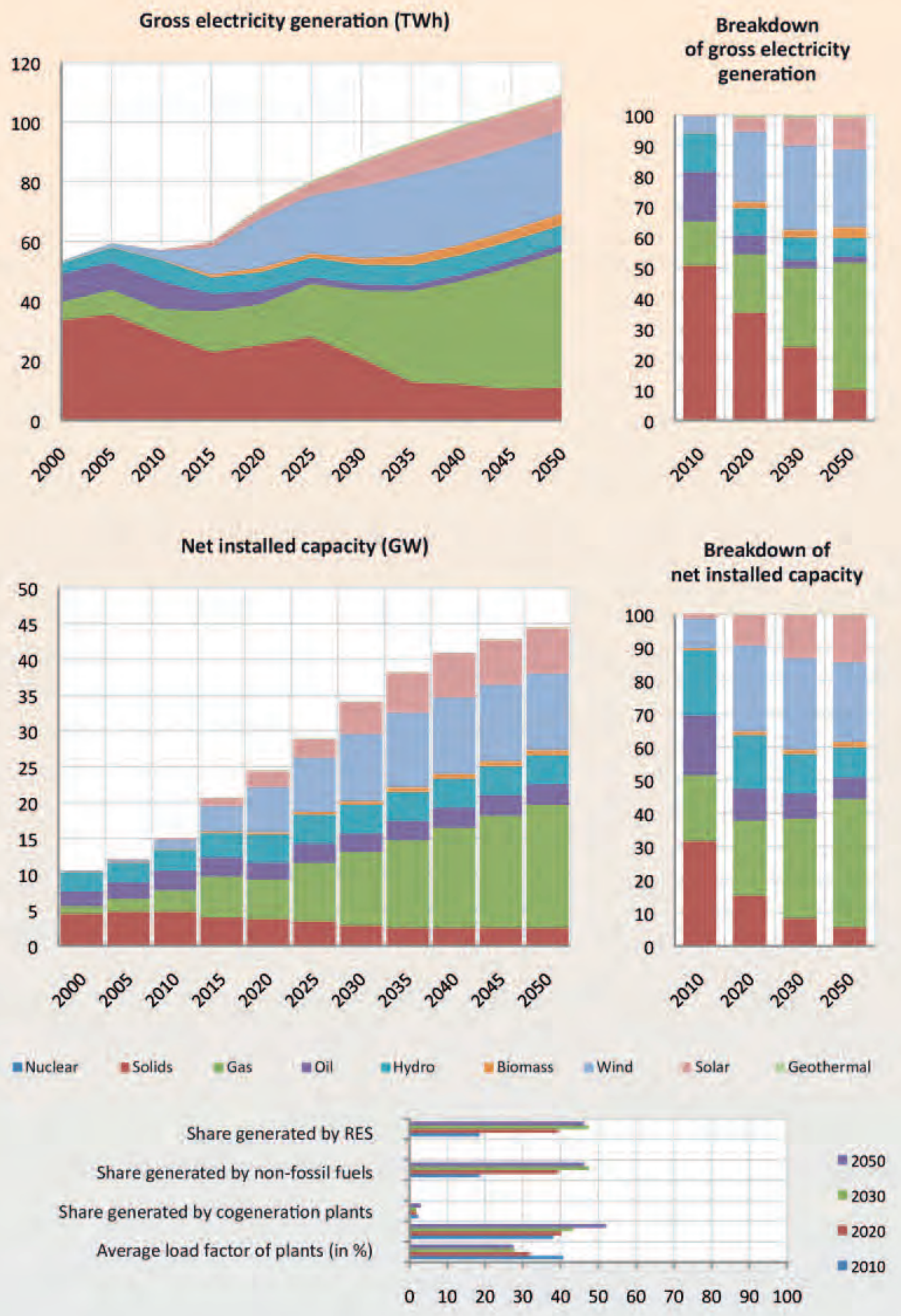
[4] TWh = terawatt hours.

Figure 4.13 **Structure of electricity generation under the Baseline Scenario**



Source: PRIMES.

to 53% in the long term. Conversely, the share of RES in power generation is projected to increase from 39.5% in 2020 to 47% in 2050.

Power generation form lignite-fired plants is progressively reduced from 51% in 2010 to 35% in 2020 and 10% in 2050. The Baseline Scenario projections show that, based on current policies, Greece's power generation is radically transformed and is freed from its lignite dependence, a key element of the country's growth strategy from the 1970s to this day.

At the same time, power generation is also freed from its oil dependence, as a result of the decommissioning of outdated oil-fired plants made possible by the interconnected system and the gradual interconnection of islands.

The only fossil fuel to follow an upward trend under the Baseline Scenario is natural gas, with a share in power generation that rises from 14.5% in 2010 to 19.2% in 2020 and to 41.5% in 2050. Natural gas consumption for power generation will multiply by 2.2 by 2030 compared to today's levels, and by a further 1.8 by 2050.

In the long term, the power generation system under the Baseline Scenario will be structured almost exclusively around RES and natural gas. This restructuring ensues solely from Greece's commitments and compliance with the "20-20-20" policy, with its specific target for RES and the extension of the Emission Trading System (EU ETS) to all emissions from power generation.

Of the available RES, wind energy prevails, with an installed capacity of 6.5 GW[5] in 2020 and 10 GW from 2030 onward, followed by solar, mainly photovoltaic, systems, with an installed capacity of 2.2 GW in 2020 and over 6 GW after 2030. Other renewable energy sources are harnessed on a smaller scale, while biomass is extensively used in co-generation plants for the generation of electricity and steam.

The degree of RES penetration incorporated into the Baseline Scenario is technically feasible and does not compromise the reliability of the power system's operation. Present-day practices will obviously have to be changed considerably so that, from 2015 onward and no later than 2020, the electricity market can function with reliability with about 1/3 of the energy in the system coming from stochastic RES. Pumped-storage hydroelectric capacity will also have to be expanded to 1,000 MW by 2020. Required network investments by 2020 are also considerable.

The "RES" Mitigation Scenario

Under the Mitigation Scenarios, emissions from power generation are nearly eliminated in the long term. Given that the "RES" Mitigation Scenario does not envisage the use of carbon capture or nuclear technologies, ridding power generation of its carbon footprint will necessarily have to be achieved via a drastic reduction in the share of fossil fuel-fired plants.

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[5] GW = gigawatts.

Renewables already become the main source of power generation as soon as 2020, reaching 85.6 TWh (83% of total power generation) in 2050. The largest share of RES-generation is accounted for by wind power plants (wind farms), with an output of 44.9% of total power generation in 2050 and an installed capacity of 17.5 GW (4.6 GW of which offshore), while an important share is also covered by photovoltaic systems (18.4% of total power generation; capacity: 11 GW in 2050). Solar thermal systems reach 628 MW in 2050. Biomass and waste account for 9.7%, with a capacity of 2.4 GW in 2050. Biomass, together with natural gas, also plays an important role in steam generation from industrial boilers. Finally, Greece's geothermal potential is largely exploited as of 2015, accounting for 3.3% of power generation in 2050, with an installed capacity of 442 MWe.[6]

Natural gas retains a very important role under the "RES" Mitigation Scenario, because of its low emissions-intensity relative to other fossil fuels and its ability to support RES penetration in power generation (the capacity-increase flexibility and low capital-intensity of gas-fired plants makes them suitable as back-up plant investments). Electrical energy generation from natural gas under the "RES" Mitigation Scenario decreases after 2030 by more than 50% relative to the Baseline Scenario, but the size of installed capacity of gas-fired plants decreases less, because of the role played by these plants in the system back-up. By 2050, the share of natural gas in power generation falls to 17%, from 31% in 2030.

Power generation from oil-fired plants decreases to 100 GW in 2050 (1260 GWh in 2030), given that the full interconnection of islands is envisaged. Lignite-fired generation is totally ceased after 2030.

Under the "RES" Mitigation Scenario, storage systems are of great importance, given that pumped-storage hydroelectric capacity amounts to 1,900 MW in 2050 and that hydrogen systems (envisaged for after 2035) will, by 2050, require about 16 GWh of electrical energy per year for hydrogen generation. The hydroelectric plants, thermal plants and storage systems envisaged will be able to cover a maximum peak load of about 21 GW in 2050. As for load fluctuations and how they will be met, the assumption is made in the scenario that there will be considerable flexibility with electrical energy imports due to coordinated load balancing in the regional market.

The "RES" Mitigation Scenario includes the development of RES-powered power generation on a very small scale (small wind system capacity of 400 MW in 2050; photovoltaic system capacity in homes and buildings of 3,400 MW in 2050), connected to the low-voltage grid. The future of RES-powered generation will depend on the development of 'smart' grids and the realisation of other improvements and investments in the distribution system. In the specific scenario, it was assumed that such wind and photovoltaic systems will have reached commercial and technological maturity before 2030.

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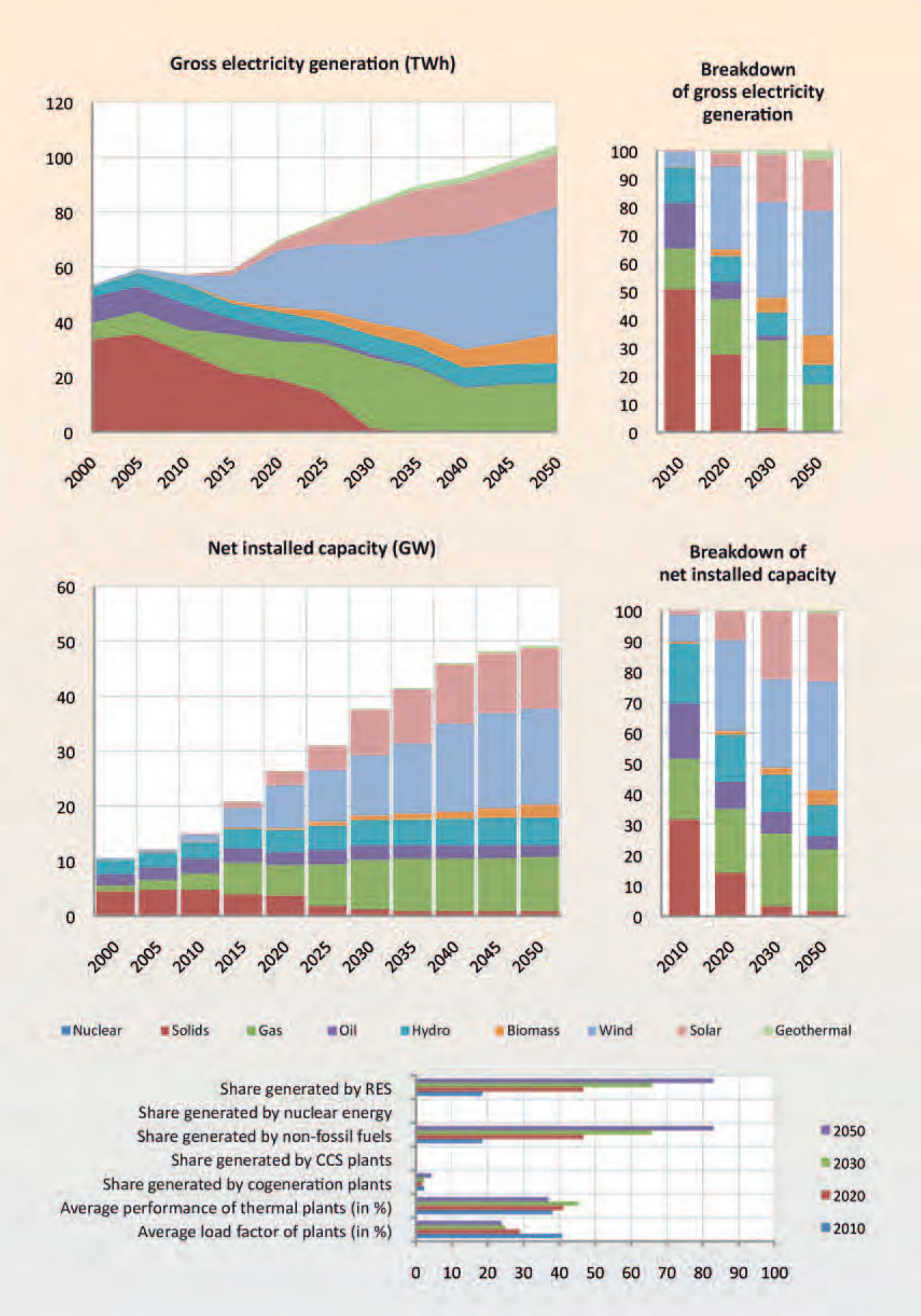
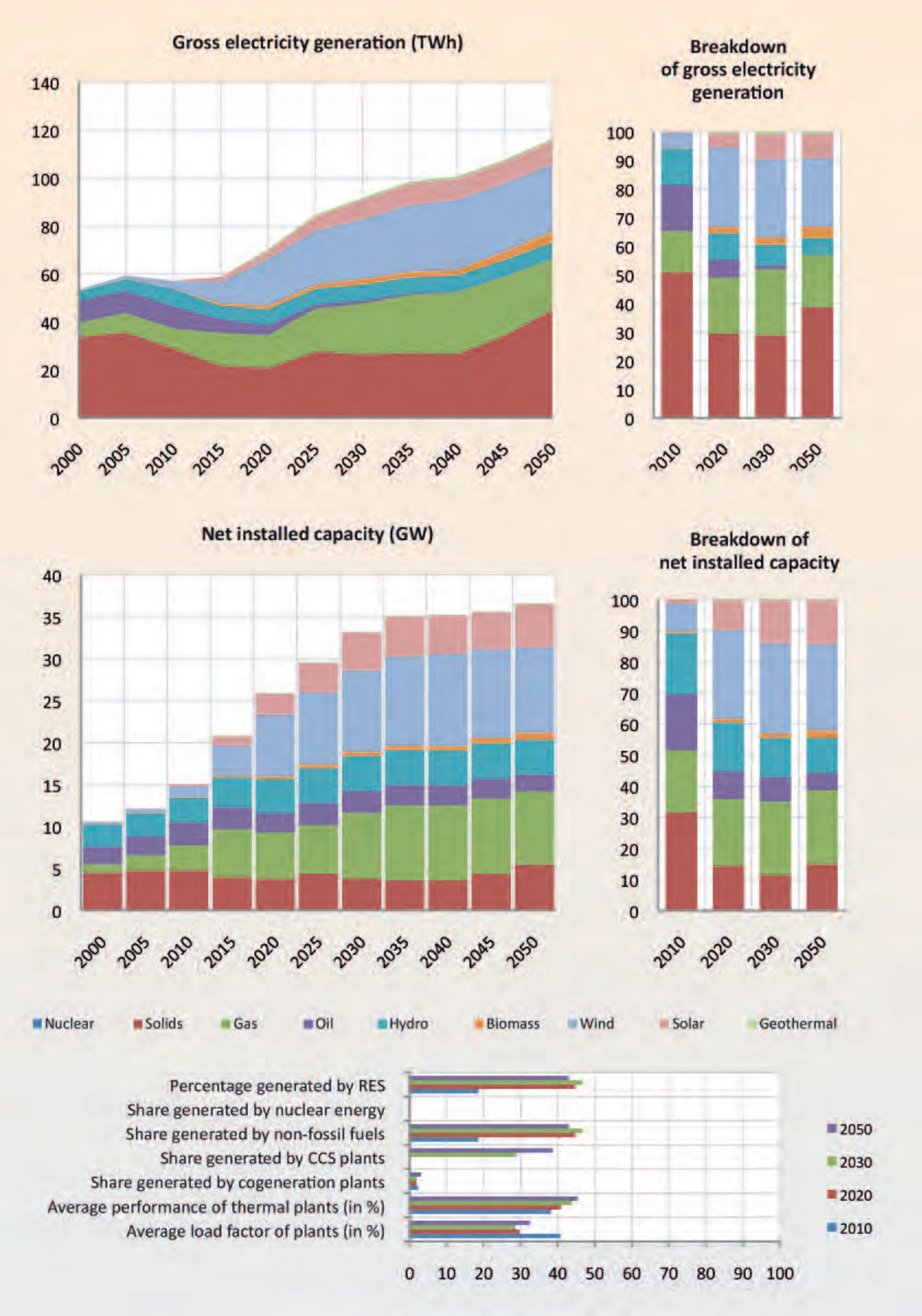
[6] MWe = Megawatt electric.

Figure 4.14 **Structure of electricity generation under the RES Mitigation Scenario**



Source: PRIMES.

Figure 4.15 **Structure of electricity generation under the Combined RES and CCS Mitigation Scenario**



Gross electricity generation (TWh)

Breakdown of gross electricity generation

Net installed capacity (GW)

Breakdown of net installed capacity

Source: PRIMES.

The “RES and CCS” Mitigation Scenario

This scenario is based on the dual assumption that CO_2 storage in geological formations is feasible (in Northern Greece, Western Macedonia and the region of Kavala) and that CO_2 capture technologies from fossil fuel usage have matured and become commercially viable. Given this assumption, the economic optimisation of future power generation, without disregarding the target of achieving a near elimination of CO_2 emissions into the atmosphere, produces different results than the ones produced by “RES” Mitigation Scenario. The “RES and CCS” Mitigation Scenario provides for the development of electrical energy generation with CO_2 capture and for a smaller development of RES than under the “RES” Mitigation Scenario.

Thanks to CCS technology, lignite-fired plants with CCS with a power output of some 2,500 MW will be incorporated into the system by 2025, in replacement of old plants. The total power output of lignite-fired plants in 2025 is roughly the same as in 2000 (approximately 4,400 MW). It then decreases to 3,500 MW (power output), as the old plants are decommissioned. In the decade 2040-2050, the scenario provides for the incorporation of an additional 2,100 MW of lignite-fired capacity with CCS. By 2050, as outlined by the scenario, a lignite-fired capacity of 5,450 MW (power output) will be in operation, of which 4,600 MW will be coupled with CCS. Lignite-fired power generation accounts for about 22-25% of total power generation in the period 2025-2045, against 51% today, and reaches 32.6% in 2050. As shown by the analysis, under the Mitigation Scenarios, the strategy of generating electricity from lignite is sustainable only if coupled with CCS technology. It goes without saying that all of the plants in existence today will have to be decommissioned and that all future plants will have to be coupled with CCS technology.

According to the scenario, lignite-fired plants with CCS with a power output of some 2,500 MW will be in operation in 2025 and 4,600 MW in 2050. The share in total clean power generation accounted for by CCS plants is projected to range between 28% and 38% in the period 2025-2050. Annual CO_2 storage will amount to some 23 million tonnes as of 2025, gradually increasing in the long term to 36 million tonnes in 2050. Total CO_2 storage over the period 2025-2050 is estimated to reach about 770 million tonnes.

Renewables once again play a very important role in this scenario, but their share in power generation only slightly exceeds 51% (in 2035) and even recedes to 47.5% in 2050 on account of the expansion of plants with CCS. RES-based power generation under the “RES and CCS” Mitigation Scenario is similar, quantity- and structure-wise, to that of the Baseline Scenario. Installed wind power capacity is projected to reach 7.4 GW in 2020 and to exceed 10 MW in the long term. Installed solar power capacity is projected to reach 2.5 GW in 2020 and to exceed 5 GW in the long term. The significant development of power plants fired by biomass, waste and geothermal energy is also envisaged under this scenario.

As under the previous scenarios, natural gas-fired plants play an important role in the system’s stability and in responding to load fluctuations. There is less of a demand here for natural gas-fired plants than under the "RES" Mitigation Scenario, for the simple reason that the new solid fuel-fired plants will be able to support the stability of the system, without burdening it with their high emissions footprint. The share of natural gas in total power generation remains at around 20% throughout the entire projection period.

The cumulative CO_2 emissions from power generation under the "CCS and RES" Mitigation Scenario were estimated to be 14% lower in the period 2010-2030, but 20% higher in the period 2010-2050 than under the "RES" Mitigation Scenario (in total, during the period 2010-2050, overall emissions under the "CCS and RES" Scenario are 6% lower than under the "RES" Scenario).

The "RES and nuclear energy" Mitigation Scenario

The use of nuclear technology is not envisaged for Greece either in the medium or in the long term. However, so as not to compromise the scientific integrity of our road map analysis for climate change mitigation, we used the PRIMES model to develop a scenario, postulating that nuclear plants could account for share of Greece's power generation after 2030 (as plants eligible for new investment). The scenario also postulated that CO_2 storage in geological formations within Greece is not feasible.

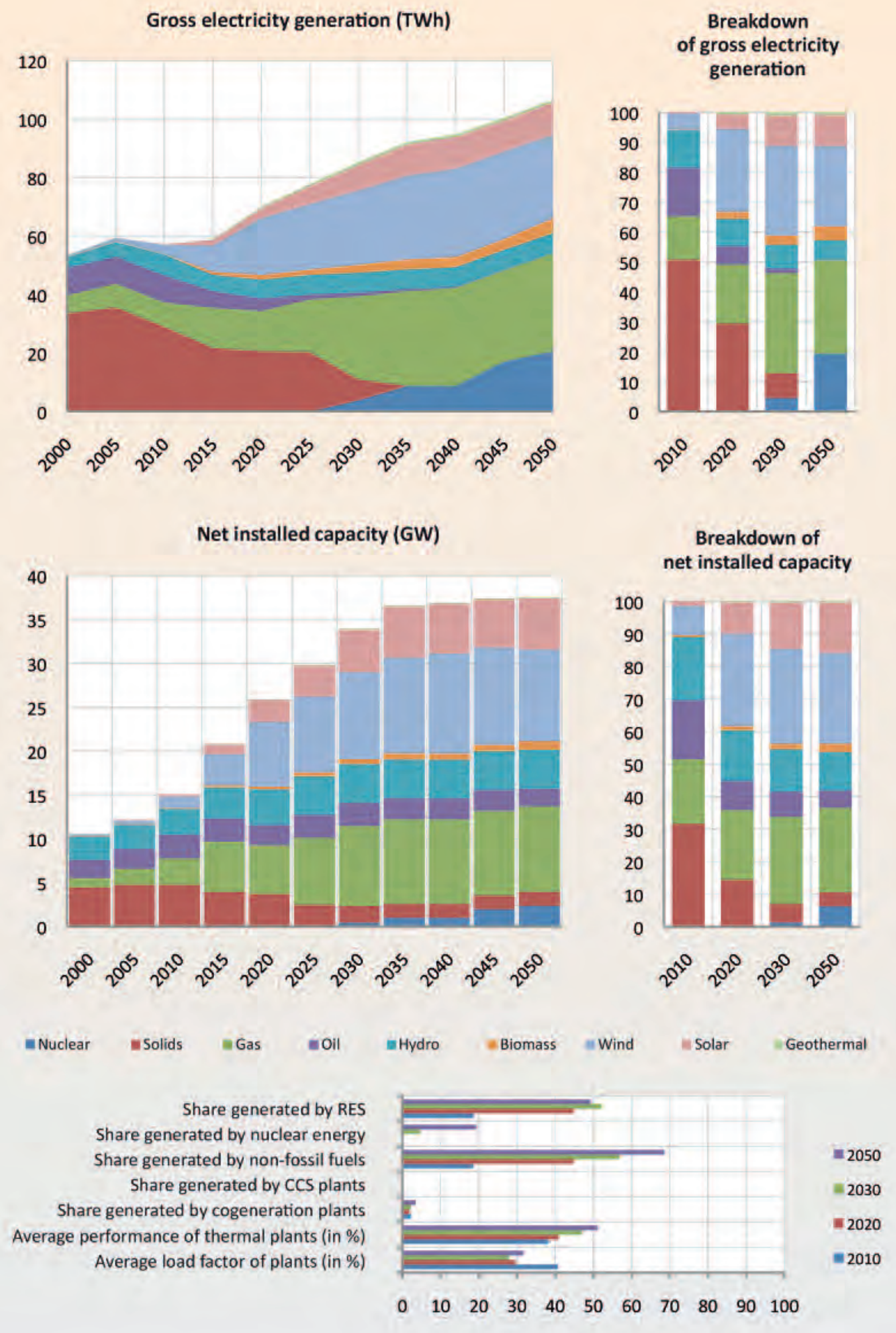
Due to the lack of know-how and to the absence of economies of scale, the cost of investing in nuclear plants in Greece was assumed to be higher than in countries where such technology has already been developed. In addition, suitable location sites for such plants would be limited. The cost and difficulty of developing sites for nuclear plants was simulated in the model with a non-linear cost curve. Account was also taken of the high costs associated with nuclear fuel and nuclear waste, by assuming that the nuclear waste would need to be exported to countries with waste management infrastructure. From an economic standpoint, these waste disposal costs pose an additional constraint on the possibilities for nuclear energy development.

Based on these assumptions, an optimisation of power generation aimed at achieving a near complete elimination of emissions indicates that the development of a limited nuclear power generation programme in Greece would be cost-effective, with an initial installed capacity of 450 MW by 2030, additional 500 MW by 2035 and between 1,000 and 1,500 MW more by 2040, bringing the total capacity to some 2,500 MW by 2050. In other words, only part of the base load power after 2030 would be provided by nuclear energy, which in 2050 would account for 19% of total power generation (4.6% in 2030).

This scenario retains a significant development of RES, which, according to the results, will account for 50% to 53% of power generation over the entire period after 2020. Installed wind capacity will exceed 10 GW, while solar installed capacity will come close to 6 GW.

Natural gas maintains its strategic importance in power generation due to the flexibility of gas-fired plant and the cost feasibility of installing gas-fired back-up plants. Power generation from natural gas under the "RES and nuclear energy" Mitigation Scenario will be definitely

Figure 4.16 Structure of electricity generation under the Combined RES and Nuclear Energy Mitigation Scenario



Source: PRIMES.

higher than under the “RES” Mitigation Scenario and even the “RES and CCS” Mitigation Scenario, because of the lack of flexibility of nuclear plants in responding to load fluctuations, for which gas-fired plants are needed (to complement the power generated from nuclear plants). In the “RES and nuclear energy” Mitigation Scenario, natural gas will account for 1/3 of total power generation from 2025 onward, up from 20% in 2020. In this scenario, lignite-fired power generation ceases after 2030, while oil-fired generation falls to very low levels.

The delay in developing nuclear energy, however justified for economic and technical reasons, has a negative effect on Greece’s emissions reduction capacity in the medium term. The cumulative emissions from power generation during the period 2010-2050 were estimated to be 25% higher in the “RES and nuclear energy” Mitigation Scenario than in the “RES” Mitigation Scenario.

Primary energy, imports

Under the Mitigation Scenarios, the demand for primary energy is considerably lower than under the Baseline Scenario due to extensive increases in energy consumption efficiency. The Mitigation Scenarios also project a wide substitution of fossil fuels, resulting in a significant decrease of the Greek energy system’s dependence on oil imports.

Table 4.9 outlines the substantial benefits that arise from the Mitigation Scenarios with regard to Greece’s energy dependence, which falls to around 50% in 2050, compared with present day level of 72% and the level of 75% projected under the Baseline Scenario for 2050.

Natural gas imports are lower under the Mitigation Scenarios than under the Baseline Scenario, thereby providing a margin of security with regard to the supply of natural gas, which remains of strategic importance in all the scenarios, as mentioned above.

Oil imports are reduced by half in the Mitigation Scenarios, relative to the Baseline Scenario, thanks to transport electrification, biomass use and energy saving.

The Mitigation Scenario outlines a course that would free Greece of its dependence on energy imports, particularly oil.

4.4 The cost of the Mitigation Scenario

The Mitigation Scenarios developed to simulate the course towards a low emissions economy involve a radical restructuring of the energy system. Such a restructuring entails considerable additional costs, as well a new allocation of these costs both between energy sectors and between capital and operating expenses.

The additional cost arises because all energy-efficient and emission-free power generation technologies are capital-intensive. Even though energy consumption and production under the

Table 4.9 **Primary energy supply and demand in million tonnes of oil equivalent (Mtoe)**

(Mtoe)	2010	Baseline Scenario 2020	2030	2050	RES Mitigation Scenario 2030	2050	Combined CCS and RES Mitigation Scenario 2030	2050	Combined CCS and Nuclear Energy Mitigation Scenario 2030	2050
Domestic production										
Oil & gas	0.10	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Solids	6.84	5.82	4.61	2.34	0.27	0.00	5.40	8.75	1.51	0.00
RES	2.01	4.96	6.01	6.97	7.67	13.65	6.24	8.36	6.39	8.61
Imports – Exports										
Solids	0.19	0.21	0.20	0.23	0.20	0.00	0.20	0.00	0.20	0.00
Oil	19.37	17.21	16.84	17.54	15.12	6.59	15.12	6.73	15.12	6.73
Natural gas	2.61	4.07	6.64	9.93	7.44	4.95	6.72	5.45	7.69	7.14
Electricity	0.42	0.41	0.31	0.38	0.36	0.57	0.36	0.57	0.36	0.57
Biomass	0.10	0.40	0.27	0.18	0.41	1.60	0.34	1.35	0.35	1.36
Domestic consumption	29.14	30.40	31.80	34.00	28.66	24.81	31.58	28.64	29.70	26.46
Solids	7.02	6.03	4.81	2.57	0.47	0.00	5.60	8.75	1.71	0.00
Oil	16.96	14.54	13.76	13.98	12.33	4.87	12.34	5.01	12.34	5.01
Natural gas	2.63	4.07	6.64	9.93	7.44	4.95	6.72	5.45	7.69	7.14
Nuclear energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	4.62
Electricity	0.42	0.41	0.31	0.38	0.36	0.57	0.36	0.57	0.36	0.57
RES	2.11	5.35	6.28	7.14	8.05	14.41	6.56	8.86	6.71	9.12
Energy dependence rate (in %)	72	67	70	75	75	50	66	45	73	54

Source: PRIMES.

Mitigation Scenario involve significantly lower operating expenses as a result of the achieved energy conservation and lower fossil fuel consumption, the expenditure needed each year to cover the additional capital costs —determined using market discount rates— outweighs the reduction in operating expenses.

Therefore, the total annual costs of providing energy services (i.e. useful energy, such as heating, cooling, electrical uses, transport, etc.) are estimated to be higher under the Mitigation Scenarios than under the Baseline Scenario, which in turn entails higher costs relative to the "No Policy" Scenario.

Table 4.10 presents the estimates obtained with the mathematical model with regard to the costs of energy services incurred by energy end-consumers. The total cost appears in the upper part of the table and includes payments for the purchase of emission allowances under the EU ETS scheme. Implementation of current policies contained in the Baseline Scenario generates additional cumulative costs in the order of €288 billion (2008 prices) for the period 2010-2050,

Table 4.10

Total cost of energy system (EUR billions, 2008 prices)

Total cost of energy services, including payments for purchase of CO_2 emission allowances

	Annual cost (EUR billions 2008)				Cumulative cost (EUR billions 2008)	Difference from No Policy (EUR billions 2008)
	2010	2020	2030	2050	2010-2050	
No Policy Scenario		39.0	47.1	54.0	1,779	
Baseline Scenario		43.6	55.1	65.1	2,067	288
Percentage change compared to No Policy Scenario		12	17	21	16	
RES Scenario	27.2	44.9	55.5	77.9	2,212	433
Percentage change compared to No Policy Scenario		15	18	44	24	
Combined RES and CCS Scenario		44.8	54.7	77.0	2,186	407
Combined RES and Nuclear Energy Scenario		44.8	54.8	77.0	2,187	408

Payments for purchase of CO_2 emission allowance (EUR billions 2008)

		2020	2030	2050	Cumulatively 2010-2050	Percentage changes compared to Baseline Scenario
Baseline Scenario		0.66	1.48	2.10	52.05	
RES Scenario		0.85	1.39	1.76	42.61	-18.1
Combined RES and CCS Scenario		0.89	1.23	2.01	43.05	-17.3
Combined RES and Nuclear Energy Scenario		0.88	1.73	2.72	54.23	4.2

Additional cost of energy services as a percentage of GDP, not including payments for purchase of CO_2 emission allowance

Percentage change between scenarios						Differential 2010-2050 (EUR billions 2008)
		2020	2030	2050	Cumulatively 2010-2050	
Baseline Scenario compared to No Policy Scenario		1.5	2.0	1.9	1.9	236
RES Scenario compared to Baseline Scenario		0.4	0.2	2.7	1.2	155
Combined RES and CCS Scenario compared to Baseline Scenario		0.4	0.0	2.5	1.0	128
Combined RES and Nuclear Energy Scenario compared to Baseline Scenario		0.4	-0.2	2.3	0.9	117

Total cost of energy services by sector of final consumption (EUR billions 2008)

	2010	2020	2030	2050	Cumulatively 2010-2050
Baseline Scenario	27.2	43.6	55.1	65.1	
Industry	2.8	3.0	3.2	3.6	127
Houses and Buildings	14.6	22.6	27.7	31.3	1035
Transport	9.8	18.0	24.2	30.2	905
RES Scenario – percentage changes compared to Baseline Scenario		3.0	0.7	19.6	7.0
Industry		1.5	-1.2	22.3	1.2
Houses and Buildings		3.4	3.7	23.7	6.7
Transport		2.7	-2.6	13.3	7.6

Source: PRIMES.

relative to the No Policy Scenario. This additional cost represents about 2% of cumulative GDP at constant prices over the 40-year period. It should be recalled that the Baseline Scenario corresponds to the current commitments arising from EU membership and, despite its higher cost, does not achieve an emissions reduction consistent with climate change mitigation. The additional cost (on top of the costs of the Baseline Scenario) that energy consumers will incur for energy services under the Mitigation Scenarios was estimated at between €120 and €145 billion (2008 prices) for the period 2010-2050.

From a national economy perspective, payments for the purchase of emission allowances (whether direct or indirect by energy consumers) are a form of transfer payment, in the sense that the auctioning-off of emission allowances under the EU ETS scheme will allow governments to raise revenue. Therefore, when estimating the cost of the scenarios from a national economy perspective, payments for emission allowances need to be excluded. The Baseline Scenario assumes a much lower price for emission allowances, but projects the emission of much greater quantities of CO_2 in the sectors subject to the Eu ETS scheme, relative to the Mitigation Scenarios. Therefore, the total payments for allowances anticipated in the Baseline and Mitigation Scenarios are intercomparable. Specifically, cumulative payments for emission allowances over the period 2010-2050 are about 18% lower under the “RES” and “RES and CCS” Mitigation Scenarios than under the Baseline Scenario, while cumulative payments under the “RES and nuclear energy” Scenario are slightly higher than under the Baseline Scenario.

Excluding emission allowance payments, the Mitigation Scenarios give rise to additional cumulative costs of between €117 billion and €155 billion (2008 prices) over the period 2010-2050, which represents about 1% of cumulative GDP over the next 40 years. The additional cost of the Mitigation Scenarios, relative to the Baseline Scenario, is mainly recorded after 2030 and clearly burdens the residential, buildings and transport sectors more than the industrial branches.

Of the three variations of the Mitigation Scenario, the “RES” Scenario is slightly more costly (entailing about 1.2% higher cumulative costs than the other two variations, which correspond to additional costs of €27 billion, at 2008 prices, for the period 2010-2050), while the “RES and nuclear energy” Scenario has the lowest cost. Of course, the “RES” Scenario is, by far, more likely to be implemented than the other two Mitigation Scenarios, especially the one involving nuclear energy.

The total average cost of reducing greenhouse gas emissions under the Mitigation Scenarios is estimated at between €190 and €240/tonne of CO_2 (2008 prices), cumulatively for the period 2010-2050.

The restructuring of the electrical energy generation sector calls for extensive investment in RES plants, back-up plants, CCS plants (for the “CCS and RES” Mitigation Scenario), etc., all of which are highly capital-intensive. It also calls substantial investments in transmission and distribution network infrastructure, since the greater the share of RES, the larger these networks

Table 4.11 Cost of electricity generation and supply in €/MWh (2008 prices)

						Percentage change compared to No Policy Scenario		
	2005	2010	2020	2030	2050	2020	2030	2050
Baseline Scenario								
Average generation cost	68.6	80.6	99.7	107.2	90.1		16	24
Fixed cost	27.5	35.9	56.5	63.6	48.0		31	35
Variable cost	39.7	41.7	35.3	31.0	29.8		-17	-21
Taxes and ETS	1.4	3.0	7.9	12.7	12.2		2721	5835
Grid cost	12.6	24.1	34.4	36.3	33.6		19	19
Supply cost	81.2	104.7	134.1	143.5	123.7		17	22
						Percentage change compared to No Policy Scenario		
	2005	2010	2020	2030	2050	2020	2030	2050
RES Scenario								
Average generation cost	68.6	80.6	105.0	110.9	96.8	5	3	7
Fixed cost	27.5	35.9	63.4	77.0	67.0	12	21	39
Variable cost	39.7	41.7	31.9	25.5	18.6	-10	-17	-38
Taxes and ETS	1.4	3.0	9.7	8.4	11.3	23	-34	-8
Grid cost	12.5	24.3	36.7	41.6	40.7	7	15	21
Supply cost	81.2	104.9	141.8	152.6	137.4	6	6	11
Combined RES and CCS Scenario								
Average generation cost	68.6	80.6	104.4	107.0	92.8	5	0	3
Fixed cost	27.5	35.9	61.2	67.0	46.5	8	5	-3
Variable cost	39.7	41.7	32.9	33.7	33.0	-7	9	11
Taxes and ETS	1.4	3.0	10.3	6.3	13.3	30	-50	9
Grid cost	12.5	24.2	36.4	37.9	33.9	6	4	1
Supply cost	81.2	104.8	140.8	144.9	126.8	5	1	3
Combined RES and Nuclear Energy Scenario								
Average generation cost	68.6	80.6	104.4	106.2	93.0	5	-1	3
Fixed cost	27.5	35.9	61.3	66.1	49.4	9	4	3
Variable cost	39.7	41.7	32.9	27.6	23.5	-7	-11	-21
Taxes and ETS	1.4	3.0	10.3	12.4	20.0	30	-2	64
Grid cost	12.5	24.3	36.3	38.2	34.4	6	5	2
Supply cost	81.2	104.9	140.8	144.4	127.4	5	1	3

Source: PRIMES.

become. However, the more power generation is freed from its dependence on fossil fuels, the more the plants' operating costs will decrease.

Nevertheless, as can be seen from Table 4.11, the total cost of the energy system is higher both in the Baseline Scenario relative to the "No Policy" Scenario (by about 20%) and in the Mitigation Scenarios relative to the Baseline Scenario (by between 5% and 10% in the case of the "RES" Scenario). An important component of the additional cost is payments for emission allowances, which are also present in the Baseline Scenario, but absent from the "No Policy" Scenario.

Due to the higher cost of supplying electrical energy, consumer prices are higher in all the scenarios than in the "No Policy" Scenario. This increase (of the order of 20%) is already high in the Baseline Scenario.

The price increases under the Mitigation Scenarios, relative to the Baseline Scenario, are fairly limited until 2030, but become more pronounced thereafter.

Included in electricity prices, as estimated with the mathematical model, is the recovery in full of all costs for power generation and distribution, as well as the recovery of all RES-related subsidies, the cost of increased back-ups in proportion to the share of stochastic RES in power generation, etc. This explains why the prices of electricity under the "RES" Scenario are higher (by about 5% in 2030 and 10% in 2050) than under the other two variations of the Mitigation Scenario. Rapid transport electrification under the Mitigation Scenarios progresses in parallel with energy saving in other uses, a combination that evens out the load curve considerably, as the difference between base and peak load decreases. This flattening out has a beneficial effect on the average cost of power generation, particularly when produced in capital-intensive plants, as in the case of the "RES and CCS" and the "RES and nuclear energy" Scenarios.

Electricity prices are slightly higher under the "RES and CCS" Scenario, relative to the "RES and nuclear energy" Scenario, mainly because of the cost of carbon transmission and storage. As mentioned earlier in this chapter, considerable uncertainty surrounds the cost of developing and operating nuclear plants in Greece. All cost estimates regarding the "RES and nuclear energy" Scenario must therefore be treated with extreme caution, unlike those for the other two Mitigation Scenario variations.

The mathematical model contains detailed investment estimates per sector of activity.

Table 4.13 presents the estimated energy-related investments (purchase of equipment, appliances, vehicles, energy saving expenditure, investment in the electrical energy sector). Given that the Baseline Scenario contains significant actions both in the field of energy saving and for RES, investments are clearly higher than in the "No Policy" Scenario, by about €20 billion (2008 prices) in the energy demand sectors (excluding transport) and by about €15 billion (2008 prices) for the electrical energy sector for the period 2010-2050.

The "RES" Mitigation Scenario involves an even greater amount of investment, totalling €172 billion (2008 prices) in the demand sectors and €30 billion (2008 prices) in the power generation sectors, on top of the Baseline Scenario investments for the period 2010-2050. The

Table 4.12 **Consumer prices of electricity in €/MWh (2008 prices)**

						Percentage change compared to No Policy Scenario		
	2005	2010	2020	2030	2050	2020	2030	2050
Baseline Scenario								
Average price	88.3	114.9	147.1	157.3	135.4	17	23	24
Industry	55.9	76.3	97.2	103.0	93.0	10	17	21
Households	93.7	129.5	169.3	179.3	151.9	21	25	26
Services	111.6	129.8	151.0	157.9	133.7	18	23	25
						Percentage change compared to Baseline Scenario		
	2005	**2010**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
RES Scenario								
Average price	88.3	115.1	155.8	168.0	169.4	6	7	25
Industry	55.9	75.7	100.2	103.4	92.7	3	0	0
Households	93.7	130.2	180.3	193.0	192.1	6	8	27
Services	111.6	130.0	159.8	167.4	161.5	6	6	21
Combined RES and CCS Scenario								
Average price	88.3	115.0	154.7	159.4	155.5	5	1	15
Industry	55.9	75.9	100.1	101.7	90.2	3	-1	-3
Households	93.7	130.0	178.6	181.2	174.9	6	1	15
Services	111.6	129.8	158.5	159.1	148.8	5	1	11
Combined RES and Nuclear Energy Scenario								
Average price	88.3	115.1	154.7	158.8	155.2	5	1	15
Industry	55.9	75.0	100.3	102.0	92.4	3	-1	-1
Households	93.7	130.5	178.6	180.5	174.5	5	1	15
Services	111.6	130.2	158.5	158.3	147.7	5	0	10

Source: PRIMES.

increased investments in the transport sector involve road transport electrification and include the additional cost of purchasing electric vehicles, the battery charging systems and other investments to upgrade public transport. The greater part of the additional investment in the electrical energy sector takes place after 2020. The investments for energy conservation in buildings and the additional cost of purchasing more energy-efficient appliances are estimated at €58 billion (2008 prices) for the period 2010-2050. The other two variations of the Mitigation Scenario involve total investment costs similar to those of the "RES" Scenario, but smaller total investments in the electrical energy sector.

Table 4.13 **Investments in the energy sector (EUR billions, 2008 prices)**

	2010-2020	2020-2030	2030-2050	2010-2050
Baseline Scenario				
Industry	2.9	2.9	5.8	11.6
Buildings	12.8	6.9	15.2	34.9
Transport (*)	174.3	190.3	415.0	779.6
Networks	9.8	10.8	20.7	41.3
Electricity generation	16.2	13.0	22.4	51.7
Total electricity sector	26.0	23.9	43.1	93.0
RES Mitigation Scenario: additional investment in relation to the Baseline Scenario				
Industry	0.1	0.0	1.6	1.7
Buildings	4.2	5.6	48.5	58.3
Transport (*)	5.1	7.7	99.6	112.4
Total for all energy demand sectors	9.4	13.3	149.7	172.4
Networks	1.1	3.4	4.1	8.6
Electricity generation	2.7	5.2	13.2	21.1
Total electricity sector	3.8	8.6	17.3	29.7

(*) Including not only energy-related investment, but also total expenditure for the purchase of means of transport equipment.

The additional investments in the "RES" Mitigation Scenario (relative to the Baseline Scenario) represent 0.7% of cumulative GDP for the period 2010-2050 excluding transport and 1.6% including transport.

In any event, the construction and operation of these new investments will benefit economic activity and employment, while the restructuring of the energy system will bring about environmental benefits, while improving energy supply security and reducing Greece's dependence on energy imports.

A low carbon emission Greek economy will have a much greater need for renewable energy sources, energy-efficient building materials, hybrid electric cars, 'smart' network equipment and low carbon energy generation. In order to make the transition to a low carbon economy and to be able to reap all of the ensuing benefits, such as, for instance, a lower oil import bill, Greece will have to spend €150 billion or 1% of GDP, on average, per year over the next four decades, in addition to the expenditures provided for under current policies (these policies attain the "20-20-20" targets, but do not suffice to mitigate climate change).

The additional investments would bring investment in Greece back to pre-crisis levels and promote growth across a wide range of production and service sectors. Payments for fuel imports could be largely replaced by expenditures for domestically produced goods and services. Intensifying pro-climate action would generate thousands of new jobs.

Transition to a low greenhouse gas economy would also yield important benefits for the local environment: acid rain and micro-particulate emissions would be nearly eliminated, while urban air quality would improve spectacularly with the expansion of electric vehicle use. Ridding the economy of carbon emissions by drastically reducing fossil fuel use would also bring about a spectacular reduction in Greece's dependence on imported energy, thereby improving the security of supply.

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Chapter 5

Findings and strategy for addressing climate change in Greece

5.1 Findings of Chapter 1*

The Mediterranean is universally recognised as particularly vulnerable to the impacts of anthropogenic climate change. Climate change in Greece was studied based on the results of a series of climate simulation models. Temperature is projected to rise significantly by the end of the 21st century, while precipitation is projected to decrease. Available observations indicate that precipitation over the previous century decreased by around 20% in Western Greece and by 10% in Eastern Greece. This is attributed in part to the positive trend in the North Atlantic Oscillation (NAO) index. Future climate projections also indicate that the next decades will see a significant increase in the frequency of extreme temperature and precipitation events.

According to the simulations of anthropogenic climate interference under the two extreme scenarios (B2 and A2), by 2100 the air temperature will have increased by 3.0ºC and 4.5ºC respectively. The temperature increase will be greater in the mainland than in the island areas, and more pronounced in summer and autumn than in winter and spring. Meanwhile, the decrease in rainfall, countrywide, is expected to range between 5% (Scenario B2) and roughly 19% (Scenario A2). The climate simulations estimate that relative humidity, countrywide, will decrease by between 1% (Scenario B2) and 4.5% (Scenario A2). Relative humidity levels are projected to drop more markedly in the mainland regions, especially in summer, but are expected to remain unchanged in the island areas.

The simulations also point to a decrease in cloud cover in Greece in coming decades, compared with the baseline period 1961-1990, by between 8% (Scenario B2) and 16% (Scenario A2). Solar radiation on a national scale is expected to increase by between 2.3 W/m² (Scenario B2) and 4.5 W/m² (Scenario A2), while mean annual wind speed is not expected to change significantly, apart from the Etesian winds the intensity of which is expected to increase by as much as 10%.

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* Sub-chapter 5.1 was co-authored by Christos Zerefos, John Kapsomenakis and Costas Douvis.

Based on the available simulations, even under the intermediate Scenario A1B, the Greek mainland in 2071-2100 will, compared to now, have some 35-40 more days with a maximum daily temperature of 35ºC or more, while even greater will be the increase (by around 50 at the national level) in the number of tropical nights (when minimum temperatures do not fall below 20ºC). On the other hand, the number of frost nights is expected to drop significantly, especially in Northern Greece (by as many as 40). Moreover, the rise in average temperature will prolong the vegetation period by 15-35 days.

One of the major impacts of global warming is that the energy demand for cooling in summer months is expected to increase. More specifically, the low-lying areas of continental Greece are projected to have increased cooling needs for up to an extra 40 days per year during the period 2071-2100, while the increase in cooling needs is expected to be smaller in the islands and the mountain areas. A positive aspect of climate change is that energy needs for winter heating are expected to decrease.

Changes are also projected in precipitation extremes. In Eastern Central Greece and North-Western Macedonia, the maximum amount of precipitation occurring within 3-day periods is expected to increase by as much as 30%, whereas in Western Greece it is expected to decrease by as much as 20%. By contrast, the greatest increases in drought periods are projected for the eastern part of the mainland and for Northern Crete, where 20 more drought days are expected per year in 2021-2050 and up to 40 more drought days are expected in 2071-2100. As a result of climate pattern changes, the number of days with a very high risk of fire is expected to increase significantly by 40 in 2071-2100 across Eastern Greece (from Thrace down to the Peloponnese), while smaller increases are expected in Western Greece. The number of days with a humidex value of >38ºC will be prolonged by as many as 40 in the coastal areas along the Ionian Sea and in the Dodecanese, and by somewhat less (roughly 25 additional days) in the low-lying areas of continental Greece and Crete, as projected for the period 2071-2100.

Based on calculations, the sea level is projected to rise by between 0.2 m and 2 m by the year 2100. Of course, any assessment of an area's vulnerability to a rise in average sea level (coastal risk assessment) inevitably involves considerable uncertainty, as such risk is determined not only by the rate and extent of the sea level rise, but also by other local factors, such as tectonics, sediment supply (from inland) and coastal geomorphology/lithology.

Typical examples are the coastal areas of the Northern Peloponnese (projected to gain 0.3 to 1.5 mm/year in elevation), Crete (0.7 to 4.0 mm/year) and Rhodes (1.2 to 1.9 mm/year). Thus, for instance, an average sea level rise of about 4.3 mm/year could be reduced to 3.5 mm/year as a result of a compensatory, tectonically-induced mean elevation uplift of about 0.8 mm/year. Changes in sediment-laden inflows to the deltaic estuaries of large rivers can potentially offset a sea level rise, if the sediment deposits increase, causing the delta in question to advance. Conversely, a decrease in fluvial sediment discharge could result in a greater marine inundation of the area in the event of a sea level rise. Finally, coastal morphology, especially in terms of coastal slope inclination and lithologic composition, is an important factor, directly related to the rate of erosion.

Calculations of shoreline length showed that of Greece's total 16,300 kms in coastline, some 6% (or 960 km) correspond to coastal deltaic areas of high vulnerability, 15% (or 2,400 km) to newly-formed soft sediment layers of moderate vulnerability, while the remaining 79% (or 12,900 km) correspond to rocky coastal areas of low vulnerability. Therefore, the total length of shoreline with a moderate-to-high vulnerability to sea level rise comes to about 3,360 km, i.e. 21% of Greece's total shoreline.

Assuming that there are no tectonically-induced and geodynamic corrections, a sea level rise of 0.5 m to 1 m would result in a shoreline retreat of between 30 m and 2,750 m in the high risk deltaic areas, such as the Axios-Aliakmon or the Alfeios deltas, while a sea level rise of 1 m would result in a shoreline retreat of between 400 m and 6,500 m.

5.2 Findings of Chapter 2*

Our analysis of the impacts of climate change per sector of the economy enabled a first quantification and cost valuation in Greece of the anticipated impacts. This, it is hoped, will serve as a valuable basis for the elaboration of adaptation policies covering most of the Greek economy. The climate change impacts identified in the respective sectoral studies are summarised below.

Water reserves

Climate change is expected to have the following negative impacts on the water resource sector in all of Greece's water districts and under all the scenarios considered:

- An overall decrease in aquifer infiltration and recharge, as a result of decreased rainfall and higher evapotranspiration;
- Increased salinity of coastal and subsea aquifers, particularly karstic ones, as a result of the advance of the sea-water intrusion farther inland due to the decline of groundwater levels caused by lower inflow and overpumping;
- Higher pollutant load concentrations in coastal water bodies and the sea, due to lower dilution;

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* Sub-chapter 5.2 was co-authored by: Christos Zerefos, Anastasios Xepapadeas, Michalis Skourtos, Georgios Stournaras, Areti Kontogianni, Sofronios Papoutsoglou, Phoebe Koundouri, Costas Papaconstantinou, Andreas Karamanos, Anastasios Nastis, Vasiliki Tsiaoussi, Eftichios Sartzetakis, Benjamin Karatzoglou, Matheos Santamouris, Dimosthenis Asimakopoulos, George Giannopoulos, John Yfantopoulos, Ioannis Oikonomopoulos, Dimitrios Damigos and John Kapsomenakis.

- The faster breakdown of deltaic regions, in cases where degradation has already begun as a result of transversal dam construction upstream (reduced drainage and sediment discharge) and parallel levee construction in the flat zone of the deltas (debris channelled to a single outlet);
- Contamination or drainage of coastal wetlands; and
- Amplification of the desertification phenomenon, due to water deficits and soil changes (compaction, sealing, etc.).

Rainfall countrywide is projected to decrease by between 3% (Scenario B2) and 8% (Scenarios A1B and A2) in the period 2021-2050, and by between 7% (Scenario B2) and 20% (Scenarios A1B and A2) in the period 2071-2100. The corresponding decreases in volume of water infiltration are projected to be between 14% (Scenario B2) and 22% (Scenario A2) for the period 2021-2050, and between 30% (Scenario B2) and 54% (Scenario A2) for the period 2071-2100. These variations, together with changes in agricultural practices, will have direct implications on crop type and area.

From an economic standpoint, the total cost for the Greek economy will —depending on the scenario and the discount rate used— range, in net present values, from 0.34% of GDP (Scenario A1B, discount rate: 3%) to 1.69% of GDP (Scenario A2, discount rate: 1%). The most vulnerable climate zones for which the heaviest cost estimates were recorded were found to be Central, Eastern and Western Greece and, in the northern part of the country, Central Macedonia. However, there appears to be considerable leeway for adaptation measures.

Sea level rise (SLR)

Coastal zones play an important role in the economy of Greece, a country with 16,300 km of coastline, and only one land-locked administrative region (out of a total of 13). Indicatively, coastal tourism alone accounts for 15-18% of national GDP. Projections place the sea level rise (SLR) at between 0.2 m and 2 m by 2100. The impact of rising sea levels will, apart from the built environment and human populations, also affect environmental systems.

The economic impacts of a sea level rise were studied from two standpoints: first in view of the long-term impact of gradual SLR, and, second in view of the short-term impacts associated with storm-driven wave and surge events as a result of climate change. This dual approach was judged necessary, as storm surges in the Eastern Mediterranean are expected to increase in both frequency and intensity as a direct result of the disruption to the hydrologic cycle. The total cost of long-term SLR in Greece’s coastal zone, measured as the negative impact on housing, tourist, wetland, forest and agricultural land uses, was estimated at between €4.4 billion (assuming an SLR of 0.5 m) and €8 billion (assuming an SLR of 1 m). The costs arising from the loss, over time, of the coastal areas’ aesthetic/recreational and cultural value were estimated at between €10.5 billion (assuming an SLR of 0.5 m) and €19 billion (assuming an SLR of 1 m). Finally, the social costs of storm surges in Greece’s coastal zone were estimated at roughly €620 million.

The value of ecosystem services provided by the Greek coastal zone was estimated mainly as use-values (i.e. in relation to five specific land uses: tourism, housing, agriculture, forestry and wetlands). These valuations thus represent a lower bound for each resource's real economic value. Adaptation options to be considered in light of SLR are the following: managed retreat (moving all human activities and land uses away from the affected coastal areas), accommodation (adapting human activities and land uses in the affected coastal areas) and protection (soft and hard protective engineering works to minimise the impact that would otherwise occur). Our estimates of the cost of adaptation measures show adaptation to be more cost effective than inaction.

Fisheries

As shown by the sample studied, a rise of 1°C in mean sea surface temperature (SST) in the Aegean would cause decreases in catches of benthic fish by 724 tonnes (1.1% of the mean) and of mesopelagic fish by 160 tonnes (1.3%), while the catches of large and small pelagic fish would increase by 12 tonnes each, i.e. by 0.5% and 0.04%, respectively. Total catches would thus decrease by 859 tonnes or 0.8%. An increase of 3.3°C in SST by 2100 would, based on present data, cause decreases of roughly 3.6% in benthic fish catches and of 4.2% in mesopelagic fish catches, but increases of 1.7% and 0.13%, respectively, in large and small pelagic fish catches. Total catches would fall by 2.5%.

Given that global warming is expected to benefit warmer-water species, total fisheries production may decrease only insignificantly, if at all. Whatever the outcome, there will be a redistribution in fish catches. Moreover, with the rise in temperature, catches are increasingly likely to include migrant species. Finally, the analysis showed that the estimated decrease in rainfall under Scenario A1B would lead to a small decrease (2%) in the production of cephalopods and crustaceans, whereas the production of other species was unlikely to be affected.

The present value of lost revenue for commercial fisheries was estimated at €14.8 million to €2.5 million depending on the discount rate (1% or 3%), while the total cost of biodiversity loss is expected to range between €287 million and €1,896 million.

These cost estimates are tentative and provisional. Considering the ecological diversity of Greece's water bodies and the gaps in our knowledge of anthropogenic impacts, more scientific evidence and data are needed for economists to perform a more reliable cost valuation of global warming impacts on Greek fisheries and aquaculture.

Agriculture

Calculations were made to assess the impact of climate change and desertification on arable and tree crops, primarily wheat, cotton, maize, olives and vines. The impact analysis was conducted both factoring in and excluding soil desertification.

The anticipated decline in rainfall and the higher frequency and intensity of extreme events lead some to believe that the current forecasts will be raised by an additional 5-10%. Of the climate change scenarios considered, Scenario B2 appears to be the most favourable to plant production, especially in NE Greece (Macedonia and Thrace are, depending on the crop, expected to be the most favourably or least negatively affected). Scenario A2 will have the most negative impact on agricultural production. The most sensitive arable crop was shown to be wheat, while cotton production is projected to decrease the most (by as much as 10%) under Scenarios A1B and A2 in Central and Eastern Greece. The impact of climate change on tree crops by 2050 will range from neutral to positive, but will become increasingly negative by 2100, especially in the country's southern and island areas. Horticulture will move northward and the cultivation period, longer than it is today due to milder (warmer) winters, will result mostly in increased production.

The present value of the total economic impact of climate change by 2100, expressed in terms of the change in agricultural revenue (% of GDP) and calculated using a discount rate of 1%, varies, depending on the scenario, from gains of 2.92% of GDP (Scenario A2) to gains of 13.37% of GDP (Scenario B2). Factoring in the negative effects of desertification, the overall impact ranges between gains of 3.31% of GDP (Scenario B2) to losses of 14.84% of GDP (Scenario A2). The impacts vary further if account is taken of changes in other factors affecting agricultural production and directly related to climate change, such the impact of weeds, diseases and insect pests (including invasive species) and possible changes in pollinator activity levels.

Forests

Forest ecosystems cover some 65% of Greece's land surface (forests 25%, rangelands 40%). Assuming that today's management strategy remains in place, it is estimated that as a result of climate change by the year 2100, Mediterranean coniferous and evergreen broadleaf forests will expand by 2% to 4%, in areas presently occupied by more productive temperate forest species such as spruce, fir, beech and black pine, which will shrink by 4% to 8% depending on the scenario (B2 or A2). As a result, wood biomass production is expected to decrease by 80,000 m^3/year to 330,000 m^3/year. The decrease on average in total wood biomass production is expected to be from 27% (529,200 m^3/year, Scenario B2) to 35% (686,000 m^3/year, Scenario A2) by 2100. Meanwhile, rangeland production is projected to fall by 10% (312,000 tonnes/year, Scenario B2) to 25% (780,000 tonnes/year, Scenario A2). Furthermore, because of the rise in sea level, rangeland production will fall by an additional 26,000 tonnes/year (Scenario B2) to 52,000 tonnes/year (Scenario A2).

With the rise in temperature, the number of summer wildfires and the total burned area will increase by 10% to 20%, resulting in increased yearly firefighting costs of €40 million (Scenario B2) to €80 million (Scenario A2). Surface runoff and erosion are also expected to worsen, curtailing the amount of available usable water by 25% (5 billion m^3, Scenario B2) to 40% (8 billion m^3, Scenario A2) per year and drastically increasing erosion by 16% (Scenario B2) to 30% (Scenario A2).

The present value of the direct economic impact of climate change estimates ranges from €1.4 billion (Scenario B2; 3% discount rate) to €9.5 billion (Scenario A2; 1% discount rate), without considering the impact on other products and services, such as non-material forest services, biodiversity, etc. which may be higher than the material losses.

On the other hand, the cost of adaptation by the year 2100 can be summarised as amounting to:

(A) €2.35 billion (Scenario B2) or €4.7 billion (Scenario A2) for constructions including: (a) sediment retention barriers: €0.5 billion (Scenario B2), €1.0 billion (Scenario A2); (b) rainwater harvesting dams: €1.75 billion (Scenario B2), €3.5 billion (Scenario A2); (c) sea levees (total length 100 km or 200 km depending on the scenario): €0.1 billion or € 0.2 billion.

(B) €0.2 billion (Scenario B2) or €2.3 billion (Scenario A2) for additional management costs (forest cultivation, firefighting, grazing systems application, etc.).

Biodiversity

Species abundance is expected to decrease in Southern Europe, in parts of the Iberian Peninsula, Italy and Greece, and species distribution will depend on habitat suitability. It has been recorded that 60 of the 127 native freshwater fish (about 47%) found in Greece are threatened by climate change. With regard to Greece's forest ecosystems, climate change is expected to lead to a contraction in distribution of cold temperate conifers (spruce, forest pine, etc.) and to warm temperate conifers invading into deciduous oak forests. Turning to wetlands, several ephemeral ecosystems are expected to disappear, while other permanent ones will shrink.

The economic impact of biodiversity loss was calculated on the basis of the present value, over the period 2011-2100, of the costs arising from the loss of the ecosystem services provided by forests and the habitats of Lakes Chimaditis and Kerkini, as envisaged under Scenarios A2 and B2 for Greece. The total cost in present value terms for the period 2011-2100 ranges from €1.14 billion to €240.8 billion for the forest ecosystems, depending on the economic value assigned to the services likely to be lost (low/high value) and from €15.6 million to €172.1 million for Lakes Chimaditis and Kerkini. Due to the difficulty in quantifying many of the impacts, these cost assessments should be regarded as lower-bound estimates of the total economic impact of climate change on biodiversity.

Tourism

Climate change is expected to have a significant impact Greek tourism, mainly in the form of a seasonal and geographical redistribution of tourist arrivals, and thus on the revenue of the tourism sector. These estimates are based on the projected impact of climate change on the

Tourism Climatic Index (TCI) by 2100. Our projections at the national level indicate that, after a slight decline during the first three decades of this century, tourist arrivals will increase significantly, by as many as 10 million additional arrivals per year, corresponding to 25% of total arrivals in the decade 2091-2100. However, these overall projections mask considerable seasonal and regional differences, as shown by the detailed breakdown of tourist arrivals. We found that Greece's major tourist destinations will experience a significant decrease in tourist arrivals in summer, i.e. at the peak of the demand for Greece's tourism. Our estimates for Crete and the Dodecanese show that total revenue in summer during the decade 2091-2100 will fall by €370 million/year in Crete and by €280 million/year in the Dodecanese. If we factor in the increase in operating costs needed to adapt to climate change, estimated at €70-90 million/year (5-7% of operating costs), the impact on the sector's annual profits will be critical to the viability of many operations and establishments. These negative economic impacts could be mitigated or even entirely offset (considering that the TCI improves significantly in spring and autumn), provided that an appropriate adaptation strategy is designed and implemented. Although it is not possible to accurately estimate the overall impact of climate change on Greek tourism, the results of the present study clearly point to the need to (a) expand the tourist season, (b) geographically diversify Greece's tourism product, and (c) develop new alternative forms of tourism. Achieving these objectives will crucially depend on the ability of the Greek state, in close cooperation with the tourism industry, to design and implement a long-term strategy plan for Greek tourism. The main goals of such a strategy plan should include: (a) marketing Greece's many still unexploited natural attractions; (b) developing and promoting alternative eco-friendly forms of tourism; (c) attracting new tourist target groups; and (d) taking measures to reduce the industry's environmental footprint.

The built environment

Buildings accounts for roughly one-third of Greece's CO_2 emissions and about 36% of its total energy consumption, meaning that Greece's buildings have the highest energy consumption in Europe. The physical impacts that climate change is projected to have on the built environment include: changes in the energy consumption of climate-controlled buildings and changes in the indoor climate of buildings without additional energy. Future improvements in power production technologies and the upgrading of building standards will to a large extent offset the impacts of climate change.

The total cost of the measures needed to adapt the existing and future building stock to the technological standards likely to be in effect in 2050 will amount to some €230 billion, about 50% of which will involve upgrading building envelopes. Interestingly, the costs of additional photovoltaic systems, needed to achieve zero energy consumption, will be small, given the very low energy needs for heating and cooling, thanks to the thermal insulation of building envelopes and improved energy-saving systems. In order to estimate the impact of climate change on these costs, we considered an alternative scenario for energy demand, assuming that climatic conditions will remain similar to the mean values for the baseline period 1960-1990. The additional costs arising from the impact of climate change range from 7.6% to 10.3% of present costs, depending on the region.

Transport

The direct physical impacts of climate change on the transport sector can be broken down into three main categories: (a) impacts on transport infrastructure from natural disasters, requiring infrastructure repair/reconstruction, as well as the implementation of additional proactive/preventive protection infrastructure projects; (b) impacts on transport infrastructure maintenance; and (c) impacts on the transport system's operation and reliability (e.g. delays and rerouting).

Based on the climate change scenarios assuming a sea level rise of 40-50 cm, a significant part of Greece's transport infrastructure would obviously be at risk from climate change impact, while the operations of a very large number of Greece's ports would be directly affected, thereby causing a direct impact on the country's maritime transport system.

The costs of transport maintenance to make up for the impact of climate change ranges from €594.8 million/year to €195 million/year, depending on the climate change scenario, while the costs of transport delays on account of climate change (extreme weather events, overheating of transport infrastructure, etc.) ranges from €28,031 billion to €9,311 billion.

Health

Climate change can cause premature death due to the increased frequency of extreme weather events, but it can also have an indirect impact on health as a result of the environmental changes and the ecological disruptions it causes (e.g. higher risk of vector-borne or rodent-borne infectious diseases), as well as other effects for segments of the population confronted with environmental degradation and economic problems due to climate change (e.g. nutritional or even psychological problems). An increasing trend in the number of extreme event deaths due to climate change is expected for Greece in the course of the century. Assuming that by 2100 the mean maximum summer temperature in Attica will increase by about 4.4ºC (Scenario A1B), the number of deaths due to anthropogenic overheating in the Athens basin would increase by around 25%. On the other hand though, the number of deaths from exposure to very low temperatures during the winter months would decrease. It should be noted that the projected drop in deaths from exposure to cold weather conditions comes at most to 3%.

Thus, the additional annual deaths in Greece during the decade 2091-2100 are estimated at 21 per day in the summer, while three fewer deaths per day are projected for winter. Based on these figures, the additional number of deaths due to anthropogenic climate change at the end of the 21st century would total 1,620 per year. Given, furthermore, that one year of life is valued at €59,000 (PESETA Report), it is estimated that the annual economic impact under Scenario A1B for the decade 2091-2100 will come to €95 million for the Attica region alone. Using the same method, the annual economic impact for Scenarios B2 and A2 was estimated for the decade 2091-2100 at €85 million and €135 million, respectively.

Mining and quarrying

The impacts of climate change on the mining industry can be divided into two categories, depending on whether they are direct or indirect. The direct impacts include: (a) damage to infrastructure (e.g. haul road erosion, failure of impoundment structures, etc.) due to extreme weather events, (b) wildfires due to drought and high temperatures, (c) decrease in water resource availability due to lower precipitation and higher evaporation, (d) increase in emissions of suspended particulates due to decreased humidity and higher temperatures, (e) loss in working-hours due to ambient temperature changes, and (f) reinforcement of environmental protection and rehabilitation measures and actions. The indirect impacts, ensuing from the need to reduce greenhouse gas (GHG) emissions, include: higher energy costs (incorporating, as of 2013, the costs of GHG emission permits and the reduction in lignite-fired electricity production), decreased employment due to reduced activity in specific sectors in compliance with GHG reduction requirements, and higher operating costs associated with the mining sector’s climate mitigation strategies (e.g. adopting low GHG emissions technologies).

The cost of climate change for the mining sector, under Scenario A1B for the period 2021-2050 in present value terms, was assessed at roughly €927 million, assuming a discount rate of 1%, and €575 million, assuming a discount rate of 3%.

* * *

The following observations can be made with regard to the findings of the above sectoral analyses:

1. The present study marks a first attempt to record the qualitative and tentative quantitative impacts of climate change on the Greek economy. This is the first time that the impacts have been systematically presented for a wide range of sectors. Previous studies were either fragmentary or simply adapted and transposed the findings of international studies to the case of Greece.

2. For all of the sectors examined, the impacts of climate change were found to be negative and, in many cases, significantly so. There were a few exceptions in specific sub-sectors of agriculture and fisheries, but the overall impact (even on agriculture and fisheries as a whole) was negative.

3. The economic impact assessments are indicative of the lower cost bound per sector, given that the valuation of many important impacts was not possible at this stage.

4. As shown by the study, the impact of climate change on certain key sectors of the economy, such as tourism, transport and forestry, could have broader implications for the national economy. **Sector-specific** adaptation policies will therefore need to be designed in such cases. As for the built environment, where the costs of reducing energy consumption will be significant, a **tailor-made** policy will need to be designed to improve power production system technology and to upgrade building standards.

5. Due to its small size and share of responsibility in climate change, Greece will be confronted with climate change developments largely determined by other players and international agreements. Therefore, it is important that the impact assessments presented in this study serve as a basis for the formulation of a national adaptation policy.

6. As shown by the findings of the sectoral studies, research must be pursued in the fields of climate change impact valuation and quantification and, more importantly, effective adaptation policy design.

5.3 Cost-benefit analysis of climate policy for Greece*

Climate change will have significant negative impacts on several sectors in Greece, with agriculture, forestry, fisheries, tourism, transport, coastal activities and the urban built environment all expected to be affected by the rise in temperature, drought, extreme weather events and sea level rise. According to the sectoral analyses presented in Chapter 2, these impacts will lead to reduced productivity, loss of capital and additional expenditure for damage repair. Negative impacts will also affect biodiversity, ecosystems and health.

The cost of climate change for the Greek economy incorporates: the direct impacts of the phenomenon on a number of sectors (as estimated in Chapter 2), the indirect impacts, as well as the impacts from interaction between sectors. Data available for the sectors of agriculture, forestry, fisheries, tourism, transport, coastal areas and the built environment were used to estimate total costs. Due to technical difficulties, the impact on biodiversity, ecosystem and health were not taken into account.

The future intensity of climate change remains difficult to predict because of the uncertainty surrounding the manner in which global greenhouse gas (GHG) concentrations will evolve. The intensity of climate change will differ depending on the scope and timing of GHG reduction action worldwide. As discussed in Chapter 1, various emission scenarios were taken into account with regard to the intensity of climate change.

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* The analysis for this sub-chapter was conducted at the E3MLab of the NTUA, under the scientific direction of Prof. Pantelis Capros, by key researchers Marilena Zambara, Leonidas Paroussos and Nikolaos Tasios.

5.3.1 Cost of the Inaction Scenario

The worst-case scenario in terms of climate change intensity, corresponding to no action whatsoever being taken to reduce emissions, was called the Inaction Scenario.

Based on the estimated intensity of climate change in the years 2050 and 2100 under the Inaction Scenario, we were able to make a quantitative estimate of the direct economic impact on specific sectors of the Greek economy, in terms of productivity, capital and expenditure. These estimates were then fed into the general equilibrium model GEM-E3 in order to calculate the aggregate costs for the Greek economy. These costs were measured as changes in GDP, sectoral activity and employment, as well as equivalent changes in wellbeing. Both static and dynamic valuations were made relative to the state of the economy in base year. The aggregate cost of the Inaction Scenario was found to comprise a decline in GDP and a negative equivalent change in wellbeing.

As shown by the results using the general equilibrium model, presented in Section 3.3, the Inaction Scenario will cause Greek GDP to contract by an annual 2%[1] assuming the climate change intensity projected for 2050, and by an annual 6% assuming the climate change intensity projected for the year 2100.

The total cumulative cost of the Inaction Scenario for the Greek economy for the period extending up to 2100, expressed as a drop in base year GDP [P1],[2] came to €701 billion (at 2008 constant prices). The estimate of the cumulative cost was based on nonlinear interpolation for the time period in question, under zero discount rate. The loss of Greek GDP from not taking action against climate change both in Greece and at the global level, taken cumulatively, would be equivalent to three times Greece's current GDP.

5.3.2 Cost of the Mitigation Scenario

Climate change mitigation calls for an immediate and drastic reduction in global greenhouse gas (GHG) emissions. Averting climate change altogether does not appear to be likely, given how high today's GHG concentration levels already are, relative to pre-industrial levels. Climate change mitigation is, however, still possible, provided that global GHG emissions are steadily reduced over the period 2020-2100. Mitigation –according to the Copenhagen Accord of 2009– is universally accepted as limiting the rise in the Earth's mean temperature to 2°C. According to global emission projection models, mitigation can be achieved if global emissions are reduced by 2050 to 50% of the emissions level of 1990 and provided that this reduction is continuous (and linear) from 2020 onwards. Based on the mathematical models and as sup-

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[1] Decrease in GDP size, not in the GDP growth rate.

[2] A dynamic simulation of the course of the Greek economy through 2100 was not attempted. We estimated the dynamic evolution of the aggregate cost for the Greek economy as a percentage decrease in GDP and applied it to the base year GDP in order to calculate the cumulative cost for the entire period. Therefore, the cumulative cost, measured in monetary units, refers to base year GDP. The base year used was 2008.

ported by many experts, for this goal to be reached, the OECD countries would have to reduce their GHG emissions by at least 80% by 2050, relative to the 1990 levels. The European Union has, accordingly, adopted this target for all the Member States, including Greece.

Greece's climate change mitigation policy would therefore have to be geared towards a continued and drastic reduction in GHG emissions, as of today, in order to reduce emissions by 70-75% by 2050, relative to 1990 emissions levels.[3] As much as 70% to 80% of all GHG emissions are attributed to the fossil fuel combustion associated with energy consumption and power production. Agriculture/animal husbandry and industry account for the rest. Climate change mitigation can of course be achieved only if all countries worldwide reduce emissions in compliance with the targets mentioned above. Action by one country alone, no matter how significant, cannot suffice to mitigate climate change.

For the purpose of the present study, the Mitigation Scenario was defined as a situation where Greece achieves a continuous and drastic reduction in GHG emissions as part of a successful global effort to contain the mean temperature rise to 2°C. Thus, the climate change impact on the Greek economy would be very limited, but still present.

Ways to reduce GHG emissions by 2050 were examined in Chapter 4, using the mathematical model PRIMES, specially developed for simulating the energy system and other activities responsible for GHG emissions. Using this model, we estimated the expenditure and investment costs that the Greek economy would incur in order to reduce emissions, compared with a 'business-as-usual' scenario under which today's trends and policies would continue and, though expected to achieve certain emission reductions relative to the past, would not achieve the drastic reduction required by the Mitigation Scenario.

These extra costs translate into a loss of GDP (compared to the 'business-as-usual' scenario) and would occur mainly until 2050. Expressed as a decrease in GDP relative to base year GDP, the cumulative costs of the mitigation policy for the Greek economy were estimated at €142 billion (at 2008 constant prices), using a zero discount rate. In other words, the total cost for the Greek economy of implementing the mitigation measures through 2100 would be equivalent to a loss of about half the base year's GDP.

Despite the emissions reduction, the cost analysis, however, also estimates the costs that the Greek economy would incur as a result of the damage caused to several sectors by the low-intensity climate change corresponding to the 2°C mean temperature rise scenario. The total cumulative damage costs for the Greek economy up to 2100 were estimated at €294 billion (at 2008 constant prices). These costs were expressed as a loss of GDP relative to base year GDP, using a zero discount rate.

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[3] The ability to drastically reduce emissions by 2050 would imply that the economy has the proper technological structure to remain a low-carbon economy beyond 2050.

These mitigation measures, provided that they are globally adopted, would result in cumulative savings of €407 billion, by containing the intensity of climate change. The benefit-to-cost ratio of the mitigation measures was estimated at 2.86.

The aggregate cost of the Mitigation Scenario for the Greek economy consists of the cost of emission reduction measures (€142 billion) *plus* the cost of the residual climate change impacts (€294 billion). Therefore, the cumulative aggregate cost of the Mitigation Scenario up to 2100, expressed as a loss of GDP relative to base year GDP, came to €436 billion (at 2008 constant prices).

In other words, the overall cost of mitigation was found to be €265 billion less than the cost of the Inaction Scenario, meaning that the mitigation policy reduces the total cumulative costs of inaction by 40%. All of these estimates were calculated using a zero discount rate.

5.3.3 Cost of the Adaptation Scenario

Despite its obvious advantages over inaction, the mitigation policy can only yield results if implemented immediately and unwaveringly by the entire global community. Any flaws or delays in mitigation policy implementation at the global level would cause a much greater intensity of climate change than the one associated with a rise in mean global temperature of just 2°C. It would not be wise for any country to rely solely on GHG reduction measures as a means of tackling climate change. A policy of adaptation is also necessary to reduce the possible impact of climate change, under every possible intensity scenario.

Adaptation consists in taking sector-specific action to reduce future damage from climate change. Chapters 2 and 3 (Sub-chapter 3.4) both detail adaptation measures for specific sectors and understandably concentrate on those sectors assessed as being more vulnerable to climate change. For the most part, these measures consist of public works and involve public expenditure aimed at providing protection against the impacts of temperature rise, extreme weather events, drought and water shortage, and sea level rise. Part of the cost of these adaptation measures would have to be borne by the private sector (e.g. in the tourism and agriculture sectors), as well as by households, particularly in urban centers.

In order for adaptation measures to be effective in containing the damage from climate change, they must be implemented before climate change takes on great intensity. Thus, much of the difficulty in drawing up a strategic plan for adaptation measures arises from the uncertainty about the future intensity of climate change. Adaptation measures will therefore have to be subject to updating and fine-tuning, and the strategy of adaptation redefined, drawing on collaboration between the public and the private sector.

Chapter 3 (Sub-chapter 3.4) presents a cost analysis for an indicative adaptation scenario, consisting of measures judged capable of reducing the damage from the climate change intensity associated with the Inaction Scenario. The procedure consisted in estimating the direct expenditure costs needed for adaptation measures and in allocating these costs between the public and the private sector. These costs were then entered as exogenous changes into the general equilibrium model GEM-E3. Using this model, we were then able to estimate the indirect impact (i.e. costs) on the Greek economy.

The total cost of the adaptation measures for the Greek economy, as estimated using the GEM-E3 model, will have negative consequences, expressed as a loss of GDP and calculated for the entire time span covered by the study. Even though the adaptation measures would generate additional activity and employment for construction projects, their funding through public expenditure, coupled with the non-productive nature of these private and public investments, means that they will be at the expense of productive and export-generating investment and activities. The adaptation measures were therefore found to have a negative impact on GDP and thus the total (direct and indirect) costs of the adaptation measures were estimated at €67 billion (at 2008 constant prices), cumulatively up to 2100, expressed as a drop in GDP relative to base year GDP and using a zero discount rate.

The adaptation measures do not eliminate all of the damage induced by climate change, but simply serve to contain it. Thus, it was estimated that the residual damages from climate change would cost the Greek economy a total of €510 billion (at 2008 constant prices) cumulatively up to 2100, expressed as a drop in GDP relative to base year GDP. This expenditure, which corresponds to containing climate change damage, would cost the Greek economy some €190 billion less than the total cumulative damage from climate change under the Inaction Scenario. The benefit-to-cost ratio of the adaptation measures was thus estimated at 2.82, using a zero discount rate.

The total cost of the Adaptation Scenario for the Greek economy is the sum of the costs of the adaptation measures and the costs of containing the damage from climate change. The total cost of the Adaptation Scenario was estimated at €578 billion (at 2008 constant prices), cumulatively up to 2100, expressed as a decrease in GDP relative to base year GDP.

5.3.4 Scenario cost comparison

Table 5.1 presents the total cost estimates for the Greek economy of the Inaction, Adaptation and Mitigation Scenarios. These estimates are based on the results of general equilibrium model GEM-E3, using the direct cost and direct expenditure estimates produced by the sectoral studies. The cost figures given in Table 5.1 were all calculated relative to base year GDP.[4]

Figure 5.1 plots the estimated annual cost of the Inaction, Adaptation and Mitigation Scenarios in terms of GDP loss.[5] The cost of the Mitigation Scenario includes the costs of mitiga-

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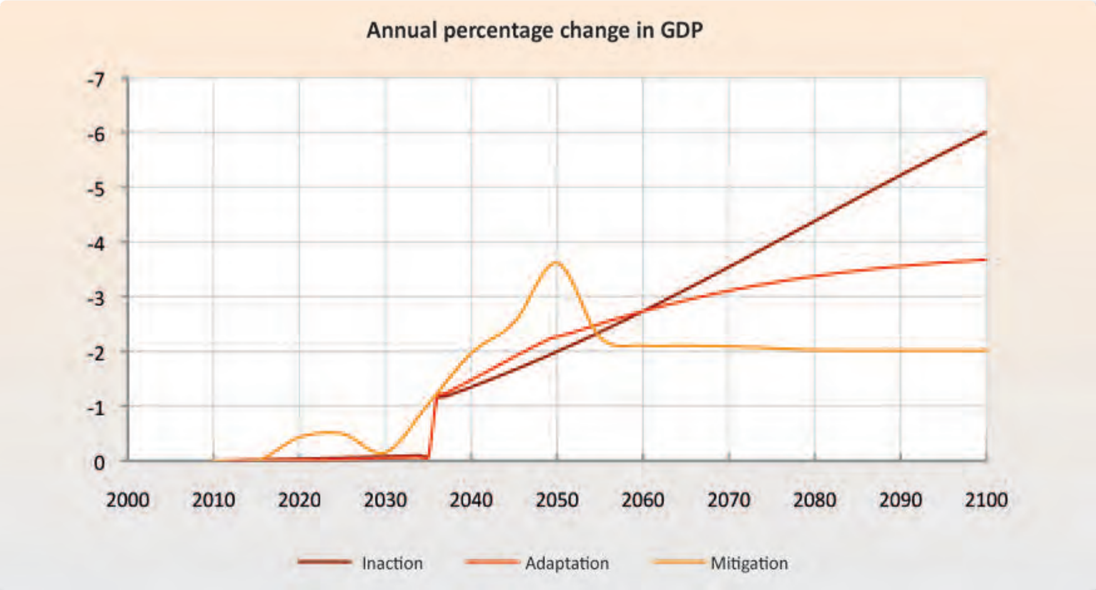
[4] Estimated at roughly €240 million at 2008 constant prices.

[5] Not in the rate of change of GDP.

Table 5.1 **The cost of climate change and adaptation and mitigation policies for the Greek economy until 2100**

Cumulative cost (EUR billions) in base year (2008) GDP values		Adaptation			Mitigation				
Period	Inaction	Total cost	Adaptation measures	Unavoided impact	Total cost	Mitigation measures	Unavoided impact	Benefit of Adaptation over Inaction	Benefit of Mitigation over Inaction
Discount rate 0%									
2011-2050	79	86	36	50	130	113	17	-7	-51
2051-2070	182	178	24	154	125	26	99	5	57
2071-2100	439	314	8	306	181	3	177	125	259
2011-2100	701	578	67	510	436	142	294	123	265
Discount rate 2%									
2011-2050	41	44	18	26	70	62	8	-3	-29
2051-2070	65	64	9	55	45	10	35	1	19
2071-2100	96	70	2	68	40	1	40	26	56
2011-2100	202	177	28	149	156	73	83	24	46

Figure 5.1 Annual cost of climate change in GDP loss terms under three different scenarios



tion measures (emissions abatement) *plus* the damage costs associated with a climate change intensity corresponding to a 2°C rise in mean temperature. The cost of the Adaptation Scenario includes the costs of the adaptation measures *plus* the costs of residual damage from climate change intensity similar to that of the Inaction Scenario.

As shown by the results, the cumulative benefit up to 2050 of both the adaptation and mitigation policies, relative to the Inaction Scenario, would, as expected, be negative, given that climate change intensity is expected to be low until then. As soon as we extended the horizon to 2070, the cumulative benefit from adaptation or mitigation turned positive relative to inaction, though remaining small in absolute terms. When the cost projections for the decades 2070 to 2100 were included, the cost of inaction for the Greek economy by far exceeded the cost of either the adaptation or mitigation policies, even when the costs of residual climate change impacts were taken into account.

It should be recalled that our damage containment estimates for the adaptation policy were based on the assumption that climate change would be of the same intensity as in the Inaction Scenario. The mitigation policy, however, presupposes a global effort to drastically reduce GHG emissions, as a result of which climate change intensity will have been contained at a level corresponding to an increase in mean temperature of up to 2°C.

Cumulatively up to 2100, the Adaptation Scenario achieves cost savings of €123 billion (at 2008 constant prices), relative to the Inaction Scenario, while the Mitigation Scenario achieves cost savings of €265 billion.

The analysis clearly points to the economic benefit of implementing a mitigation policy. It is, however, necessary to underline the considerable uncertainty surrounding mitigation as a policy, since its overall effectiveness will largely be determined by how strictly emission abatement policies are implemented at the global level. It is precisely this uncertainty that tilts the balance in favour of adaptation policies. As shown by our analysis, if the global effort to mitigate climate change is expected to fail and if climate change intensity is expected to be significant, then the implementation of adaptation measures would, from an economic standpoint, be advisable.

A question which naturally ensues is whether it might be even wiser to combine mitigation measures (to reduce emissions) and adaptation measures (to contain climate change impact). Simultaneous implementation of adaptation and mitigation measures would result in increased costs for the Greek economy. However, based on the estimates presented in Table 5.1, with the total cost of the adaptation measures amounting to €67 billion and the total cost of Mitigation Scenario amounting to €436 billion, there would be a significant (cost-saving) benefit of €200 billion, relative to the cost of Inaction.

Deciding on the optimal mix of mitigation policy and adaptation measures is no more, no less a matter of determining an optimal strategy under conditions of heightened uncertainty. This uncertainty will obviously decrease to some extent over time, as global efforts to reduce emissions unfold and phenomena attributable to climate change begin to manifest themselves. However, the time by which these uncertainties will dissipate does not coincide, which makes managing them a difficult task. One thing is certain: the strategy for reducing emissions as well as for adaptation measures will need to be re-evaluated periodically.

Given present circumstances and Europe's commitments, Greece has an obligation to implement an ambitious policy across all sectors to reduce GHG emissions. This policy, up to 2020, is clearly outlined in EU Directives. High cost adaptation measures will need to be extended beyond 2030, whereas a number of important low-cost adaptation measures, mostly of an institutional nature, can be taken in the upcoming decade. In other words, the mitigation and adaptation strategy is clearly marked out and economically sound at least as far as 2030. This strategy would need to be reevaluated in the course of the next decade.

All the cumulative cost estimates given earlier were obtained using a zero discount rate. However, even when using a 2% discount rate[6] (see Table 5.1), the conclusions drawn from the cost-benefit analysis remained the same: mitigation remains a better option than inaction, while an eventual parallel implementation of adaptation and mitigation measures, as opposed to inaction, would lead to a reduction in total cumulative costs.

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[6] The 2% discount is slightly higher than the one used in the Stern Report.

Figure 5.2 Sensitivity analysis using a range of discount rates

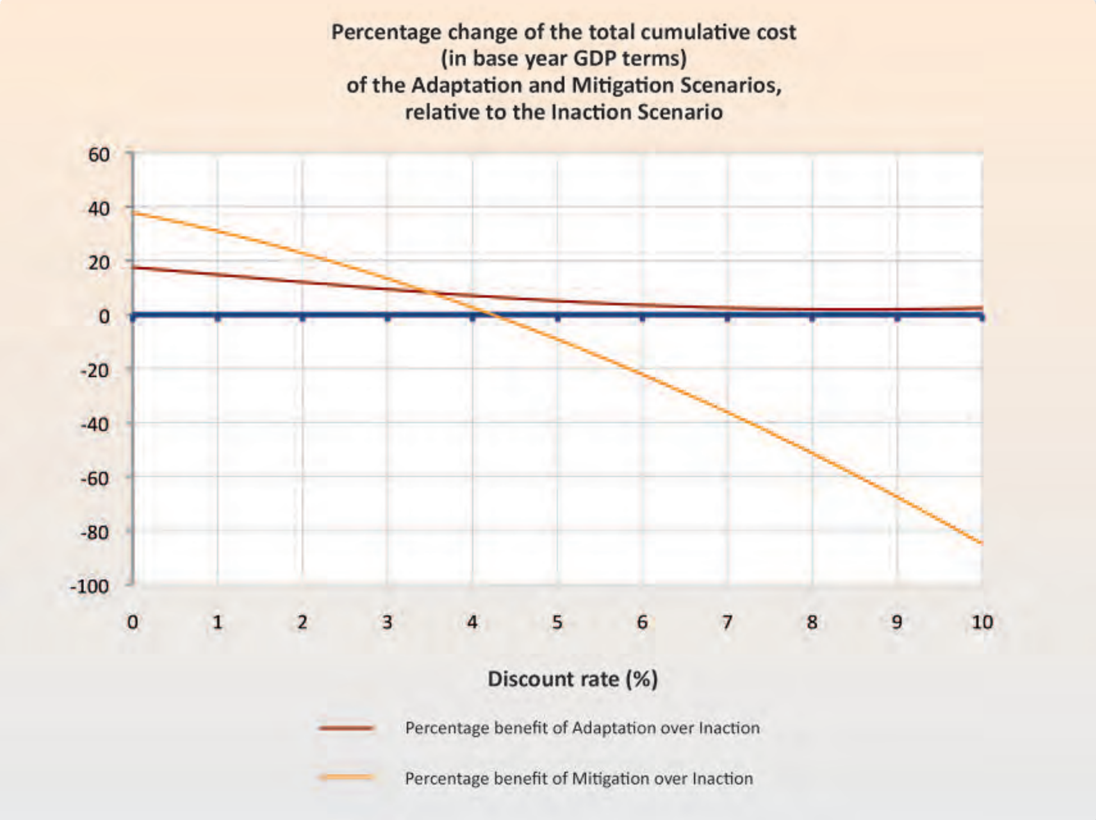

Figure 5.2 graphically represents the sensitivity analysis of cost estimates across a range of discount rates. For discount rates above 4.2%,[7] the total cumulative cost of the Mitigation Scenario exceeds the cost of the Inaction Scenario. However, the cost of the Adaptation Scenario remains lower than the cost of the Inaction Scenario.

It is worth noting that, on the basis of the theoretical premises discussed in Chapter 3 (Sub-chapter 3.1), the case for action to reduce emissions and mitigate climate change should not be based solely on the results of cost-benefit analysis, like the one carried out in this section and which estimated the climate change cost burden most likely to ensue in the event of inaction. However, there is a small, but distinct possibility that climate change intensity and the damage associated with it could be colossal. In such an eventuality, any action to reduce emissions and mitigate climate change would be safeguarding against devastation. And as soon as an action is shown to have safeguarding value, it becomes worth implementing, no matter the cost.

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[7] See Chapter 3 (Sub-chapter 3.1) on the choice of discount rates.

5.4 Social impacts*

The UN Millennium Summit of 2000 concluded with the setting of ‘Millennium Development Goals’ for the period till 2015. These goals included: eradicating extreme poverty, improving health worldwide and fostering global growth. The distributional effects of climate change on the poor, the unemployed and the less developed countries call for in-depth research and effective policy formulation. Considerable progress in combating poverty and social exclusion worldwide has, without a doubt, already been made. It is, however, feared that the adverse effects of climate change on society and the economy could significantly undermine these achievements. According to estimates from the United Nations (UNFCCC), a mean temperature increase of 2°C could cause GDP to decline by 4-5%. In the absence of sufficient data, the present report has only selectively, rather than comprehensively, touched upon certain of the social dimensions of climate change and of relevant policy in Greece. Research in this area, however, is ongoing.

Since the early 2000s, Greece has seen its per capita GDP converge remarkably with the EU27 average. Poverty indicators have, however, remained relatively stable over the period 2000-2009, with 20% of the population remaining persistently below the poverty line. When designing strategies to combat poverty and social exclusion, policy-makers will need to take into account that the impacts of climate change will be more acute for lower-income earners (without the means to address the problems induced by climate change and, even less so, to take *timely preventive* measures). The adoption of adaptation or mitigation measures would require households to make certain *capital* expenditures *today* (e.g. to improve the insulation and energy efficiency of their homes, be able to use solar energy, relocate away from vulnerable coastal areas) if they want to face less expenses in the future, as opposed to a scenario where no protective action is taken. This, however, is beyond the means of poor households already facing liquidity constraints, without sufficient savings or access to bank credit. Therefore, poor households, minorities and immigrants already living in deprivation and facing significant environmental and social problems, not to mention inadequate access to social and health services, will see their situation deteriorate further in terms of housing, food, health, education and access to basic services. Equally questionable will be their ability to join energy-saving programmes, purchase advanced technology equipment and pay more for cleaner energy, as would be required under a policy for reducing greenhouse gas (GHG) emissions. Poorer households thus risk losing out on the benefits of adaptation policies and measures, as well as on developments in terms of a low-emissions economy, which will arise from climate change mitigation policy.

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* Sub-chapter 5.4 was co-authored by John Yfantopoulos, Isaac Sabethai and Pantelis Capros.

The risk of a **vicious cycle** of *poverty, lack of access to energy and technologies, and limited protection against losses induced by climate change* is therefore real and is expected to lead to an exacerbation of phenomena commonly referred to in the literature as ‘energy poverty’ and ‘climate poverty’.[8]

Similarly, climate change is expected to impact developed and developing countries differently. Both the Netherlands and Bangladesh are, for instance, among the countries most at risk from sea level rise. Bangladesh has already taken action, primarily at a societal level, to protect its population by setting up an impending cyclone and flood warning system. The possible benefits of this measure, however, appear to be limited, given the country’s low per capita income (US$ 450 per year). The Netherlands, on the other hand, with a per capita income 100 times higher, have pressed ahead with extensive investments to support relocation programmes to safer areas.

Thus, just as with social groups, economically weaker countries will be more vulnerable to the impacts of climate change that have already begun to be felt. Extreme weather events like drought, tropical storms and storm surges, but also the gradual sea level rise due to climate change, will be a matter of increasing concern to the international scientific community in the future.

According to data from the United Nations High Commissioner for Refugees (UNHCR), the number of migrants fleeing poverty, extreme deprivation, environmental disasters, climate change and armed conflict has grown significantly in recent years, with the term ‘environmental refugees’ now frequently used in discussions on climate change-induced migration. According to estimates,[9] the number of environmental refugees today is in the vicinity of 50 million and could reach as many as 200 million by 2050. Although these estimates, produced by N. Myers (2005), have been corroborated by N. Stern, there are still numerous reservations about the exact number.

Greece has already received large numbers of immigrants, and these numbers will increase significantly in future as the flow of environmental refugees increases. In the meantime, internal migration from low-lying coastal areas to higher altitudes will obviously also have become an issue, thereby pointing to the serious need for further investigation, based on which adequate policy can be formulated (as mentioned previously).

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[8] See, for instance: (a) Ruth, M. and M. E. Ibarraran (eds) (2009), *Distributional impacts of climate change and disaster – concepts and cases*, Edward Elgar Publishing, (b) Skoufias, E., M. Rabassa and S. Olivieri (2011), “The poverty impacts of climate change – a review of the evidence”, World Bank policy research paper No. 5622, April, (c) Greenstein, R., S. Parrott and A. Sherman (2007), “Designing climate-change legislation that shields low-income households from increased poverty and hardship”, Center for Budget and Policy Priorities, Washington D.C., 25 October.

[9] (a) Myers, N. (2005), “Environmental Refugees: An Emergent Security Issue”, 13th Economic Forum, Prague, 23-27 May; (b) Simms, A. (2003) “The Case for Environmental Refugees”, New Economics Foundation, London; (c) Brown, O. (2008), “Migration and Climate Change”, IOM, No. 31, Geneva, (http://www.migrationdrc.org/publications/resource_guides/Migration_and_Climate_Change/MRS-31.pdf).

As clearly indicated by the findings of the present study, **the strategic planning of both adaptation measures and emissions reduction measures**, in the context of a global mitigation effort, is necessary to address climate change and reduce its negative impact on wellbeing, the environment and economic growth. This implies that a key focus of future policy must be the fight against poverty and, in particular, against the further worsening of poverty and social exclusion induced by climate change and policies to address it.

Along with adaptation measures and an emissions abatement policy, *each individual country*, including Greece, will have to draw up an adequate corrective policy to effectively address the problem of poor households and their inability to pay for what is needed to cope with climate change impacts at their micro-level and gain access to clean energy and technologies.

This is a problem that can only be solved through public intervention. The State will have to create the necessary conditions for the financing of large-scale infrastructure projects (obviously, entailing a corresponding level of financial risk) that will improve the housing conditions of poor households and their access to energy. Moreover, the duty to provide public services, i.e. guaranteeing access to standard public services or goods (e.g. electricity, potable water) will have to be upgraded, in the light of climate change and global warming, by ensuring special rates (discounts) for low-income consumers. For the rest of society, the rates for services affected by climate change should be set through free market competition.

At the *global level*, protection of the more vulnerable countries will have to be achieved with the help of developed and economically more robust countries, through multilateral agreements negotiated under the auspices of the UN. As shown by the experience of the last two years, progress in this field may have been slow, but is nonetheless imperative and urgent.

Protecting the planet from climate change also means that consumer behaviour will have to change. Apart from public policy and the contribution of technology, the cost of harnessing climate change can undoubtedly be reduced if consumers and producers alike modify their behaviour so as to adapt to climate change and reduce emissions. Any strategy development geared towards adaptation and mitigation, in order to be effective, will imperatively have to involve collaboration between the public and the private sector, and will have to be periodically revised. This will help make up for the large degree of uncertainty both about the future extent of climate change and about the consistency with which the global economy will remain on track towards drastic emissions reduction.

Afterword and avenues for future work

The present volume represents a first attempt at a comprehensive study of the impact of climate change in Greece – in particular of the cost of climate change that would be borne by the Greek economy, the cost of implementing adaptation measures, as well as the cost of moving to a low-emissions economy, in the context of a global effort to mitigate climate change. For the first time and for close to two years, this project brought together teams from different scientific disciplines; the teams included physicists of the atmosphere, climatologists and geophysicists, experts in agriculture, forestry and fisheries, as well as experts on water resources, tourism, the built environment and energy, not to mention economists and sociologists.

The study produced climate projections for Greece, in a detailed geographic breakdown up to the year 2100. These data are available to the research community. A series of sectoral studies analysed the biophysical impact of the anthropogenic (human-induced) component of climate change and estimated the costs of climate change, disaggregated by sector, across time horizons extending to 2050 and 2100. The findings of the sectoral studies were then incorporated into a general equilibrium model of the Greek economy, in order to estimate the overall cost of climate change in terms of changes in GDP, social welfare and sectoral output. The sectoral studies also helped define the scope for adaptation to climate change through preventive measures. The next step was to assess the total cost for the Greek economy of adaptation measures, as well as the cost savings that can be achieved thanks to these measures, given that the damage from climate change would be reduced.

Using a mathematical model designed for the energy sector and industrial processes, researchers considered scenarios of drastic reduction in greenhouse gas emissions in Greece in line with current European Union policy and objectives. The cost for the Greek economy of achieving emission reduction was estimated, together with the benefits of mitigating climate change, under the hypothesis of a global reduction in emissions. Taking the above into account, the cost and benefits for the Greek economy of an adaptation scenario and a mitigation scenario were calculated and were then compared with those of the inaction scenario (where climate change reaches high intensity as a result of no global action being taken). The estimates were made for the years 2050 and 2100, but also cumulatively for the period extending till 2100. The cost-benefit analysis showed that the mitigation policy was clearly a *better* option than the inaction scenario, while the adaptation policy was also found to be of *benefit*. The study thus makes a clear case for taking action to reduce greenhouse gas emissions in line with the targets set by the European Union; it also points out the urgent need for work to begin on the formulation of a long-term strategy for adaptation measures.

Considering that the occurrence of extreme climate events in the future cannot be excluded, policies for both mitigation and adaptation should be viewed as contingency measures against such an eventuality; as such, they are advisable irrespective of the results of the cost-benefit analysis.

The present study is a starting point for more comprehensive and detailed research that could provide the backbone for a national strategy for addressing climate change. As such, it is by no means exhaustive and has its fair share of weaknesses and omissions, especially when it comes to the scope of the biophysical impact of climate change and the assessment of the economic impact disaggregated by sector. Further investigation would be needed to determine the advisability and the sequencing of, as well as the scope for adaptation measures in each individual sector. Other issues needing more thorough study are the impact of climate change on biodiversity and ecosystems in Greece and the indirect effects that changes in the ecosystems could, in turn, have on economic and social activities. Moreover, specific research is needed into the human health risks posed by higher temperatures, heat waves and the climate change-induced deterioration of living conditions in urban centres.

The present study does not examine issues related to the redistributional effects of climate change and of the mitigation and adaptation policies. The impact of climate change has social dimensions which deserve to be explored, especially as regards possible increases in poverty and migration, given that the effects of climate change and of policy responses to it will be most strongly felt by the lower-income population groups, which lack the necessary resources to address the problems caused by climate change and to finance measures for emission abatement and adaptation. Specific policies will be needed to avert the exclusion of any social groups from access to clean energy and technologies and to ensure adequate protection against damage from climate change.

Long-term energy planning is the core of climate change mitigation policy. The transition to an economy of low greenhouse gas emissions concerns all sectors of economic activity, consumption and energy production. Many aspects of this strategy, such as ways of removing the obstacles to energy conservation and to the diffusion of emission-free energy technologies, remain open to further exploration.

Further investigation is needed into the possible synergies between economic activity in Greece and the future markets for clean technologies in all sectors. Challenges for future study include energy pricing policy issues, market-based mechanisms that will support the diffusion of clean technologies, as well as restructuring policies designed to ensure that consumers and energy self-producers can participate in the energy market on a decentralised basis.

Future studies will have to look deeper into the fundamental strategic question of how dealing with climate change and reducing emissions can help boost growth in all sectors of the economy. This opportunity, if properly seized, could help reduce the costs of the mitigation and adaptation policies. New technologies, new activities, new standards for buildings and means of transportation, as well as the reorganisation of production activities need to become the focus of the new growth effort aiming at a low-emissions economy and protection against possible climate change-induced damage.

It is important, in further examining the impact of anthropogenic climate change, to take the sectoral studies deeper, by disaggregating their analysis by geographical area and focusing on the more vulnerable areas and the more vulnerable social groups. Pursuing this research in greater depth, enlarging its scope and disseminating its findings could all contribute decisively to creating a “critical mass” in society, which would, whenever necessary, push for proper policy decisions on climate change on the basis of long-term planning, and not in a myopic manner dictated by short-term political cost-benefit considerations, which would only multiply the burden on future generations.

The continuation of this project will provide both a challenge and an opportunity to improve the mathematical models of integrated assessment and to incorporate redistributional effects, uncertainty and non-linear modes of the ecosystems’ response to climate change.

There is still ample room for improving and expanding data and projections on climate and the atmosphere. Future simulations should be carried out in greater spatial detail, so that topography and the distribution of land and sea areas are more accurately factored in. The systematic updating of climate data and supporting the provision of timely information to the public about weather phenomena and their consequences is another area that needs developing. While being of help to the formulation of a strategy of adaptation to the anthropogenic component of climate change, these elements would also help shield Greece from the dangers posed by climate change. Climate change should also be “mainstreamed”, meaning that climate change strategies should be gradually integrated into all areas of policy, including foreign policy. Climate change cannot be addressed without the direct cooperation of all countries worldwide. Greece, as a member of the European Union, can and should play a role in mitigation strategy negotiations at the international level. The cost-effectiveness of Greece’s emission reductions will be higher if its energy market operates within a regional market, integrated as much as possible. Regional cooperation on climate change should therefore become a key axis of our country’s foreign policy, while another matter warranting particular attention is the strategy that Greece will adopt on the issue of emissions —on a global scale— from shipping.

At first glance, the current adverse economic conjuncture appears to constrain the financing of mitigation and adaptation policies. To the extent, however, that these policies can be exploited as an opportunity for new lines of economic activity and for growth, they can be part of the strategy for the Greek economy’s exit from the crisis and for setting up a new growth model – in other words, the adoption of mitigation and adaptation policies, rather than being hampered by the grave economic problem faced by Greece today, may actually contribute to its solution.

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