GREEN economy and TRADE

GE-TOP Ghana Strategy Proposal

Realizing solar PV projects in a cross-border power supply context

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List of acronyms

AAAC	All Aluminium Alloy Conductors
AACSR	Aluminium Alloy Conductor Steel Reinforced
AFD	Agence Française de Développement (French Development Agency)
AfDB	African Development Bank
AFLR	Automated Fault Location and Restoration
AFLS	Automated Frequency Load Shedding
AGC	Automatic Generation Control
AREI	Africa Renewable Energy Initiative
BAU	Business As Usual
BFI	Bilateral Financial Institution
BP	Boson Peak
CHP	Combined Heat and Power
CFI	Climate Finance Institution
CSR	Controllable Shunt Reactors
DA	Distribution Automation
DEG	Deutsche Investitions- und Entwicklungsgesellschaft (German Investment and Development Corporation)
DFID	Department for International Development
DSI	Demand Side Integration
DSM	Demand Side Management
EBRD	European Bank for Reconstruction and Development
EC	Energy Commission of Ghana
ECG	Electricity Company of Ghana
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EEG	Erneuerbare-Energien-Gesetz (German Renewable Energy Law)
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPC	Engineering, Procurement and Construction
ERERA	ECOWAS Regional Electricity Regulatory Authority
ESEI	ECOWAS Solar Energy Initiative
ESIA	Environmental and Social Impact Assessment
FACTS	Flexible AC Transmission Systems
FISES	Fraunhofer Institute for Solar Energy Systems
FS	Frankfurt School
GEDAP	Ghana Energy Development and Access Project
GEF	Global Environment Facility
GE-TOP	Green Economy and Trade Opportunities Project
GhEA	Ghana Energy Access
GIIF	Ghana Infrastructure Investment Fund
GIPC	Ghana Investment Promotion Centre
GIVAR	Grid Integration of Variable Renewables
GoG	Government of Ghana
GRIDCo	Ghana Grid Company
GSGDA	Ghana Shared Growth and Development Agenda
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IER	Institute for Energy Research
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
JICA	Japan International Cooperation Agency
KNUST	Kwame Nkrumah University of Science and Technology

kWp	Kilowatt-peak
LCOE	Levelized Cost of Electricity
LDCF	Least Developed Countries Fund
LFC	Load Frequency Control
LI	Legislative Instrument
MESTI	Ministry of Environment, Science, Technology and Innovation
MDB	Multilateral Development Bank
MoF	Ministry of Finance
MoP	Ministry of Power
MoTI	Ministry of Trade and Industry
MOU	Memorandum of Understanding
NGO	Non-Governmental Organization
NITS	National Interconnection Transmission System
NT	Numerical Technology
OPIC	Overseas Private Investment Corporation
PAGE	Partnership for Action on Green Economy
PCC	Point of Common Coupling
PEA	Preliminary Environmental Assessment
PER	Preliminary Environmental Report
PHS	Pumped Hydro Storage
PQ	Power Quality
PPP	Public–Private Partnership
PSEC	Power Systems Energy Consulting
PSS	Power System Software
PURC	Public Utilities Regulatory Commission
PV	Photovoltaic
RBF	Results-Based Financing
RE	Renewable Energy
SEFA	Sustainable Energy Fund for Africa
SEPS	Solar Export Potential Study
SMES	Super Conducting Magnetic Energy Storage
SOE	State-Owned Enterprise
SONABEL	Société Nationale d'Électricité de Burkina Faso (National Electricity Company of Burkina Faso)
SP	Strategy Proposal
SVC	Static Var Compensation
SVR	Step Voltage Regulators
STATCOM	Static Synchronous Compensator
TAQA	Abu Dhabi National Energy Company
TEC	The Energy Center
THD	Total Harmonic Distortion
TICO	Takoradi International Company
TOR	Terms of Reference
TSO	Transmission System Operator
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UPFC	Unified Power Flow Controller
US	United States of America
US$	United States Dollar
VRA	Volta River Authority
VRE	Variable Renewable Energy
VSC-HVDC	Voltage Source Converter – High Voltage Direct Current
WAPCO	West African Gas Pipeline Company
WAPP	West African Power Pool
WSSD	World Summit on Sustainable Development
WTG	Wind Turbine Generator

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Executive Summary

Background

The Ghana Solar Export Potential Study (SEPS) (UNEP, 2015) estimated that Ghana has a significant solar PV electricity potential, totalling 167,200 GWh (106.2 GW)[1]. This provides opportunities for furthering national electrification while pursuing trade in solar PV-based electricity within the ECOWAS region. Although Ghana's solar radiation is not superior to that of its neighbours, Ghana's transmission networks and political and institutional frameworks form essential advantages for attracting investments into generation capacity and infrastructure for subregional solar power trade.

Key related constraints identified by the SEPS include the financial competitiveness of PV-based electricity in cross-border trade and the capability of the interconnected power system to accommodate increasing levels of variable renewables such as solar PV. Based on a robust analysis, the study found that a grid-connected 100 MW solar plant in the north of Ghana could save 40,000 tCO2 annual emissions compared to business-as-usual (BAU), create 3,000 direct jobs, provide livelihoods for 23,000 of the poorest people, and earn Ghana an annual US$ 38 million in foreign exchange from export. Recommendations made by the SEPS to harness this solar PV potential included, *inter alia*, a case study of the technical and financial needs for incorporating new solar electricity supplies into cross-border trade, including the effect of solar variability, the need for base load and load balancing, towards determining the requirements for grid system improvements.

This report, the "GE-TOP Ghana Strategy Proposal – realizing solar PV projects in a cross-border power supply context", responds to findings and recommendations from the SEPS. It proposes a strategy for selecting a solar-ready, cross-border grid line between Ghana and Burkina Faso, securing preferential financing, and approving installation, including an in-depth assessment of technical and financial requirements.

Key findings

Technical and Regulatory

High and rising shares of variable renewable energy have generally been managed through measures such as: access to flexibility resources within power pools (including interconnected transmission networks); improvements in resource forecasting techniques; investments to improve ramping rates of conventional power plants; and diversification of utilization options for power from variable renewable energy sources.

Based on load forecast information from 2016 and expected transmission projects in the pipeline, up to 220 MW of variable solar PV power could be accommodated by the Ghana National Interconnected Transmission System (NITS). The capacity that can be integrated at a single point is dependent on other planned installations. Within the West African Power Pool (WAPP) arrangement, the Ghana Grid Company (GRIDCo) is in the process of constructing a 225 kV line from Bolgatanga in Ghana to Ouagadougou in Burkina Faso, in order to interconnect the electricity systems of both countries. Further, the construction of another 225 kV line from the same Bolgatanga sub-station through Burkina Faso to Mali is planned. The two lines are expected to transmit up to 400 MW of power. Beyond the carrying capacity of the existing and planned transmission lines, a transmission upgrade or construction of a new transmission line with adequate capacity would be required.

Additionally, as interconnections among WAPP Member States increase, more spinning reserves become available, the forecasting of solar resource improves, and more intermittent solar PV could be grid-integrated in Ghana, as the interconnected grid could be used as a back-up for any unforeseen variations in solar generation in Ghana.

1 It needs to be noted that the total of 167,200 GWh (106.2 GW) is a maximum potential, which is constrained in practice by the capacity of Ghana's infrastructure and other factors (including competing land uses) that are further elaborated in the Solar Export Potential Study and this Strategy Proposal.

Financing and risk

Renewable energy investment support schemes exist mainly in the form of low-interest loans, grants and risk mitigation packages, available through multilateral, bilateral and local entities. In Ghana, the most common forms of support are loans and grants.

Notable entities that have provided support for energy sector infrastructure development include: Agence Française de Développement (AFD), Overseas Private Investment Corporation (OPIC), Kreditanstalt für den Wiederaufbau (KfW) and German Investment Company (DEG). These institutions could potentially be engaged in arrangements to finance solar power projects.

At the multilateral level, entities such as the World Bank Group, the African Development Bank Group and the European Bank for Reconstruction and Development (EBRD) provide financial support, for which utility-scale export-oriented solar PV could be eligible. There are also some local financing sources.

Key eligibility requirements for accessing financing from these sources include: geographic location or regional setting, sector / technology covered, type of financing sought (grant, concessional loan, etc.), size of project, type of proposing entity (government, NGO, etc.), co-financing / cost-sharing requirements, and the implementation timeframe. The major risks identified for renewable energy investment are related to financing, off-takers / markets and socio-cultural aspects.

Licensing procedure

Ghana's existing transmission system network is wholly owned and operated by GRIDCo. To construct new transmission lines, a project developer or third party applicant must obtain two main licenses: a technical license from the Energy Commission, and an environmental permit from the Environmental Protection Agency (EPA).

In Burkina Faso, the state utility, SONABEL, has the mandate to construct and operate transmission infrastructure. A solar investor intending to engage SONABEL as an off-taker must submit an application that sufficiently demonstrates the need for a new power line. Engineering, Procurement and Construction (EPC) for the project may begin after completion of an Environmental and Social Impact Assessment (ESIA). The WAPP project implementation and coordination unit facilitates infrastructure projects within member states in the context of their existing regulations.

Step-by-step approach

This report concludes by suggesting a step-by-step approach to help interested stakeholders navigate the regulatory, technical and financing issues regarding transmission infrastructure for solar PV projects in a cross-border power supply context. As outlined in the technical analysis, two possible scenarios may call for the construction of a transmission line by a solar project developer or an independent entity. The first scenario assumes an intended grid-connected solar PV plant that is not located in close proximity to the GRIDCo network. The second scenario is a cross-border transmission line linking Ghana with Burkina Faso. Beyond the cross-border transmission lines currently planned and under construction, there are two drivers that could call for the construction of a new transmission line, one being economic (if it is cheaper to construct a new transmission line) and the second being technical (in case there is not enough capacity on the existing line). The Strategy Proposal provides a figure (Figure 6.1) that shows the detailed steps required towards selecting, seeking approval for, and financing new transmission lines.


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1 Background

Over the past decades, it has become increasingly clear that traditional models of development, which emphasize the development of physical, human and financial capital at the expense of natural capital, are unsustainable, and that new pathways to development are needed. The World Summit on Sustainable Development (WSSD), held in Johannesburg in 2002, underscored the need for a fundamental shift in production and consumption patterns (UN, 2002).

The concept of a green economy has developed and evolved over the years, guided by the working definition used by the United Nations Environment Programme (UNEP) as an economy "that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP, 2011). In a green economy, growth in income and employment is characterized by investments that reduce carbon emissions and pollution, enhance energy and resource efficiency and prevent the loss of biodiversity and ecosystem services.

The transition to a low-carbon growth trajectory presents both challenges and opportunities for various sectors of economic activity. In pursuit of this fundamental change in global development patterns, key sectors that offer significant opportunities for green growth were identified by the Rio+20 Outcome Document and included agriculture, fisheries, forests, manufacturing, renewable energy, and tourism (UN, 2012). The Rio+20 Outcome Document further tasked the United Nations (UN) with the coordination of the global green economy transition, and underscored the role of trade as an engine for development and economic growth.

In response to this affirmation of trade as an engine for sustained and sustainable growth, UNEP undertakes the Green Economy and Trade Opportunities Project (GE-TOP), which aims to identify, assess and inform trade opportunities that arise from a green economy transition, and to address related risks and challenges.[2] The global GE-TOP is structured in two phases: in Phase I, GE-TOP produced the global report "Green Economy and Trade – Trends, Challenges and Opportunities" (UNEP, 2013). In Phase II, UNEP applies key findings and recommendations from the global report in the context of five sector-specific country projects, including Ghana. In this context, UNEP cooperates with The Energy Center (TEC) at the Kwame Nkrumah University of Science and Technology (KNUST). The first stage of this partnership resulted in the Ghana Solar Export Potential Study (SEPS) (UNEP, 2015), which examines opportunities and challenges relating to the participation of solar photovoltaic (PV) electricity and component parts in subregional trade. The SEPS was undertaken in consultation with key stakeholders in energy, trade, environment, finance, the private sector and non-governmental organisations (NGOs). The Strategy Proposal forms the second stage of GE-TOP Ghana, in which UNEP cooperates again with TEC-KNUST.

Key findings and recommendations of SEPS

The SEPS showed that solar electricity generation capacity is significant, totalling 167,200 GWh (106.2 GW).[3] This creates opportunities for participation in subregional trade in electricity from solar photovoltaic (UNEP, 2015). The report viewed the national and subregional policy environment as conducive, as both the Government of Ghana (GoG) and ECOWAS have set objectives for encouraging subregional electricity trade, and developed mechanisms to help realize them. Significant private sector participation also exists in Ghana's power sector, which is being further encouraged as the country seeks to ramp up investments in generation capacity, for example by means of a Feed-in-Tariff (FIT) scheme.

In terms of resources, Ghana's solar radiation is not superior to that of its neighbours. However, the country has a comparative advantage for attracting investments in solar energy, in many areas such as:

- a clear policy objective and framework for becoming a major power exporter in the subregion;
- a renewable energy law (Act 832 of 2011) that creates the fundamental legal and regulatory framework for renewable energy projects;
- an open power sector with separate and different players in generation, transmission (open access) and distribution, and with various Independent Power Producers (IPPs) involved;
- a politically stable and democratic system, with a thriving private sector; and
- a transmission network that runs across the entire country, reducing the cost of power evacuation for potential investors.

From a financial point of view, in the absence of preferential financing or other support schemes, solar PV electricity will be unable to compete favourably with other generation sources, considering the existing tariffs currently in use for cross-border electricity supply arrangements. The cost of electricity generation from solar PV remains relatively high in comparison to the current cross-border bulk supply tariff of around US$ 0.15/kWh, depending on the individual plant characteristics. Solar PV technology can be enabled to cater for regional power trade, with the help of international funds that can provide preferential financing until equipment and installation costs fall to lower levels that better support the competitiveness of solar PV projects, and thereby support low-carbon and climate-friendly technologies.

In the meantime, the Ghana Ministry of Power has initiated the process to tender the first 20 MW of solar PV, alongside the existing renewable energy Feed-in-Tariff scheme, as a measure to inject competition and eventually bring down the levelized cost of electricity (LCOE) for solar PV to grid parity and below.

Variable renewables, such as solar PV and wind power, pose challenges for grid managers due to their potential impact on power quality, power fluctuations, frequency variation and transmission system stability.

2 For more information, please visit: www.unep.org/greeneconomy/GreenEconomyandTrade/GE-TOPPhase2/tabid/105782/language/en-US/Default.aspx

3 The total of 167,200 GWh (106.2 GW) is a maximum potential, which is constrained in practice by the capacity of Ghana's infrastructure and other factors (including competing land uses) that are further elaborated in the Solar Export Potential Study and this Strategy Proposal.

At the time of publication, the GoG had set a cap of 150 MW for grid-connected solar PV and 300 MW for wind power within the National Interconnected Transmission System (NITS). Additionally, solar plants without grid stability or storage systems with a capacity of up to 20 MWp per plant are allowed to be connected to the national transmission system via 161 kV or 330 kV lines, at any generation site. If project developers for intermittent renewables simultaneously provide appropriate grid stability / storage systems, this maximum capacity of 20 MWp can be exceeded. As additional base loads and dispatchable generations are added to the existing installed capacity, and further investments are made in the transmission networks, it is expected that the grid will become sufficiently robust to accommodate more variable renewables, and that power generation caps will be raised accordingly.

Based on these findings, the SEPS made a number of recommendations that included:

1. Regional bodies such as the West African Power Pool and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) should engage Member States and / or international stakeholders to develop new financial support mechanisms for solar PV trade, and to determine support mechanisms that can make cross-border trade in solar electricity an attractive investment within the current technical limits of the regional interconnected grid. Regional or international funds structured to support low-carbon energy production and infrastructure should be engaged in this effort.

2. Financial and institutional support mechanisms available to investors in the renewable energy sector (particularly, solar PV) should be documented and promoted, for example through an investor reference catalogue. These could include public–private partnership opportunities or concessionary financing arrangements provided by WAPP, the ECOWAS Solar Energy Initiative (ESEI), bilateral or multilateral partners, or the World Bank, among others.

3. The current capacity of Ghana's grid, including planned upgrades and expansions, should be investigated in order to identify technical and financial needs for incorporating new solar electricity supplies into cross-border trade. The effect of solar variability, including the need for base load and load balancing, should be considered for determining the requirements for grid improvement.

4. Preferred sites for solar PV installation and grid feed-in in Ghana should be identified. Such a study could be undertaken in conjunction with the Ghana Grid Company Limited (GRIDCo) and WAPP, and analyse the effect of MW-scale solar PV injection at various locations under various scenarios. It should account for both existing and planned local and regional (WAPP-related) power infrastructure.

5. The GoG should initiate steps to ease the process of land acquisition for ground-mounted solar PV projects. MW-scale solar PV projects often require large areas of land. Ghana's current land tenure system causes significant challenges and often hampers investment.

6. The technical process for adding new solar generation capacity in Ghana and incorporating it into cross-border trade should be documented. This would facilitate project developers and government policy-makers in their efforts to improve Ghana's solar trade potential. The process may be mapped out in partnership with the Volta River Authority (VRA – Ghana's state power generation utility), given its decades of experience in Ghana's cross-border power supply.

Rationale and objectives of the strategy proposal

The GE-TOP Ghana Strategy Proposal (SP) builds on findings and recommendations of the SEPS to recommend a strategy for selecting a solar-ready, cross-border grid line between Ghana and Burkina Faso, for securing preferential financing, and for approving installation, which will be useful for attracting the necessary investments. In order to achieve this objective, it is important to understand the challenges of matching grid infrastructure upgrades with the increasing export of variable renewables, particularly solar PV.

Fundamental questions that have guided the development of the Strategy Proposal include:

- What levels of solar PV penetration can Ghana`s current grid infrastructure take?
- What infrastructure upgrades and associated investments are required for increased solar PV penetration?

- Does the penetration level increase with expanded grid interconnections within WAPP?
- What is the infrastructure approval process for cross-border grid infrastructure?
- Which financing instruments, requirements and sources are available to support renewable energy infrastructure development and projects?
- What risk factors are relevant?
- Where does Ghana stand in relation to these perceived or real risks, and how can they be mitigated?

National context and vision

Although Ghana is currently experiencing load shedding as a result of inadequate power generation, several interventions are ongoing to address the deficit and consolidate the country's position as a key player in cross-border electricity trade in the West African subregion.

The existing national energy policy (Ministry of Energy, 2010) supports the "energy economy" agenda, which recommends that power generation for domestic needs and power generation for export be parallel and complementary energy policy objectives. This Strategy Proposal, therefore, outlines a medium- to long-term vision, and assumes an adequate base load and dispatchable capacity to help manage the variability in the grid.

Ghana's "energy economy" agenda, and its ambition to be a key player in cross-border electricity trade in the West African subregion, are spelled out in the following national and subregional policies, strategies and statements. The following documents provide ample evidence of the strong political convergence and the sector policy support for the strengthening of Ghana's position as an exporter of electricity in the subregion.

Regional energy and infrastructure policies
- ECOWAS Regional Strategic Plan 2011–2015. Priority Goal 3 (Sustained Development and Cooperation in the Region), Objective 1 (Promote cooperation among Member States for the development of a viable regional infrastructure), in particular the specific sub-objective 1.4: *"Promote provision of efficient, reliable and competitive energy sources to Member States through the common exploitation of traditional and alternative energy sources"* (AfDB and ADF, 2011).

Strategic National Energy Plan (SNEP), 2006–2020
- *"To produce adequate, high quality, reliable and efficient power supply to meet economic and social development needs of Ghana and for export."* (Energy Commission, 2006).

National Energy Policy (2010)
- *"The energy sector vision is to develop an "Energy Economy" to secure a reliable supply of high quality energy services for all sectors of the Ghanaian economy, and also to become a major exporter of oil and power by 2012 and 2015 respectively."*
- *"[Electricity generation and supply] is also an important source of foreign exchange earnings in the country as Ghana exports power to neighbouring countries, including Togo, Benin, and Burkina Faso."*
- *"Becoming a major exporter of electricity is a key objective of the energy sector vision and the opportunity exists for Ghana to expand its electricity exports under the West African Power Pool (WAPP) Project."* (Ministry of Energy, 2010).

Ghana Shared Growth and Development Agenda (GSGDA), 2010–2013
- *"Fundamentally, energy sector policies will seek to ensure secure and reliable supply of high quality energy products and services for all sectors of the economy, as Ghana regains her position as a regional exporter of power and becomes a net exporter of oil."*
- *"The generation and supply of electricity provides employment for a significant number of Ghanaians. It is also an important source of foreign exchange earnings through exports of power to the neighbouring*

countries, Benin, Burkina Faso, and Togo. Ghana also has a mutual interconnection and supply agreement with Cote d'Ivoire." (National Development Planning Commission, 2010).

Ghana Shared Growth and Development Agenda II, 2014–2017

- *"Provide adequate, reliable and affordable energy to meet the national needs and for export."* (Policy Objective 5.1 of the National Development Planning Commission, 2014).

Ghana Grid Company Limited (GRIDCo), Annual Report 2013

- *"GRIDCo continues to pursue several initiatives to augment the Government's efforts at positioning Ghana as a net exporter of electricity in the sub region."*

- *"At the regional level, a number of efforts were also made during the year under review to augment the Government of Ghana's plans of making Ghana a net exporter of electricity."* (Ghana Grid Company Limited, 2014).

Volta River Authority, Annual Report 2012

- VRA reported net earnings of US$ 106 million in 2010 from electricity exports; this decreased to US$ 60 million in 2011 (VRA, 2012).

Parliamentary Statements

- *"As a policy, therefore, the Government is pursuing a generation mix that fully exploits the country's energy resources potential to ensure self-sufficiency and also to become a net exporter of power. [..] We are confident that the policy of becoming self-sufficient in our energy supply requirement and eventually becoming a net exporter will be a successful one."*

  Parliamentary Statement by Joseph Kofi Adda (MP), Ministry of Energy, On The Current Energy Situation In Ghana (June 23, 2007)[4].

Overview of transmission infrastructure (status quo & proposed upgrades)

In Ghana, GRIDCo undertakes the transmission of electricity. The primary backbone of Ghana's transmission system is a network of 161 kV lines and substations that are supplemented with a subtransmission system of 34.5 kV lines and a single 69 kV line in parts of the southern Volta region (PSEC, 2010). Recent projects that are either under construction or completed have expanded the NITS with 330 kV lines from Aboadze to Volta (Tema), passing through Prestea, Kumasi, Kintampo, Tamale and Bolgatanga; and have closed the 161 kV loop from Tumu to Han to Wa, and a loop between Tema and Takoradi. Once finished, these upgrades will be able to haul four (4) times the transmission capacity of the current 161 kV lines.

Ghana's national transmission system interconnects with the power system of its neighbours, Benin and Togo at 161 kV, and Cote d'Ivoire at 225 kV, respectively. Further, there are currently five interconnection lines between Ghana and Burkina Faso, at 34.5 kV (medium voltage), with total current power supply of about 10 MW. These lines enable cross-border power transfer arrangements with the following interconnection points in Ghana and Burkina Faso, respectively:

1. Hamale (Ghana) ➔ Hamélé (Burkina Faso),
2. Gwolu ➔ Léo,
3. Paga ➔ Badongo,
4. Zebila ➔ Youga,
5. Bawku ➔ Kanyiré.

This yields opportunities for power trading. For decades, Ghana and its neighbours have implemented cross-border power supply arrangements, with Ghana supplying power to Benin, Burkina Faso, Cote d'Ivoire and Togo. Since 1995, however, Ghana has imported electricity from Cote d'Ivoire to supplement its

4 Available at www.ghanadot.com/reviews.energy.062407.html

own generation in times of deficit (Energy Commission, 2006). At the regional level, the WAPP envisages Ghana as one of the main producers of electricity within the power pool, exporting to its neighbours, and particularly to the landlocked countries (WAPP, 2011).

Within the WAPP arrangement, GRIDCo is in the process of constructing a 225 kV line from Bolgatanga in Ghana to Ouagadougou in Burkina Faso, which is expected to serve as the main electricity transmission link between the two countries. This project, referred to as the 225 kV Ghana-Burkina Faso Interconnection Project, is currently at the bidding stage; the line is expected to be operational at the end of 2017. At its inception, it is foreseen that a steady supply of 100 MW of power will be supplied from Ghana to Burkina Faso. The construction of another 225 kV line from the same Bolgatanga substation through Burkina Faso to Mali has also been planned. The two lines are capacitated to transfer a total of 400 MW of power in the medium- to long-term.

The SEPS estimated the solar electricity generation potential in the northern parts of Ghana at 106.2 GW, 167.2 TWh/yr, and of 6,877 MW on those available lands within 5km from the grid (UNEP, 2015). It needs to be noted that this is the maximum potential. Investors could harness it for subregional power export, but it is constrained in practice by the capacity of Ghana's infrastructure and other factors (including competing land uses) that are further elaborated in the Solar Export Potential Study and this Strategy Proposal.

1.1 Aim and objectives

The overall aim of this report is to recommend a strategy for the selection of a solar-ready, cross-border grid line between Ghana and Burkina Faso, securing preferential financing, and approving installations. This Strategy Proposal aims to make the following contributions to this overall objective:

1. An assessment of Ghana's technical and financial needs for solar-ready, cross-border grid expansion (incl. estimated location, length, and cost), based on the inputs of national and regional experts;

2. An assessment of financial support mechanisms available for transmission infrastructure and related gaps, including leveraging resources to attract private investment;

3. An assessment of real and perceived risks for solar energy infrastructure investments;

4. An assessment of the approval process for new grid infrastructure in Ghana and Burkina Faso, including permits and relevant authorities; and

5. A step-by-step plan for selecting, financing, and obtaining approval for the installation of a solar-ready, cross-border grid line between Ghana and Burkina Faso.

1.2 Methodology

A variety of methodological tools and techniques has been used for the data collection and analysis. Content analysis was used to explore both local and international institutional research reports to understand country approaches to solar PV grid integration, challenges and more generally, to seek answers to the questions of interest in this Strategy Proposal. The technical section used the Siemens Power Transmission System Planning Software (PSS), with the live network data in Ghana, in order to:

- simulate solar PV penetration levels and their impact on the transmission system stability;

- identify locations on the transmission network where power from solar PV can be optimally injected, using a load flow analysis;

- simulate the effect of variability and the need for base load, and the right levels of spinning reserves to establish the amount of power from renewables, particularly solar PV, that can be injected into Ghana's grid; and

- identify the transmission line upgrades required to haul solar PV power from Ghana.

The following key institutions provided foremost inputs to the process and development of the Strategy Proposal:

- Ministry of Power (MoP),
- Ministry of Environment, Science, Technology and Innovation (MESTI),
- Ministry of Trade and Industry (MoTI),
- Ministry of Finance (MoF),
- Ghana Grid Company (GRIDCo),
- Environmental Protection Agency (EPA),
- Energy Commission (EC),
- ECOWAS Regional Electricity Regulatory Authority (ERERA),
- Ghana Investment Promotion Centre (GIPC), and
- West African Power Pool (WAPP).

Two working group meetings were held with financial and technical experts in the energy sector, respectively, to obtain stakeholder inputs and to identify and rate relevant risk factors.[5]

A national stakeholder workshop was organized to present and discuss preliminary findings of the Strategy Proposal, and to synthesize contributions and feedback from key stakeholders.[6] During the workshop, the Ghana Solar Export Potential Study (SEPS) was launched, and discussions were held on the uptake of its findings, including through this Strategy Proposal and under the Partnership for Action on Green Economy (PAGE) in Ghana.

The final draft of the Strategy Proposal was shared with selected stakeholders for feedback and comments.

1.3 Report structure

Section Two of this report draws on three national case studies – Denmark, Germany and Cabo Verde – to identify issues and options associated with integrating large-scale renewable energy into electricity grid infrastructure. Section Three contains the technical assessment, including findings regarding the potential sites identified for hosting solar PV generation plants, and the transmission and load flow analysis to propose infrastructure upgrades for facilitating power exports to Burkina Faso. Section Four discusses the financial requirements for exporting solar power to Burkina Faso, and assesses potential sources of finance and existing instruments to facilitate climate-friendly investments. Section Five discusses the infrastructure approval processes required for the construction of grid lines in Ghana, Burkina Faso and within the context of the WAPP. Section Six proposes a step-by-step guide for selecting, financing and approving the installation of a solar-ready, cross-border transmission line between Ghana and Burkina Faso, and proposes areas for future research and analysis that could not be addressed by this Strategy Proposal.

5 Please see Appendix A for the attendees of the financial working group, and Appendix B for the attendees in the technical working group.

6 Please see Appendix C for the attendees of this workshop.

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2 Renewable energy grid integration: an overview and key challenges

Renewable energy may be integrated into electricity grids at various levels. Integration can be at the distribution level, where solar panels are mounted on the roofs of houses at low voltages of 0.6 kV or less. Integration may also be at medium voltages, where utility-scale solar farms ranging from a few hundred kilowatts to several megawatts are coupled to the grid at voltages of 0.601–69 kV. Power from solar farms can also be integrated at high voltages, of 69.001–230 kV or above. For large-scale, long-distance renewable energy power transmission, lines of more than 500 kV are usually needed (International Electrochemical Commission, 2012).

At all levels of integration, the key components of the solar PV system remain the same: modules, balance of system components, grid-tied inverters, and monitoring equipment. Different grid-connected inverters may be used in residential, medium-sized and large-scale PV systems, depending on the inverter manufacturer. While string inverters are commonly used in residential to medium-sized commercial PV systems, central inverters are commonly used in large commercial and utility-scale systems. Table 1 shows the inverter / converter market, as of 2014.

In utility-scale solar PV systems, output voltage of central inverters is usually stepped up from 0.415 kV to 11 kV, 22 kV, 33 kV etc., using specially designed transformer stations for the medium voltage grid.

Table 1: Inverter / converter market (as of 2014)

Type	Power	Efficiency	Market share (est.)
String inverters	Up to 100 kWp	98%	~ 50%
Central inverters	More than 100 kWp	Up to 98.5%	~ 48%
Micro-inverters	Module power range	90–95%	~ 1.5%
DC/DC converter power optimizer	Module power range	98.8%	N/A

Source: (FISES, 2015)

2.1 Key challenges

Integration of Variable Renewable Energy (VRE), in particular solar and wind, poses many challenges to the grid. These challenges have the potential to stall efforts of further promoting renewable energy in the electricity generation mix. The variable nature of supplies is a major factor for the potential negative impacts of solar PV power on transmission grids; as VRE penetration increases in the grid, its impacts become more significant. This characteristic of variable renewable sources is one of the factors accounting for issues in power quality, frequency variations, power fluctuations and system stability. This section provides a summary of the key challenges arising from variability and other characteristics of renewables.

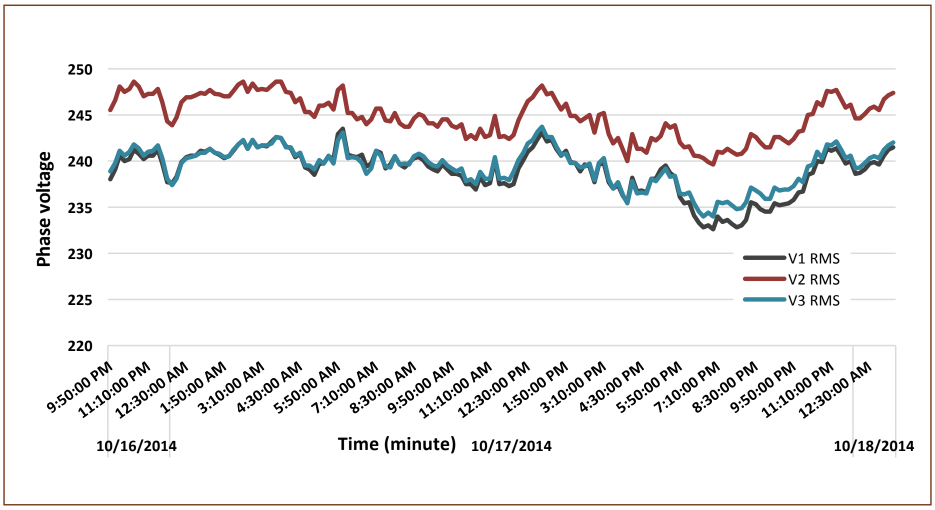
2.1.1 PV power fluctuations

Solar PV plants experience fluctuations in power output due to cloud movement. In some cases, such fluctuations can exceed 60 per cent of peak insolation in seconds, resulting in similar changes in solar PV power output (Mills et al., 2009). Power fluctuations may contribute to power swings in lines, frequency fluctuations, voltage fluctuations and voltage flickers, and thus limit the overall penetration level of solar PV in the system (Eltawil and Zhao, 2010). Some studies found solar PV power swings caused by cloud movements to drastically limit penetration levels, sometimes leading to PV penetration levels not exceeding 15 per cent of the maximum level (Whitaker et al., 2008).

2.1.2 Voltage fluctuations

Variations in solar PV output may cause unacceptable voltage fluctuations and voltage flickers, but it is difficult to track to which extent these are caused by PV systems, as they may also be attributed to load variations, power swings from other generating sources, or system switching. It is particularly difficult to characterize such fluctuations in power grids in Ghana, as the system is prone to excessive variations that could be attributed to various factors, including load shedding, loss of generation, lack of reserve margin, among others. Figure 1 shows a voltage profile in Ghana (specifically at the location of Walewale) with typical voltage variations; V1, V2 and V3 represent voltages on each of the 3 Phase Voltage lines.

Figure 1: Voltage fluctuations at Walewale, Ghana



Liu and Bebic (2008) show that voltage variations may cause excessive transformer tap changes, and interrupt operation of switched capacitor banks and Step Voltage Regulators (SVR), which consequently reduce the life expectancy of the equipment. Solanki et al. (2012) have shown that, at a solar PV penetration of 50 per cent, the existing voltage regulation set points fail to mitigate voltage deviations, and thus limit the PV penetration level.

2.1.3 Frequency variations and system stability

Imbalances between load and generation can trigger frequency variations within a power system. This phenomenon can adversely affect system stability, and even cause system collapse (Sayeef et al., 2012). Severe frequency disturbances, beyond acceptable limits, are encountered when clouds interrupt the output from a large PV generation plant to the grid over a long period of time, since conventional generators are not designed for fast ramping to meet variable PV output. Electrical power systems containing a contribution from solar PV stations of more than 10 per cent require a 2.5 per cent increase in Load Frequency Control (LFC), compared to conventional systems (Asano et al., 1996).

2.1.4 Grid disturbances and anti-islanding

Interconnection standards, such as the Institute of Electrical and Electronics Engineers (IEEE) Standard 1547,[7] require distributed generation, such as solar PV inverters, to disconnect within two seconds upon loss of the utility source (Basso and Friedman, 2003). Disconnections of PV systems, due to system overvoltage, undervoltage and / or frequency excursions, will become a problem in the power system as the penetration level increases (Miller and Ye, 2003). At a 40 per cent penetration level, voltage and frequency events can lead to low voltages in the network (General Electric Corporate Research and Development, 2003).

2.1.5 Protection coordination

Higher penetration levels of grid-connected PV systems affect the operation of protection devices in the power system. In some studies, PV systems have been seen to increase fault currents until an islanding situation is detected (Phuttapatimok et al., 2008). In some cases, PV systems reduce fault impedance, resulting in a delay in the overcurrent relay operation. Other impacts include false tripping of feeders, unsynchronized reclosing, and nuisance tripping (Chowdhury et al., 2008).

2.1.6 Power quality

Power quality is a major issue with renewable energy integration. The challenge arises from switching in the power electronic interfaces that introduce harmonics into the power system. Also, the capacitive output impedance from solar PV inverters can form resonance with grid impedance, which is usually inductive, and create severe distortions at the grid interconnection point (Sun, 2012).

Kadir et al. (2012), in a study that observed a distribution system with a penetration level of 40 per cent, concluded that Total Harmonic Distortion (THD) does not violate the harmonic limit, even when the inverter-based distributed generations are modelled in various ways. A literature review revealed that there are no penetration level limits found for harmonics (Whitaker et al., 2008).

2.2 Integrating large-scale renewable energy

The conventional grid was designed for unidirectional power flow, where electricity only flows from generating facilities to end users. Solar PV systems introduce variability, bidirectional power flow, overvoltage and harmonics that can interrupt the normal operation of the conventional grid and ancillary devices (Walling et al., 2008; Sun, 2012).

To enjoy the full benefits from solar PV systems, grid operators are changing the face of the aging generation, transmission and distribution infrastructure. The future of grid-integrated renewable energy looks promising, and many countries have shown that introducing high penetration levels of renewable energy is feasible. Yet, more needs to be done to successfully achieve full reliance on variable renewables. The following sections introduce some concepts and methods that are either currently being researched or implemented to achieve higher penetration levels of VRE.

7 The IEEE Standard 1547 provides interconnection requirements for solar PV systems at the point of common coupling. For more information, please see Coddington et al., 2008.

2.2.1 High Voltage Direct Current (HVDC)

Voltage Source Converter – High Voltage Direct Current (VSC-HVDC) is desirable for renewable energy integration and power supply in order to isolate systems in densely populated metropolitan areas, and to help to balance power fluctuations over the lines (International Electrochemical Commission, 2012).

There are relative benefits of HVDC over High Voltage Alternating Current (HVAC), as HVDC provides higher power for the same mast height and ground clearance, while it does not require reactive power compensation along the line, and reduces power losses over long distances. HVDC is used in some off-shore wind farms and distant solar farms, such as the Shanghai Nanhui project in China, the Inelfe line between Spain and France, the Tjæreborg project in Denmark, and the TransWest Express Transmission Project in the United States (International Electrochemical Commission, 2012; Transwest Express LLC, 2015).

2.2.2 Flexible AC Transmission Systems (FACTS)

A Flexible Alternating Current Transmission System (FACTS) improves the capacity, stability and flexibility of alternative current transmissions, enabling the system to transmit a larger capacity of renewable energy. Static Var Compensation (SVC), Static Synchronous Compensator (STATCOM) and Controllable Shunt Reactors (CSR) can solve reactive power compensation and voltage control issues, which are problematic due to fluctuations in renewable energy output (International Electrochemical Commission, 2012).

2.2.3 Forecasting

The ability to accurately forecast variability in solar PV and wind will increase its successful integration in relation to unit commitment, spinning reserves, Load Frequency Control (LFC) and other grid operations.

Present satellite technology such as Numerical Technology (NT) can look into cloud patterns and provide day-ahead and even hour-ahead forecasts. Lew et al. (2010) have shown that the prediction of solar PV patterns has not progressed as far as for wind generation. Improvement in this area is an indispensable necessity for the cost-effective operation of solar PV systems and for grid stability.

2.2.4 Advanced grid modelling and planning

Generation, transmission and distribution planning by power system operators will enable a high penetration of solar PV. New measures include planning for generation flexibility relative to variability in net load (Belbic, 2008). Other transmission and distribution planning methods involve grid extension to areas with abundant renewable energy sources, and grid interconnectivity for load and generation balancing.

Planning units of utility companies need to develop skills in the use of advanced modelling tools and real-time simulation environments which can be used to quantify the maximum penetration of variable renewables, impact on power quality, impact on protection systems etc. Accurate methods in modelling solar PV generation can help reduce fears of integrating variable renewables in the grid (Sayeef et al., 2012).

2.2.5 Grid-friendly renewable energy generation

The further development of power electronics and control strategies can enable large-scale solar PV systems to play an active role in ensuring power system reliability and stability. Some advanced operational capabilities of grid-friendly renewable energy units are:

1. Voltage / Var Control and Regulation
   Reactive power support and power factor control can be provided either through a built-in capability or through a combination of switched capacitor banks and power electronic-based transmission technologies (International Electrochemical Commission, 2012).

2. Fault Ride-Through
   New renewable energy systems need to be able to ride through voltage variations, different frequencies, and faults or disturbances in the power system.

3 Active Power Control, Ramping and Curtailment
   Active power control, ramping and curtailment can be achieved through unit control mechanisms for renewable energy units.

4. Short-Circuit Current Control
   All inverter-based variable generators have a built-in capability to limit the fault current to a level that does not exceed 150 per cent of the full load current.

2.2.6 Smart grids

Smart grids represent the latest revolution in the power industry. In essence, utility operators are moving towards a more intelligent grid to allow for flexibility with variable renewables, using methods such as Demand Side Management (DSM), Distribution Automation (DA), Automated Fault Location and Restoration (AFLR) and Smart Inverters, among others (IRENA, 2013).

One of the largest smart-grid deployment programmes in the world to date is the ARRA Smart Grid Program of the United States (US) Department of Energy, which aims to make the electric grid friendly to a high penetration of renewable energy (US Department of Energy, 2015). This programme serves as a pioneer for managing challenges in renewable energy integration.

2.3 Country approaches to integrating variable renewables in electricity grid infrastructure

A number of countries have experience with the integration of significant amounts of renewable energy, and VRE in particular, into their electricity generation mix. In order to gather practical lessons on how such challenges have been overcome in different contexts, this study presents three illustrative country case studies, from Denmark, Germany and Cabo Verde.

2.3.1 Denmark

Denmark is a relatively small country in terms of size, population and economic output, but a powerhouse in regards to energy. With a population of just over 5.6 million people, and an area of 43,000 square miles, Denmark is a global leader and frontrunner in energy generation. It is one of the countries with the highest penetration of renewable energy per capita. In addition, Denmark has put forward an ambitious plan for renewable energy. According to the country's energy roadmap, coal for power plants and boilers is to be phased out by 2030; renewables will provide all electricity and heat by 2035, and all energy forms used in the country will be free of fossil fuels by 2050, with an estimated reduction in carbon dioxide (CO2) emissions of 90 per cent, compared to 2000 levels. The Danish renewable energy roadmap is perhaps the most ambitious in the world at current. Close to 50 per cent of energy demand in 2050 is expected to be met by wind energy, and over a quarter from biomass. Today, wind energy is the renewable source that is most widely tapped in Denmark. The development of wind energy has evolved at a high rate in Denmark, making it one of the most experienced nations in the generation and use of variable renewables globally.

Expanding wind energy in Denmark was not always met with optimism. In the early days, the variability of wind energy was seen as a major challenge. However, Denmark has since emerged as one of the few countries that has effectively managed the variability of wind power in the energy mix, using a range of technologies and innovation systems, mostly locally developed. The Danish experience shows clearly that variable and decentralized production can be handled without affecting the efficiency and resilience of the power sector. As a matter of fact, Denmark has a very high security of supply (Low Carbon Transition Unit, 2012). At the same time, Denmark continues to have one of the highest electricity prices in the world (US$ 0.40/kWh), which could make the sustainable energy transition prone to popular critique (Bach, 2014).

In 2013, Denmark had a renewable energy capacity of 5 GW, with a large percentage coming from onshore wind, and a smaller share of offshore wind, besides a solar PV capacity of 0.5 GW. Wind power provided, on average, 33 per cent of Denmark's total power supply in 2013, up from 21 per cent in 2004. The system has been highly variable; for example, in January 2014, wind supplied an average 62 per cent of total power demand. On one specific day (January 19, 2014), wind generated even 105 per cent of the power demand (Martinot, 2015). According to Martinot (2015), the Low Carbon Transition Unit (2012) and OECD (2013), the following innovations have helped the Danish electricity system cope with variable power supply:

1. Improvements in wind forecasts have helped to manage variability in wind power availability. Wind forecasts are used to calculate how much wind power the wind turbines will generate minute-by-minute. Accurate wind forecasts have become key, because one m/s more or less can cause a sudden increase or decrease in wind power generation, which would be quite noticeable in the system and lead to high costs. Weather forecasting has seen much improvement in Denmark. During the day, in real time, the Danish power system control centre constantly compares the actual output of renewable sources against

the prediction made the day before. The error of actual vs. predicted output is then used to forecast the output of renewable power in the coming hours. This leads to a situation that virtually eliminates errors in the predictability of renewable output through continuous learning, and thus ensures that the power system is efficient and reliable. The Danish Transmission System Operator (TSO) has developed a management and forecast system with an enhanced real-time monitoring of the grid, including real-time estimates of wind power. To receive necessary inputs into the system, the Danish TSO legally requires all plants with a capacity of more than 10 MW to provide production data every five minutes.

2. Another important factor for integrating and balancing renewables is the operation of the electricity market itself. The full integration of Danish grids into the Nordic Pool market (Denmark, Sweden, Norway, Finland) allows for the integration of large domestic wind generation capacity with foreign (and quite distant) pumped storage plants, in order to smooth production profiles using price mechanisms. This procedure is enhanced by existing transboundary transmission links between Denmark and adjacent countries, which allow for the export of surplus wind power to large pumped storage hydroplants in other Nordic countries, particularly Norway and Sweden. Also, Denmark can freely trade power with its neighbours in order to balance renewables. The flexibility of electricity output from both Combined Heat and Power (CHP) and coal plants allows Denmark to profit from selling into both normal wholesale markets and balancing markets, which are designed to provide balancing power for fluctuations in system demand compared to system generation. Today, most power markets around the world provide second-by-second, minute-by-minute, and hour-by-hour balancing of electricity supply and demand, even in the absence of renewable energy.

3. As explained in point 1, Denmark's power control and market operations have developed an advanced system for balance management and grid reliability, which allows the power controller and the market operator to quickly respond to changes in renewable power output. The TSO has greatly improved its daily reliability calculations, to ensure constant power supply in the event of unexpected occurrences or outages, even with variable renewable sources. It cooperates with neighbouring countries, as well as within the context of the European Union (EU), under a reliability framework.

2.3.2 Germany

Germany has made significant progress with the uptake of renewable energy technologies since passing its renewable energy law (the *Erneuerbare Energien Gesetz* – EEG) in 2000 (reformed in 2014). With a cumulative installation of 38 GW, Germany has, by far, the highest level of solar PV installations globally (FISES, 2015). The country has a total installed capacity of about 177 GW (reported in 2014), which also includes almost 36 GW of wind energy, a VRE source. Table 2.1 shows the net installed capacity of various power generation technologies in the German power system, with the variable renewable sources in yellow.

Table 2.1: Net installed generation capacities in Germany, 2014

Technology	Capacity Installed, GW	% of total
Nuclear (uranium)	12.068	6.8%
Brown coal	21.206	12.0%
Hard coal	27.853	15.7%
Gas	28.439	16.1%
Wind	35.678	20.1%
Solar PV	38.124	21.5%
Biomass	8.153	4.6%
Hydro	5.619	3.2%
Total	**177.14**	**100.0%**

Source: (FISES, 2015)

From Table 2.1, it can be seen that solar and wind together constitute over 41 per cent of the net installed electricity generation capacity in Germany.[8] In 2014, the maximum amount of solar energy injection recorded was 24.2 GW (6 June), while wind recorded 4.5 GW on that day (although non-coincident). Wind energy recorded a peak of 29.7 GW (12 December), while maximum solar injection on that day was 4.9 GW (also non-coincident). This shows the complementarity of intermittent solar and wind power supplies.

The maximum (coincident) solar and wind injection in 2014 was 37.8 GW (14 April), when peak production was approximately 70 GW (FISES, 2015). This represented more than 50 per cent of maximum power produced in that hour, and 21 per cent of the generation capacity (see Table 2.1). Actual generation as a proportion of the annual system production was about 6.9 per cent for solar and 9 per cent for wind.[9]

According to the Fraunhofer Institute for Solar Energy Systems (FISES, 2015), the current output levels of variable renewables (5–7 per cent for solar and 9 per cent for wind, respectively) appear not to have presented any technical challenges for the German grid operators. This view is consistent with the International Energy Agency's (IEA) report on Grid Integration of Variable Renewables (GIVAR) (IEA, 2014), which suggests saturation levels of 25–40 per cent, with current levels of system flexibility. In the GIVAR report, the IEA concludes that the operation of a power system with low shares of VRE (5–10 per cent of annual generation) should not create significant technical challenges, provided that the following basic principles are observed:

- avoid uncontrolled local concentrations of VRE power plants ("hot spots");
- ensure that VRE power plants can contribute to the stabilization of the grid, when needed; and
- forecast the production from VRE, and use forecasts when planning the operation of other power plants and electricity flows on the grid.

The GIVAR report points out that power systems already deal with system variability arising from demand variation and unexpected outage of power plants. The key to integration of VRE is system flexibility. The four primary flexibility resources identified by the IEA (2014) are:

- flexible power plants;
- grid infrastructure;
- electricity storage; and
- demand-side integration (DSI).

It has also been suggested, given the fact that Germany's solar installations are mainly rooftop systems, that power generated is usually consumed in the proximity of the installations, therefore reducing the need for major system upgrades (Wang, 2014). Wind power has been installed as centralized plants in the northern part of Germany, and is intended to serve load centres in the energy-intensive and industrial south. This indicates that, in Germany, proximity to load centres and access to the EU grid have been helpful for grid integration of renewables. However, the effort to build long-distance north–south transmission lines has evoked not-in-my-backyard protests ("When the wind blows", 2015), and sometimes needed the wheeling of power to neighbouring countries such as the Czech Republic (Wang, 2014).

The country's flexible resources have played a key role in stabilizing the grid in the face of increasing shares of VRE. The Institute for Energy Research (IER) reports that about 20 power companies in Germany have pledged to cut or add electricity within seconds to keep the power system stable. These companies are paid for participating in the balancing market (see the Box below).

8 For comprehensive comparison, the capacity factor should be taken into account, besides the net installed generation capacity. The capacity factor is the generation capacity of an energy source divided by the actual generation; i.e. the total availability. The capacity factor for solar PV is generally 10–20 per cent, depending on local conditions and seasonal variations (Frankfurt School – UNEP Collaborating Centre, 2015).

9 Computed from FISES (2015), using 11 months of data.

Financial incentives for power companies to participate in the balancing market
Power companies in Germany that help to keep the power system stable are paid for participating in the **balancing market**. Utility companies must be ready to provide power or cut output in notice periods of either 15 minutes, 5 minutes or 30 seconds. These companies earn fees, whether their services are needed or not. An estimated US$ 1.1 billion was paid in 2013. As an example of the amount of power needed for stabilization, in one week, utilities were asked to reserve 3,898 MW, which is about 2 per cent of Germany's total installed generating capacity of 183,649 MW.* In 2013, it occurred around a 1,000 times that Germany's second-largest grid operator told power plant operators to adjust output in order to keep the grid stable, compared with 209 times in 2010. To adapt to volatile supply and demand, one utility company spent as much as EUR 700 million on technology to allow its lignite units to change output by 30 MW within a minute.

Source: (IER, 2014)
* FISES (2015) reports a net generation capacity of 177 GW.

On the basis of an analysis of data published by the FISES, Cloete (2014) suggests that Germany uses a lot of the dispatchable capacity of its neighbours to help balance sharp daily fluctuations in solar output. The situation is not quite the same with wind, which shows a good capacity factor, particularly during the winter periods, and does not require ramping up of balancing power plants. Cloete (2014) proposes that the share of variable renewables in the German grid should be visualized within the context of the combined, integrated grid of Germany and its neighbours. He proceeds to estimate, conservatively, that for every 1 per cent of ramping for solar and wind capacity in Germany, 0.3 per cent of dispatchable capacity of its neighbours is used for balancing (Cloete, 2014).

To deal with variability resulting from solar and wind power plants, it has been projected that Germany will need between 80 and 90 GW of dispatchable capacity by 2030 as a backup — nearly as much as the total conventional capacity available today (BCG, 2015).

In summary, Germany has managed variable renewables in its grid system through:

- The availability and flexibility of power plants that are able to quickly respond to the need to increase or reduce electricity output;
- An incentive system that encourages power plant operators to participate in the balancing market, resulting in significant investments by power plant operators, which improve their ability to quickly adjust their output upon requests from grid operators;
- Interconnection with power grids of neighbouring countries and access to dispatchable capacity across borders; and
- The significant use of distributed PV systems (rooftops instead of large centralized plants), which ensure consumption of power output in the proximity of generation sites.

2.3.3 Cabo Verde

Cabo Verde is an archipelago of ten islands in the Atlantic Ocean. The country covers about 4,000 square km of land area, and has a population of 500,000 people. Being an island nation with limited natural resources, Cabo Verde has been dependent on fossil fuels for power generation for many years, resulting in an electricity tariff of US$ 0.38 (IRENA, 2014). The country continues to face electricity deficits, due to the fact that demand grows with 8 per cent per year, and is largely unmet. Although significant investments have been made into the electricity sector, they have not yet been sufficient to ensure a high-quality and reliable access to electricity at affordable prices.

ELECTRA is the Transmission System Operator, responsible for power generation, transmission and sale. Each island has its own fossil fuel-based power generation plant. The national electricity transmission system comprises independent grids on different islands. The government's primary objective for the energy sector is to ensure the availability of a reliable system of energy supply that is efficient, affordable, sustainable and environmentally friendly (UNIDO and ECREEE, 2011).

To realize this objective, the Government of Cabo Verde implemented a National Energy Policy (2003–2012). Subsequently, the Government developed a Renewable Energy Plan to be implemented over a ten-year span (2010–2020) (ECREEE, 2011a). The objectives of the Renewable Energy Plan include, among others, to strengthen the institutional and human resource capacity, to enhance research and development in energy, and to improve and expand the existing energy supply systems in an efficient manner.

Additionally, the Government of Cabo Verde is pursuing an ambitious plan to reduce the country's dependence on fossil fuel-based electricity, and to promote investments in renewable energy production. The set targets were 25 per cent of renewable energy in the total generation mix by 2011, and 50 per cent by 2020. These targets are to be realized through increased private sector involvement in power generation and government-supported projects (ECREEE, 2011b). The action plan also considers the installation of 140 MW of new renewable energy power plants considering wind, solar, hydro and wave power, as well as waste-to-power generation. Table 2.2 provides an overview of the proposed renewable energy projects in Cabo Verde, adding to a total estimated capacity of 589 MW.

Table 2.2: Proposed renewable energy projects in Cabo Verde (as of 2011)

Technology	Number of projects	Estimated capacity (MW)
Wind	21	180
Solar PV	17	341
Waves	2	10.5
Municipal Solid Waste	2	7.5
Pumped storage	4	50
Total	**46**	**589**

Source: (ECREEE, 2011a)

With an installed capacity of 140.5 MW in 2012 (IRENA, 2014), 33.5 MW (24 per cent) of which from renewable energy generation capacity (made up of 26 MW of wind and 7.5 MW of solar – for the breakdown, please see Table 2.3), Cabo Verde has a significant penetration of renewable energy in its total generation mix. With the various renewable energy projects in the pipeline (see Table 2.2), Cabo Verde is expected to have about 50 per cent of its electricity produced from renewable energy sources in 2020. This government target will require an increased participation of private actors in energy generation, finance and infrastructural improvements.

Table 2.3: Renewable energy installed capacity in Cabo Verde (as of 2011)

Island	Technology	Capacity Installed (MW)
Santiago	Solar PV	5
Santiago	Wind	9.35
Sal	Solar PV	2.5
Sal	Wind	7.65
São Vicente	Wind	5.95
Santo Antão	Wind	0.5
Boavista	Wind	2.55
Total		**33.5**
% (of total capacity)		**24%**

Source: (ECREEE, 2011a)

There are several challenges that could potentially hinder a higher level penetration of VRE into grid systems, including insufficient transmission line capacity, uncertainty of resource availability, and fluctuating generation outputs. Grid flexibility is, therefore, seen as a key enabler to increase the share of VRE in the total generation mix (OECD and IEA, 2012).

Cabo Verde's national interconnection system has a significant number of low voltage (LV) and medium voltage (MV) lines. The LV lines operate at 6, 10 or 15 kV, which results in high loss rates during transmission and distribution. The medium voltage lines are standardized to operate at 20 kV. A significant number of the LV lines and some of the MV lines have deteriorated.

Through Cabo Verde's subscription in 2011 to the Electricity Transmission and Distribution Network Development Project of the African Development Fund (ADF), electricity transmission networks have been upgraded. International development banks and donor agencies, like the African Development Bank (AfDB), the Japan International Cooperation Agency (JICA) and their accessories, are also playing a significant role in upgrading and constructing new transmission and distribution lines.

According to Kaatz-Dubberke (2014), the current VRE penetration level of approximately 24 per cent has been realized by relying on diesel generators without storage. The government acknowledges that the aim of 50 per cent renewables by 2020, and potentially the full reliance on renewable energy afterwards, is visionary and ambitious. Yet, it could be feasible, if the appropriate initiatives are taken and rigorously implemented.

Cabo Verde has developed a policy strategy to promote independent power producers (IPPs). This strategy allows a power purchase agreement to be signed over a 15-year time span, and provides tax exemption on all imported renewable energy equipment (ECREEE, 2011a).

Consistent with the suggestions of OECD and IEA (2012), Cabo Verde plans to manage a high penetration of renewable energy through:

- An increased grid capacity. The first high-voltage transmission line of 60 kV (43 km of overhead line), to connect the Palmarejo power station to the Calheta substation, is under construction.

- The diversification of variable energy and renewable energy technologies, in order to also include non-variable renewable energy technologies, such as bio- and geothermal energy.

- The use of storage technologies. In the short term, Cabo Verde seeks to use battery and energy management systems to ensure the stable operation of the grid, without using diesel generators. The development of long-term storage options focuses on technical options such as pumped hydrostorage (PHS) and power-to-gas (Brito, 2013).

- The use of oversupply. It is believed that excess electricity could be used to drive growth in other areas of the economy. Unique opportunities are anticipated in, for example, the use of excess energy to desalinate ocean water, for agricultural purposes (Brito, 2013).

Overall, the three case studies offer valuable lessons that can be used for effectively integrating supplies from intermittent renewables into Ghana's national grid. Key recommendations for Ghana include to enhance the flexibility of power plants to ramp output up and down; the enhancement of storage capacity; and the adoption of a legislative instrument to require all plants beyond a certain generation capacity to frequently provide production data. However, one must be mindful, when applying these findings to the case of Ghana, that the countries analysed are very different from Ghana, since Cabo Verde is an island nation with a small population, and Denmark and Germany have a higher level of development compared to Ghana. Applicability for the case of Ghana must therefore be checked, and lessons learned tailored.

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3 Technical needs assessment – analysis of grid infrastructure for exporting solar power

The amount of variable solar energy that can be integrated into the power system for export to neighbouring countries depends on the potential and the constraints of the current grid infrastructure. Little is known about the impact of variable solar energy on Ghana's grid infrastructure, or about the upgrades necessary for exporting solar energy through the West African Power Pool interconnections with Burkina Faso. This section first presents candidate sites for solar plants, feasible plant sizes and the performance of the grid under some system dynamics of variable supply. It then presents the technical analysis of Ghana's grid infrastructure for exporting intermittent solar power to Burkina Faso, working off the 150 MWAC cap for grid-connected solar PV, set by the Ministry of Energy.[10]

Within the power system of Ghana, there are several planned transmission network upgrades, from 161 kV to 330 kV. These upgrades, when completed, would reinforce the network to haul about four (4) times the transmission capacity of the current 161 kV lines. National solar PV capacity is expected to be about 150 MW by 2020 (Ministry of Energy, 2010).

A systematic methodology has been adopted for this section. Firstly, the three northern regions were considered for the potential siting of solar PV farms, given their high solar resources compared to the other regions in

10 In November 2014, the Public Utilities Regulatory Commission (PURC) introduced a cap of 550 MW on capacities of intermittent renewables that will be permitted in the National Interconnected Transmission System. Grid-connected solar PV is capped at 150 MW, with a 20 MWp (MW-peak) cap for individual solar PV plants, provided that plant developers do not simultaneously provide additional grid capacity or storage solutions (see Section 1) (UNEP, 2015).

Ghana (see UNEP, 2015). The available lands in the three regions of northern Ghana were assessed in light of competing land uses, by means of the Ghana Energy Access (GhEA) toolkit, the ArcGIS desktop tool and Google Earth. Study scenarios were then created through a development process that reflects power system dynamics at play. Subsequently, the power system load flow was analyzed for each study scenario, while the plant size was gradually increased until 150 MWAC was realized. Finally, candidate locations were sieved from the available land, together with suggestions on feasible plant sizes, infrastructure upgrades, equipment needed and equipment suppliers.

3.1 Selection of candidate locations

Three overriding factors influenced the selection of candidate locations in this Strategy Proposal, namely (i) the solar resource potential assessed in UNEP (2015), (ii) grid proximity, and (iii) land availability and competing issues. Sections 3.1.1 and 3.1.2 discuss the latter two factors.

3.1.1 Grid proximity

The process of selecting candidate locations for a solar plant starts by earmarking the available land within close proximity to power evacuation centres. In selecting the appropriate distance from the grid, a number of factors were considered, including potential power losses, the voltage drop, right-of-way and cost per kilometre of transmission lines.

Solar PV plants dissipate power in the form of heat, due to the internal resistance of power transformers and transmission lines, as power is transmitted to load centres. More power is lost when the surrounding air around transmission lines is ionized at voltages greater than the critical breakdown voltage, resulting in electrical flashovers usually called corona losses (Sharma et al., 2012).

Selecting a location for a solar PV plant at an appropriate distance from the grid is a major factor to consider, as it affects the voltage drop of the power cable. The voltage drop depends on the length of the cable, the current through the cable, and the impedance per unit length of the cable. The voltage drop generally increases with distance. Table 3.1 provides information on plant sizes, matched with their corresponding maximum distance from the grid, based on a utility standard of 2 per cent as the maximum voltage drop of rated voltage.

Table 3.1: Plant size and corresponding maximum distance from the grid

Plant size (MWp)	Interconnecting voltage level (kV)	Cable size (mm²)	Solar PV plant current output (A/phase)	Maximum distance from grid, in km (at 2% voltage drop – VD)
5	34.5	120 AAAC	84	30
10	34.5	120 AAAC	163	15
20	161	600 ASCR	64	920
30	161	600 ASCR	93	633
40	161	600 ASCR	119	495
50	161	600 ASCR	143	412
60	161	600 ASCR	167	352
70	161	600 ASCR	189	311
80	161	600 ASCR	210	280
90	161	600 ASCR	230	256
100	161	600 ASCR	250	235
110	161	600 ASCR	268	220
120	161	600 ASCR	289	204
130	161	600 ASCR	304	194
140	161	600 ASCR	321	183
150	161	600 ASCR	537	110

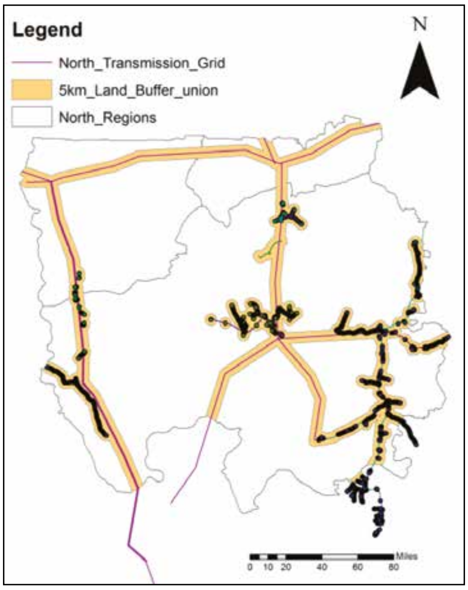
Source: Developed by authors

The overall cost of transmission lines increases as the distance from the grid increases. From stakeholder consultations and from RETSCREEN user guidelines[11] the average cost per kilometre of 161 kV transmission line has been estimated at US$ 100,000 per km. Though this figure may vary between different cable manufacturers, cable types or cable sizes, it is a reliable estimate. Due to this high cost of constructing transmission lines, and in line with the SEPS, this Strategy Proposal adopted the requirement for generation plants to be located within 5 km from the transmission grid.

3.1.2 Land availability and competing uses

The available land resource for solar PV generation was determined through the elimination of other competing land uses in the northern belt of Ghana, such as agriculture, forests, wildlife, protected areas, restricted areas, lakes, rivers, and water bodies. The land buffer used in this study is 5 km (See Figure 3.1). The northern belt was selected because of its high solar irradiation. All figures in this section are taken from UNEP (2015).

Figure 3.1: 5 km land buffer from the transmission grid



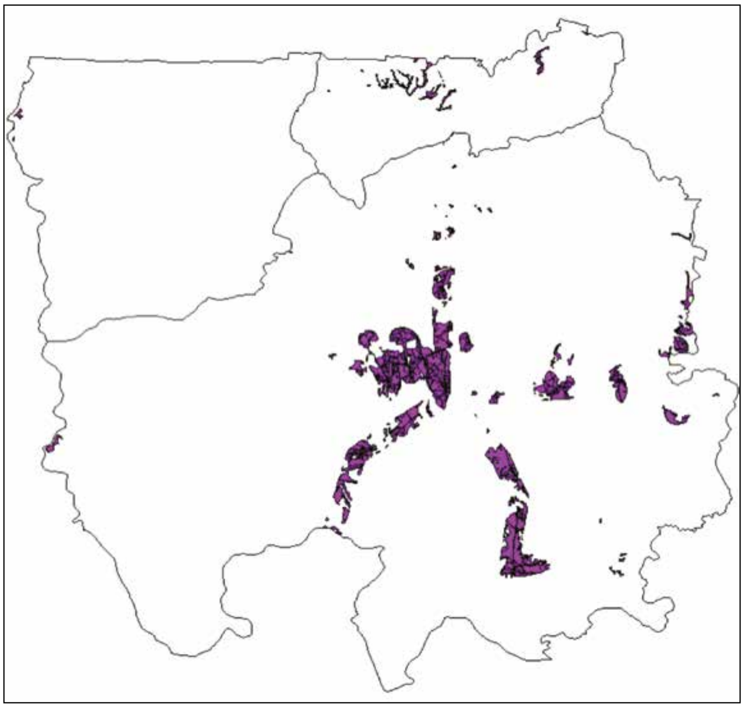
Due to the existence of several competing land uses in Ghana, certain regions were marked as unsuitable for siting solar PV farms, and hence eliminated as potential sites. These included:

- public infrastructure, such as existing road networks;
- water bodies, such as rivers, lakes and lagoons;
- forest areas, nature and game reserves, and protected areas for endangered species;
- lands containing calcareous rocks;
- agricultural land;
- unsuitable physical land covers; and
- settlement areas.

Additionally, land areas which could not support at least 1 MW of solar PV generation were also eliminated. After subtracting all of the abovementioned land areas, 99 potential sites were obtained, which are presented in Appendix D. These sites were aggregated into nodes using substations. Twelve nodes were derived and coded A to M, and 51 sub-nodes were then obtained. Figure 3.2 shows the initial potential areas obtained at this stage. This was migrated into Google Earth, where satellite imagery was used to depict the level of human presence, in order to determine the potential for solar PV farms.

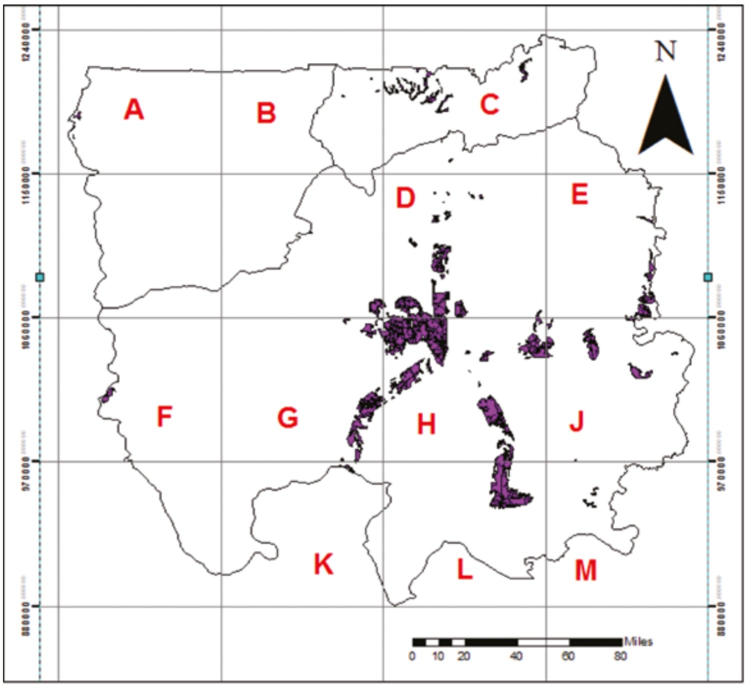
11 Available at: publications.gc.ca/collections/collection_2008/nrcan/M39-115-2005E.pdf

Figure 3.2: Initial available land within the 5 km land buffer



For transmission and load flow purposes, the final lands classified as potential sites were aggregated on the basis of zones. The final available land obtained for siting solar PV farms is shown in Figure 3.3. See Appendix D for further information on candidate locations within 5 km of the MV and HV network. Over 50 per cent of the final available land potential is located to the north-eastern part of the northern belt of Ghana.

Figure 3.3: Final available land



The final available land for siting solar PV farms has an estimated total maximum power generation capacity of 6,877 MW, obtained from the transmission and load analysis studies (see Table 3.2).

Table 3.2: Final available power output for 5 km land buffer

Group	Start substation	End substation	Plant size (MW)
A	Tumu	Bolgatanga	140
B	Tumu	Bolgatanga	39
C	Bolgatanga	Tamale	441
D	Bolgatanga	Tamale	10
E	Tamale	Yendi	1 418
F	Wa	Sawla	10
G	Bolgatanga	Tamale	10
H	Tamale	Yendi	1 400
J	Tamale	Yendi	3 159
K	Bolgatanga	Tamale	30
L	Tamale	Yendi	210
M	Tamale	Yendi	10
Total plant size (MW)			**6 877**

Source: Developed by authors

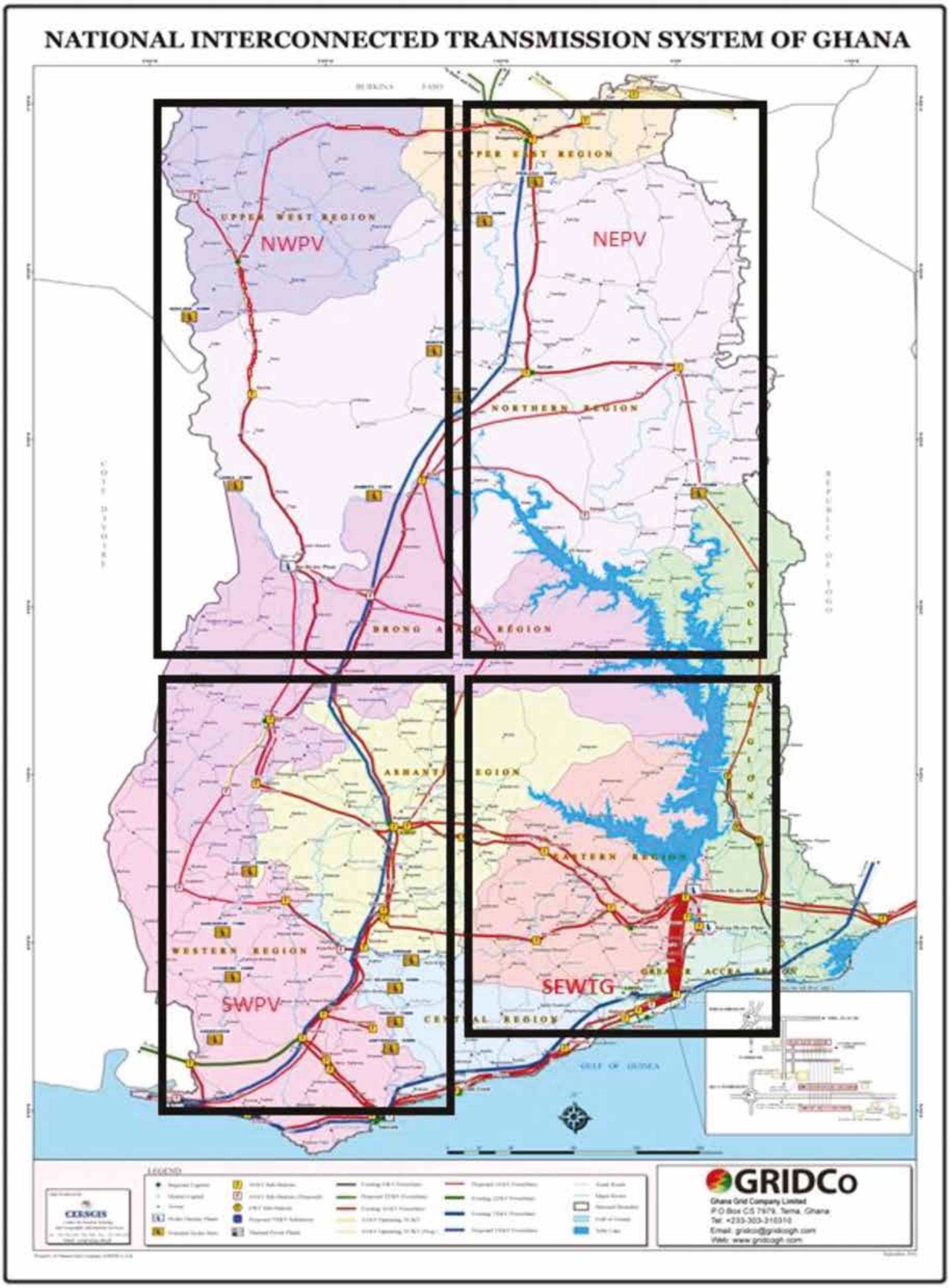
3.2 Transmission and load flow analysis

This section analyses the existing transmission capacity for solar PV integration using load flow simulation tools, to provide further inputs into the recommendation of candidate sites, and the respective infrastructural upgrades required. The study involves the evaluation of the capacity of the transmission system infrastructure within the northern part of Ghana (Upper East and Upper West regions), to accommodate 50 MWp and 100 MWp solar PV plants, and to determine the required reinforcement or infrastructural additions that would ensure optimum power evacuation. The scope of the study also covers operational flexibility of existing switchgear at the Tumu, Wa, Tamale and Bolgatanga substations, to handle the increased fault current caused by the solar PV power plant integration in the north, and determines what levels of appropriate upgrades are required. Additionally, stability assessments were conducted to check system stability under contingency conditions.

For the purpose of this analysis, the National Interconnected Transmission System for Ghana was divided into four main segments, referred to as regions, i.e. North-West (NW), North-East (NE), South-West (SW), South-East (SE) (see Figure 3.4). The construction and interconnection of two solar power plants in the northern region – one of 50 MWp and one of 100 MWp – is being modelled, in addition to two other variable supply sources (a solar and a wind turbine generator with a capacity of 100 MWp each) already considered in the southern section as part of the generation schedule for 2016[12], as shown in Figure 3.4.

12 The generation schedule for 2016 can be found in Appendix F.

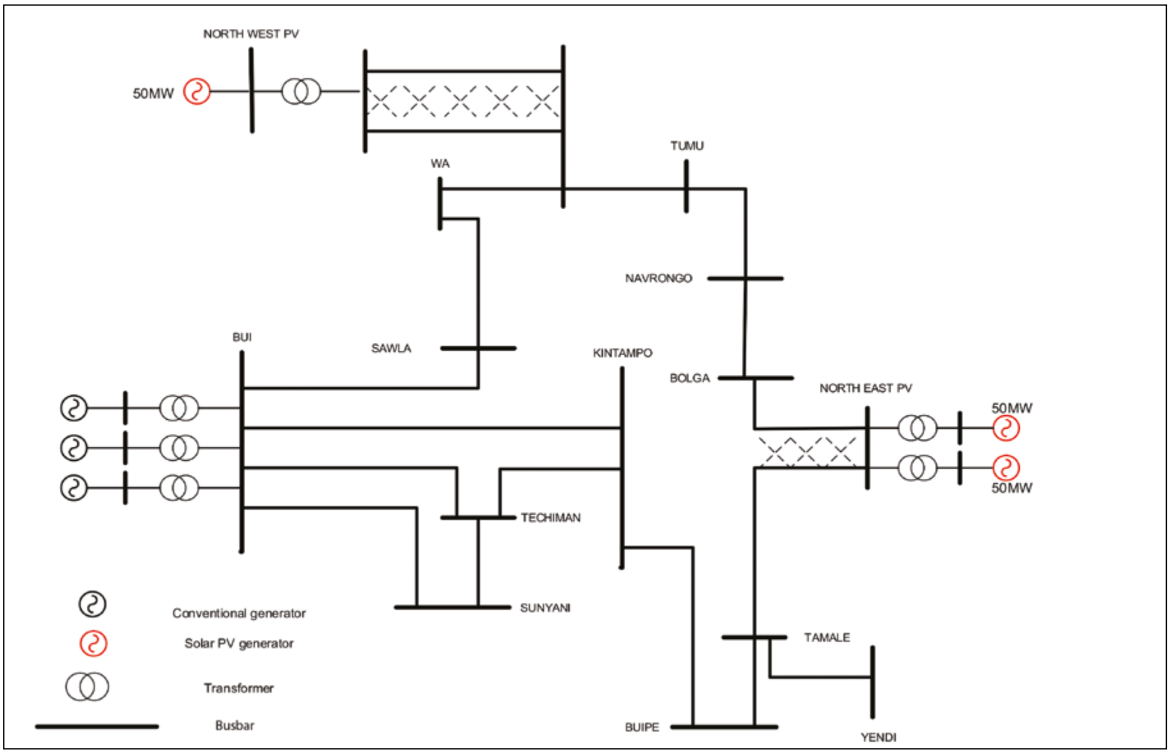
Figure 3.4: Transmission network infrastructure in Ghana



Source: (GRIDCo, n.d.)

The approach used for this study was to interconnect the variable renewable energy at a break-in point between Tamale and Bolgatanga. The line loadings, voltage profiles and system losses for the various scenarios were monitored. This site was a consolidated aggregation point for the proposed sites, which generally indicate a higher potential in the North-East than in the North-West. Taking into account other factors, a total of 100 MWp was allocated to the north-eastern region and 50 MWp for the north-western part of the Upper West region. The single line diagram showing the integration of the 50 MWp and 100 MWp solar PV plants, respectively, is shown in Figure 3.5.

Figure 3.5: Single line diagram of the interconnection of 150 MWp solar PV in the north



3.3 Steady state simulations

Each of the scenarios assessed below integrates solar PV, wind power and emergency plants into the grid across the country. The scheduled dispatch for both scenarios are also shown in Appendix E and Appendix F, respectively. The plants are connected via 10 km of 161 kV single bundle double circuit lines to the Point of Common Coupling (PCC), which are break-in points between Tumu-Wa and Tamale-Bolgatanga. Equivalent models were used to represent each of these solar panels and inverters.

The following scenarios were considered for steady state:

i) Load flow analysis for a 2016 base case without the solar PV power plant (Scenario 1).

ii) Load flow analysis for integrating the plant at a break-in point between the Tamale and Buipe transmission line and the Tumu and Wa lines, which are the points of interconnection for the two proposed solar PV plants (Scenario 2).

When conducting the Steady State Simulations, one should also bear in mind that transmission line additions are expected in 2016, as shown below:

- Connection through a 330 kV line from Volta to Lomé;
- Break-in of a 161 kV Akosombo–Nkawkaw line at Tafo;
- Break-in of a 225 kV Prestea–Abobo line at Elubo, and the closing of the Essiama–Effasu–Elubo loop.

3.3.1 Scenario 1: Base Case for 2016

In this scenario, generation dispatch is made up of some solar PV and wind power plants in the south, intended to be connected to the grid in 2016, and emergency plants integrated into the grid across the country (as shown in Figure 3.5). Under this scenario, the proposed northern PV plants (in the Upper East and Upper West regions), with a capacity of 150 MWp, are not connected. The generation dispatch under this scenario is shown in Appendix E.

Under this system condition, no line overloads are experienced in the entire network, as the load flow simulation is for the off-peak period. The only lines on which overloads are observed are the Volta-Achimota corridor lines which are already earmarked for capacity upgrades. Substation voltage profiles in the entire country also remain good, due to the 15 per cent load reduction. High voltages are, however, experienced in the north. The overall transmission losses recorded are 3.98 per cent of total generation. The line loadings, the bus voltages, as well as the total load and the total generation assumed for this case are shown in Tables 3.3 and 3.4 below.

Table 3.3: Bus voltage simulation results (Scenario 1)

Bus voltages		
	kV	Per unit
Kumasi	154.04	0.9568
Tamali	161.00	1.0000
Bolgatanga	164.41	1.0212
Tumu	166.36	1.0333
Wa	165.72	1.0293
North West PV	166.16	1.0320
North East PV	163.27	1.0141

Table 3.4: Line loadings simulation results (Scenario 1)

Line loadings			Generation	Load	Losses	
Line	MW	%	MW	MW	MW	%
Tumu - North West PV	N/A	N/A	2002.1	1877.8	79.6	3.98%
North West PV - Wa	N/A	N/A				
Tamale - North East PV	N/A	N/A				
North East PV - Bolgatanga	N/A	N/A				

3.3.2 Scenario 2 (Case 1): Integration of 150 MWp solar PV in the north

In this scenario, renewable energy power plants and emergency plants are integrated into the grid across the country. The 150 MWp solar PV plants displace in total 100 MW generation from TICO/TAPCO (Aboadze) and 50 MW from KarPower in Takoradi. The generation dispatch under this scenario is shown in Appendix F.

Under this system condition, no line overloads are experienced on the entire network, as the load flow simulation is performed during the off-peak period. As a result, high substation voltage profiles in the north are reduced. The overall transmission losses stand at 3.13 per cent compared to the base case of 3.98 per cent. Under steady state conditions, the introduction of the solar PV plants into the grid seems beneficial to the grid, as it reduces system losses and does not present any unwanted system conditions. The integration of the PV power plants reduces the high voltages observed around Tumu, Wa, Tamale and Bolgatanga, since the PV inverters – by virtue of their characteristics – can absorb reactive power and hence reduce bus voltages. This is achieved with the inverter operated in underexcited mode. However, a reactor of appropriate size would be required in the practical situation where the inverter is incapable of absorbing excess reactive power.

The line loadings, the bus voltages, as well as the total load and total generation assumed for this case are shown in Tables 3.5 and 3.6 below.

Table 3.5: Bus voltage simulation results (Scenario 2)

Bus voltages		
	kV	Per unit
Kumasi	156.13	0.9698
Tamali	161.00	1.0000
Bolgatanga	162.85	1.0115
Tumu	164.04	1.0189
Wa	162.15	1.0071
North West PV	162.54	1.0096
North East PV	161.00	1.0000

Table 3.6: Line loadings simulation results (Scenario 2)

Line loadings			Generation	Load	Losses	
Line	MW	%	MW	MW	MW	%
Tumu - North West PV	4.8	6%	1984.7	1877.8	62.1	3.13%
North West PV - Wa	45.1	25%				
Tamale - North East PV	98.1	40%				
North East PV - Bolgatanga	80.9	33%				

3.4 Short circuit levels and penetration factor

The short circuit levels computed for a 3-phase fault at the PCCs was calculated using the PSS/E software. The fault values at Wa, Tumu, Tamale and Bolgatanga as well as the PCCs (NEPV and NWPV) are recorded in Appendix G.

Generally, the maximum contribution to the fault current by a renewable energy plant is 120 per cent of its full-capacity current. The effect of a generation plant on the network is proportional to the size of the generation plant, and inversely proportional to the fault level. The smaller the size of the plant, and the higher the fault level, the smaller the impact. A penetration factor in the region of 5 per cent indicates that the performance of the plant will not have a significant impact on the grid. In order to compute the penetration factor for the integration of 100 MWp in the North-East and 50 MWp in the North-West region, the short circuit MVA and the power produced from the PV plant are used, per the following equation:

$$\frac{MWspfl}{MVAsc} \times 100$$

In this equation, MWspfl is the full load power of the solar PV plant, and MVASC is the short-circuit apparent power, due to the occurrence of the fault.

The power injection at the PCC is determined from the load flow and the short-circuit apparent power is also determined from the short-circuit fault calculations. The penetration factor at the North-West PV PCC is:

$$\frac{50 \times 100}{487.76} = 10.25\%$$

The penetration factor at the North-East PV PCC is:

$$\frac{99.8 \times 100}{350.3} = 28.49\%$$

A penetration factor of such magnitudes means that this size of solar PV capacity at such a location will have a bigger impact on the voltage profile at the PCCs and its environs. Therefore, much attention should be given to the ability of plants to regulate the voltage according to the limits set forth in the Renewable Energy Subcode (Energy Commission, 2015).

3.5 Voltage and reactive power control

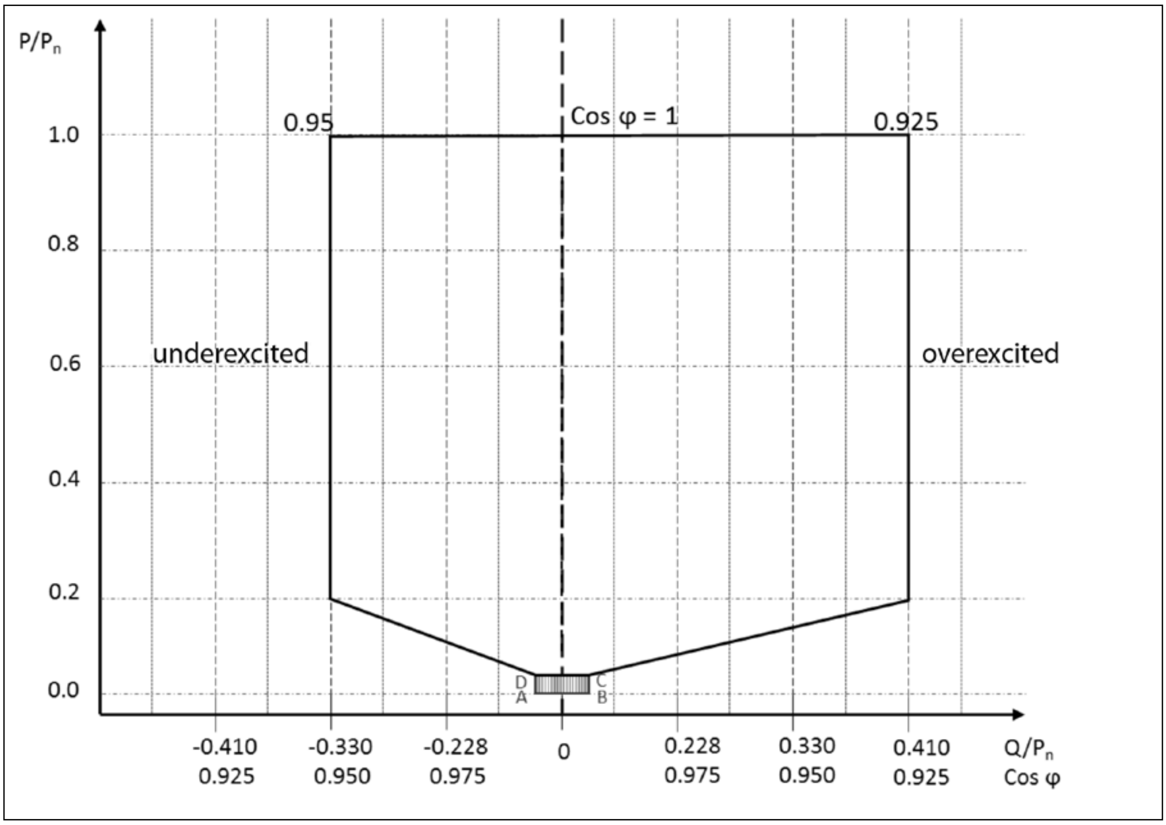
The Renewable Energy Subcode (Energy Commission, 2015) sets a requirement for normal operation of the inverter between 0.95 leading and 0.925 lagging, as in the power quality (PQ) capability curve in Figure 3.6.

Figure 3.6: Reactive voltage requirements at full or partial active power requirements

Source: (Energy Commission, 2015)

If inverters cannot operate within the required range, reactive compensation is necessary to operate within the PQ capability limits under unity power factor, overexcited and underexcited. As required by the Renewable Energy Subcode, the PQ capability of the inverters should be within the limits of the curve shown below in Figure 3.7.

Figure 3.7: Reactive power requirements at full or partial active power requirements



3.6 Harmonics

The Renewable Energy Sub-code stipulates that, in the absence of any other limits from GRIDCo, the allowable total harmonic distortion (THD) should not exceed 2.5 per cent. For actual integration, it is expected that any inverter used will adhere to this standard THD. Introduction of harmonics above the stipulated limit could lead to conductor overheating, rises in capacitor heat, false or spurious trips of fuses and circuit breakers, damaging or blowing system components, and a shortened life span of generators and transformers. THD mitigating could be realised by passive techniques like the connection of series line reactors, tuned harmonic filters, and the use of higher pulse number converter circuits (Kazem, 2013).

3.7 Transient stability simulations

For all dynamic simulations in the following, normal system conditions exist till t=1s, after which time the simulation shows loss of generation due to cloud cover. t=1s is also considered as the fault inception time for fault studies. If significant generation is lost, the time it takes for load shedding to occur is shorter. This is also the case when the frequency begins to rise after a fall.

3.7.1 Scenario 1: Effect of partial (50 per cent) shading on the PV plants in the north

This scenario involves the loss of 75 MWp due to partial shading on the PV plants in the north, caused by cloud cover. As shown in Figure 3.8, the partial loss of the northern PV plants results in a decline in the system frequency. This loss causes temporary fluctuations in the active power output of the generating units (see Figure 3.9). The lowest observed system frequency is 49.53 Hz, after which the frequency begins to rise and is maintained. The system frequency rises and recovers to 49.60 Hz at t=20s. This is attributed to the extra active power produced by the Akosombo hydro-units. These hydro-units are the only ones with Automatic Generation Control (AGC). The frequency is unable to reach the required operating dead band (50±0.2 Hz), but is acceptable for a short period of time as per the grid code.

Figure 3.8: Frequency plot for effect of partial / complete shading on solar PVs in the north

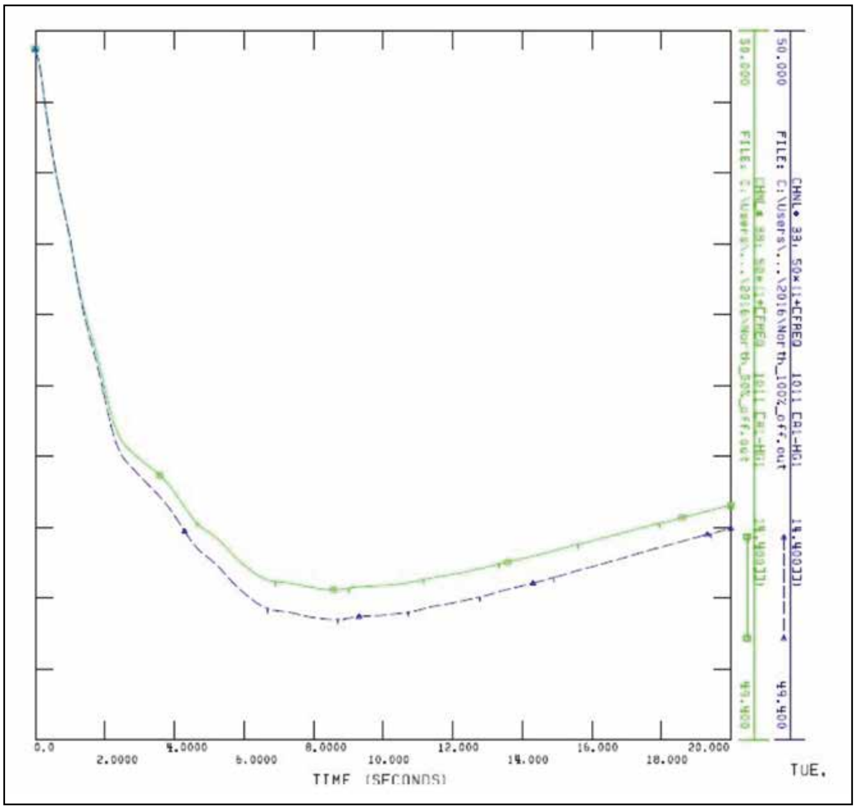
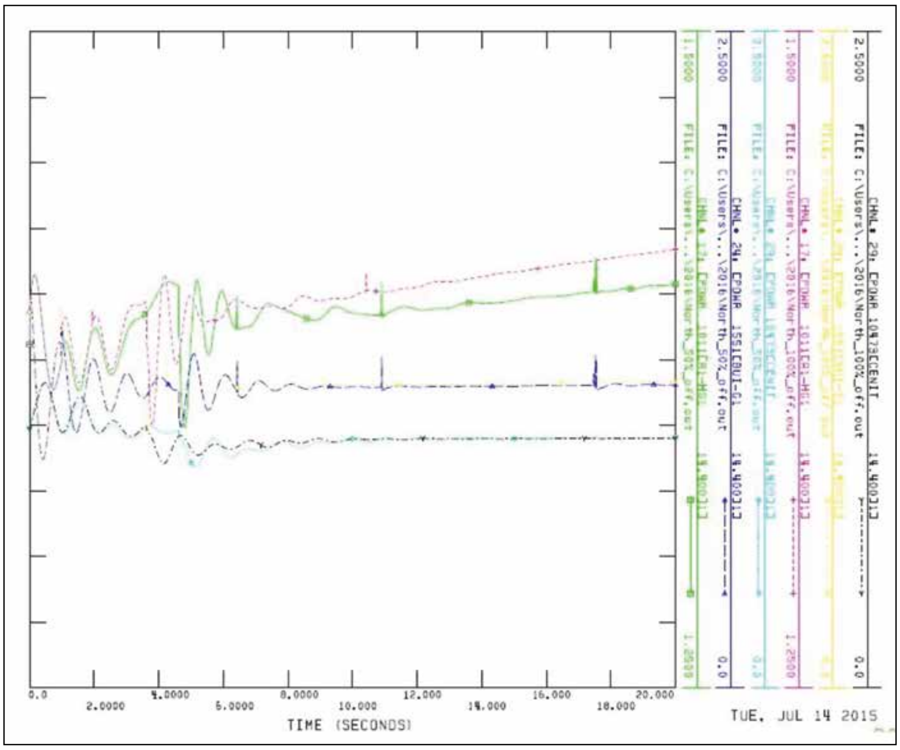


Figure 3.9: Active power plot for the effect of partial / complete shading on solar PVs in the north



3.7.2 Scenario 2: Effect of complete shading on the PV plants in the north

This scenario involves the loss of 150 MWp, as the output of both PV plants in the north drops to 0 MW due to complete cloud cover over the north. As shown in Figure 3.8, this complete loss of the PV plants in the north results in a decline in the system frequency. This loss causes active power fluctuations at the output of each generator (see Figure 3.9). The lowest observed system frequency is 49.50 Hz. The frequency recovers to 49.58 Hz at t=20s and is maintained, which is attributed to the active power produced by the Akosombo hydro-units that have spinning reserve. The frequency is unable to reach the required operating dead band (50±0.2 Hz), but is acceptable as per the grid code. It should be noted that at a level of 49.5 Hz and below, load shedding must begin, and the Automated Frequency Load Shedding (AFLS) will start curtailing load to prevent a possible system collapse.

3.7.3 Scenario 3: Effect of partial (50 per cent) shading on all solar PV plants and 50 per cent wind availability

This scenario involves the loss of 175 MWp, as all solar PV plants are expected to generate less output due to partial cloud cover over the entire country and the wind power plant produces 50 MW due to low wind speeds. As shown in Figure 3.10, this partial loss of solar PV output and half the output from the wind power plant results in a fast decline in system frequency. This loss is immediately detected in the system and the generating units begin to react, as can be seen in the active power output at each generator (see Figure 3.11). This effect is shown in the active power deviations in the graph at each generator. The lowest observed system frequency is 49.49 Hz (3.95s), at which point load shedding begins. This is because the extra-active power (spinning reserve) produced by the Akosombo hydro-units is insufficient to restore the system frequency. As compared to the other scenarios, the load shedding causes a steady rise in the system frequency. The system frequency is restored at a level close to the allowable operating deadband (49.96 Hz at t=20s), but at the cost of undesirable load shedding.

Figure 3.10: Frequency plot for the effect of partial / complete shading on all solar PVs and partial / complete loss of wind

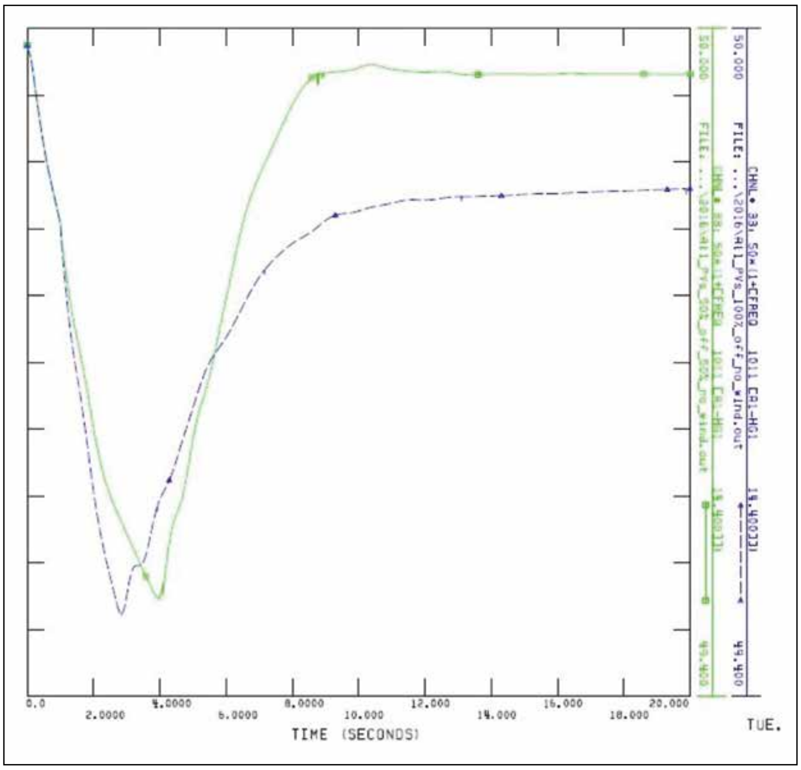
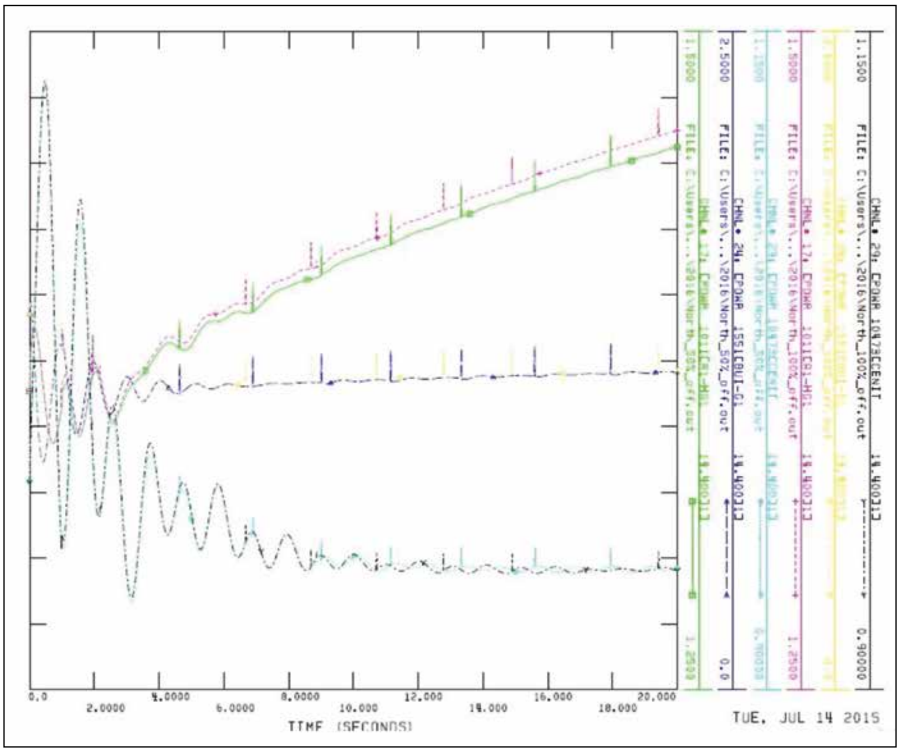


Figure 3.11: Active power plot for the effect of partial / complete shading on all solar PVs and partial / complete loss of wind



3.7.4 Scenario 4: Effect of complete shading on all solar PV plants and no wind speed

The scenario involves the loss of 350 MWp as the outputs of all solar PV plants are reduced to 0 MW due to complete cloud cover over the entire country, while the wind power plant produces 0 MW due to low wind speeds. Scenario 2 (see above) gives a fair idea of how the situation would be with the additional loss of 150 MWp; it is expected that a lower system frequency would be observed and massive load shedding experienced. As shown in Figure 3.10, the complete loss of the solar PV plants over the system, coupled with 0 MW output from the wind power plant, results in a fast decline in the system frequency. It must be noted here that this scenario was carried out merely to evaluate the resilience of the Ghana power system; a country-wide cloud cover is not likely.

The loss of 350 MWp is immediately detected in the system and the generating units begin to react, as can be seen in the active power output at each generator (see Figure 3.11). As apparent from the power deviations, the effect is significant. The loss is the biggest amongst all generation loss contingency scenarios. The lowest observed system frequency is 49.47 Hz (2.85s), after which the frequency begins to rise due to load curtailment. The extra-active power (spinning reserve) produced by the Akosombo hydro-units is insufficient to restore the system frequency. As compared to the other scenarios, the load shedding causes a steady rise in the system frequency. The frequency gets close to the allowable operating deadband (49.88Hz at t=20s), but at the cost of undesirable load shedding.

A summary of the dynamic simulations is provided in Table 3.7 below.

Table 3.7: Summary table of the four dynamic simulation scenarios

Scenario	Description	Lowest frequency	Comments
1	Loss of 50% solar PV output due to partial cloud cover in the north	49.530 Hz	• Intervention by AGC • No load shedding • Frequency does not recover completely
2	Loss of full solar PV output due to complete cloud cover in the north	49.501 Hz	• Intervention by AGC • No load shedding • Frequency does not recover completely
3	Loss of 50% output of all solar PV plants due to partial cloud cover, and loss of 50% wind power plant output	49.490 Hz	• AGC is not enough • Extreme load shedding occurs • Frequency begins to recover
4	Loss of output of all solar PV plants due to complete cloud cover, and loss of all wind power plant output	49.474 Hz	• AGC is not enough • Extreme load shedding occurs • Frequency begins to recover

NB: Scenarios 1 and 2 are similar to the situation in which no other renewable plants are considered and the northern PV power plants are the only ones considered for Ghana's energy mix.

3.8 Key findings of the analysis

Based on the results of the technical analyses, the following results were obtained:

1. The addition of a 150 MWp PV plant in the north can be integrated into the grid under steady state conditions without any system challenges.

2. The inverter absorbs reactive power to help reduce the high voltages already experienced in the north.

3. The study shows the ability of the grid to withstand the extreme situation of total cloud cover over the northern part of Ghana, as no load shedding is observed under this condition. This complete cloud cover results in the instantaneous loss of 150 MW from the grid.

4. The partial or complete loss of additional generation from the southern part of the country, in addition to the loss of the 150 MWp mentioned above, is favourable to the grid as load shedding begins to occur.

5. Additional studies have shown that it is advisable to have a renewable energy plant in close proximity to a conventional power plant, because of the inertia provided by these plants.

6. The addition of more spinning reserves or units with AGC can help increase the total renewable energy penetration in the grid. This means that the limit to the level of penetration will increase with the addition of more units at Akosombo, and decrease when the number of running units at Akosombo is reduced.

3.9 Infrastructure upgrades required to export power to Burkina Faso

The Strategy Proposal established that the ongoing grid infrastructure upgrades and the new constructions as part of the WAPP will make it possible to wheel significantly more power across borders. In particular, reference is made to the 225 KV line between Bolgatanga and Ouagadougou, which is expected to be operational at the end of 2017, and a planned 225 kV line from the same Bolgatanga substation, through Burkina Faso to Mali. Upon completion, these two lines combined are expected to wheel approximately 400 MW of power in the medium- to long-term. Even with the current agreement between VRA and SONABEL for a total transmission capacity of 100 MW of power from Ghana to Burkina Faso, there is still sufficient capacity available on the inter-state grid to export power to Burkina Faso. For eventual supply volumes beyond the current inter-state grid capacity, the existing lines would have to be upgraded or a new transmission line constructed.

Against this backdrop, and the findings outlined above, the following infrastructure upgrades are required to export power to Burkina Faso:

1. For large-scale integration of solar PV of 20 MWp[13] and above, direct integration into the 161kV line is recommended. For such 161 kV single-circuit twin-bundle AAAC-conductor transmission line connection to the existing grid system at the substation points, the following will be needed: steel towers, conductors (AAAC 570), optical ground wire, alumoweld shieldwires (AACSR 116) under 34.5 kV, fog type U120 BP (boson peak) glass insulators, and other associated accessories.

2. Reactive power compensation devices will be required to control the voltage level, since the voltage profile is already higher. The simulation cases show that an underexcited mode of operation for the PV inverters under normal system operating conditions would improve network conditions. The installation of FACTS systems such as Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC) or Unified Power Flow Controller (UPFC) is recommended.

3. For more solar PV integration in the north, especially in the eastern part of the northern section, conventional generators with big inertia will be required to maintain system stability. Acquisition and installation of advanced weather prediction technology, such as satellite technology, is recommended for improved and exact forecasting of solar irradiation and cloud movement. Upgrading of the forecasting software of existing grid operators will be crucial to make use of accurate weather prediction and solar resource forecasting.

4. As interconnection among ECOWAS countries increases, while more spinning reserves become available in member states and forecasting of solar resource improves, more solar PV supplies could be integrated in Ghana, as the interconnected grid could be used as a back-up for any unforeseen variations in solar generation.

3.10 Recommendations

Based on the conclusions above, the following recommendations are made;

1. With respect to line loadings and system bus voltage levels as well as system losses, the integration of variable renewable energy in the north at 150 MW is a viable option that improves the state of the system and does not violate any of the steady-state criteria as per the grid code.

2. Reactive power compensation devices may be required to control the voltage level, since the voltage profile is already higher and the case shows that underexcited operation for normal conditions would improve network conditions. Operation within the PQ curve as required by the renewable energy subcode is optimal.

3. An additional 70 MW of solar PV can be integrated in 2016 with little or no system upgrade at an off-peak load of 1,877.8 MW and a generation of 1,986.9 MW, representing 11.07 per cent of total generation in the generation mix. This value depends on the regional dispatch and some values may not support this.

4. Proper planning and coordination is required to establish the exact solar PV capacity integration in the north, at a single PCC. The 11.07 per cent value must be shared among the IPPs nationwide that intend to be on board to develop additional solar PV capacity by 2016.

5. It is generally encouraged to develop potential sites for hydroelectricity of any size alongside the large integration of solar PV, in order to serve as ramping and dispatchable back-up. For solar PV integration in the north, even though most of the sites are located in the eastern part of the northern section, the analysis strongly indicates that more PV integration close to the Bui hydroplant (western part of the north) would be beneficial to the system stability because of the big inertia generator available.

6. In cases where ramping conventional generation cannot be installed or developed alongside large solar PV above 20 MW, a Super Conducting Magnetic Energy Storage (SMES) is recommended as a

13 It was established – through stakeholder consultation – that the first 20 MW of solar PV integration at distribution voltage has been successfully completed at Mankoadze in the Central Region of Ghana.

grid utility upgrade to help control both the voltage level and power. SMES is a grid-enabling device that stores and discharges large quantities of power almost instantaneously. The system is capable of releasing high levels of power within a fraction of a cycle to replace a sudden loss or dip in line power.

7. As the system load grows and the conventional power plants also increase in capacity on the grid, further penetration studies must be performed to determine the maximum level of penetration. In doing so, GRIDCo can further advise on how much can be connected per PCC in phases, until all of the expected MW capacities are connected for each renewable energy developer.

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4 Financing needs assessment – financing requirements for exporting solar power

This section discusses the financial requirements for exporting solar power, and the risk and barriers associated with renewable energy projects. It also assesses the existing financial instruments and their adequacy for supporting renewable energy projects, particularly for solar energy. The section gives an overview of funding sources available and their requirements for renewable energy projects in the electricity sector, and explores the potential use of public–private partnerships to leverage private investments for infrastructure development.

4.1 Financial requirements for identified infrastructure upgrades

Renewable energy generation technologies are characterized by a high up-front cost and very low operation and maintenance costs. The project lifecycle suggests that about 95 per cent of the total cost for solar projects is incurred at the construction phase, with the feasibility study and the financial closure accounting for the remaining 5 per cent of the total costs (FS–UNEP, 2014a). In the same vein, the highest risk is associated with the construction phase, and risks decrease rapidly after the initial operation phase.

4.2 Barriers and risks to renewable energy development

The Parliament of Ghana passed the Renewable Energy Act in 2011. As of 10 November 2015, the Energy Commission had issued 76 provisional licenses to potential renewable energy developers. Of these licences, 52 are for solar PV projects, but only one of these is currently under construction, namely a 20 MWp solar PV plant at Mankoadze in the Central Region of Ghana.

The literature on the financing of renewable energy projects categorizes the barriers and risks to renewable energy uptake into two categories:

- barriers and risks related to underdeveloped financial markets; and
- barriers and risks related to the development of renewable energy.

The following barriers and perceived risks have been identified as contributing factors for the slow uptake in renewable energy developments (World Bank and Climate Investment Fund, 2013):

a. Lack of project financing;

b. Lack of equity finance;

c. Lack of long-term financing;

d. High and uncertain project development costs and lack of equity finance;

e. High (up-front) investment cost of renewable energy technologies relative to conventional generation technologies using fossil fuels;

f. Uncertainty over resource adequacy;

g. Regulatory risks; and

h. Political, technical, economic and social risks.

Of the risks described above, the first four belong to the category of risks related to underdeveloped financial markets, while the remaining four are related to the development of renewable energy. The abovementioned barriers and risks give credence to the fact that having adequate and appropriate financing instruments for renewable energy development is essential for increasing uptake, particularly in developing economies.

The financial market in Ghana is relatively underdeveloped. The participation of the local financial sector in renewable energy financing is practically non-existent. A number of factors (e.g. high interest rates and high exchange rate volatility) hinder the ability of local banks to provide long-term financing beyond five years, and this in turn is impacting the renewable energy sector.

In regards to specific risks related to the development of renewable energy projects, the following categories are to be assessed. Political risks are mostly associated with the political climate of the country undertaking the renewable energy project, but also include risks associated with the political stability in the subregion (for example in the country that will buy the additionally produced energy) and even the political stability in the country where the necessary investments come from. The regulatory environment of the implementing country is also a factor to be considered. In Ghana, the political climate has been rather stable over the past two decades, making it a preferred destination for investments, in comparison to other sub-Saharan African countries.

Economic risks include risks associated with securing favourable financing for renewable energy projects, and risks related to the counterparty's ability and / or willingness to pay the agreed tariff for the electricity provided (off-taker and market risk). For illustration, the Ghana Energy Commission has issued about 52 provisional licences for solar PV projects (see above), but only one plant is under construction; this fact is largely attributable to the weak balance sheet of the main off-taker (i.e. the Electricity Company of Ghana) and the Government's lack of willingness to provide sovereign guarantees. Economic risks also include foreign exchange market risk, if transactions are indexed in local currencies. Ghana's currency has been a major source of concern to investors over the past decade, as it has been continuously depreciating against other trading currencies like the US Dollar.

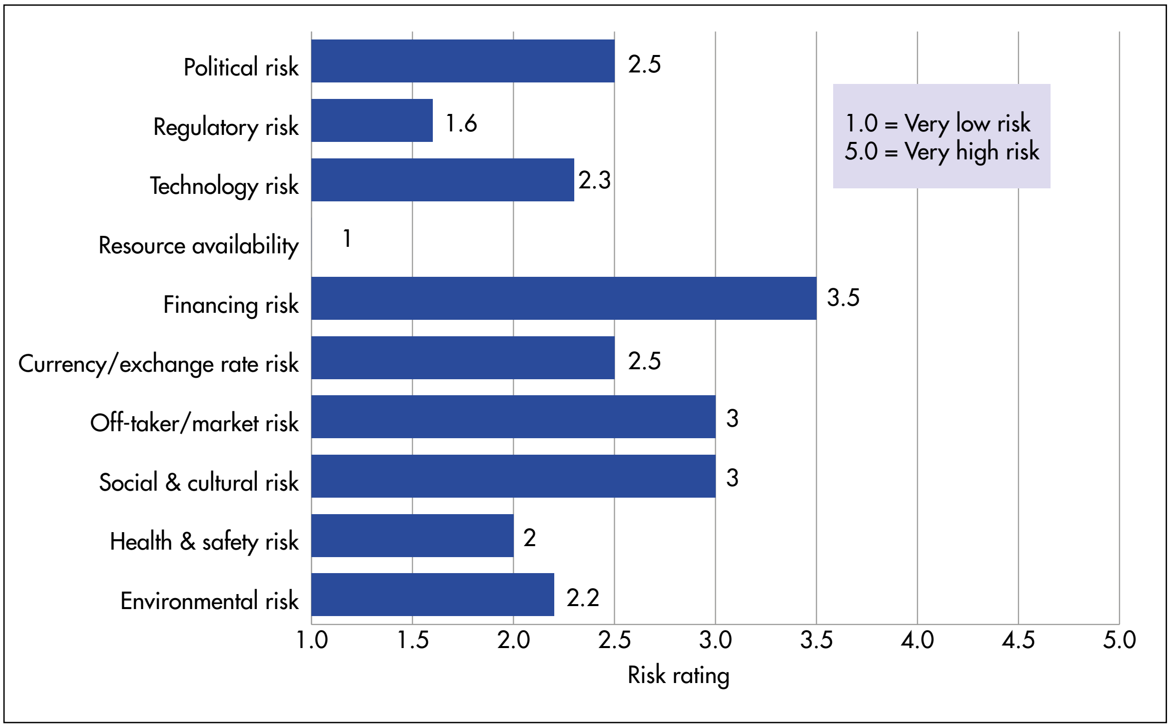
Technical risks include risks associated with the availability of the renewable energy resource and also the maturity of the renewable energy technology being implemented. The annual output of a plant depends on the resource availability, which can vary significantly from year to year. Africa receives the highest level of solar radiation in the world, making it a very good location for solar projects. Renewable energy development involves new technologies, which need to be field-tested to determine technical feasibility. The key concerns relate to the performance of the equipment over its lifetime, in particular taking into account local circumstances. Solar PV module technologies have matured and can generally last up to about 25 years. Manufacturers often provide guarantees for 10 to 15 years.

Social risks include the risks associated with implications of renewable energy projects on the environment as well as the culture and social lives of people.

Through a broader stakeholder consultation, these risks were analysed and ranked on a scale of 1-5, with 1 being the lowest and 5 the highest perceived risk. Figure 4.1 shows how stakeholders ranked the various risks associated with the renewable energy sector, and specifically the solar energy segment.

As Figure 4.1 shows, the financing risk of renewable energy projects was ranked highest, while the resource availability was considered the lowest risk.

Figure 4.1: Stakeholder perception of risks associated with renewable energy financing



4.3 Financial instruments and their adequacy for renewable energy developments

Over the years, Ghana's energy sector has received financial support from bilateral and multilateral sources, including:

1. The Japanese International Cooperation Agency (JICA), which has provided grants for projects ranging from the development of solar PV systems to the reinforcement and extension of the electricity distribution network in the northern part of Ghana;

2. The Agence Française de Développement (AFD), whose support includes a loan facility to the VRA, through the Government of Ghana, for retrofitting the Kpong Hydroelectric Power Plant. The AFD has also provided a loan to GRIDCo, for upgrading the transmission line from Kumasi to Bolgatanga and for constructing substations at various locations along the line;

3. Proparco, a subsidiary of the AFD devoted to private-sector funding, has supported the expansion work of the Takoradi International Company Ltd. (TICO) plant; and

4. The World Bank has provided loans for the various phases of the Ghana Energy Development and Access Project (GEDAP).

These funding instruments, mostly loans and grants, are not sufficient or adequate, as can be concluded from the low number of projects being supported, when compared to the number of projects that would need support.

This section examines the merits and demerits of other incentives and financing instruments in place to fund renewable energy projects. Funding for renewable energy projects can be obtained from both private and public sources. Most governments use public support instruments to address the dominating barriers of high perceived risk and limited availability of long-term financing (FS–UNEP, 2014b). Some financial instruments might be better suitable to address certain barriers or risks than others, but the choice for a financial instrument is not always straightforward (World Bank & Climate Investment Funds, 2013).

Public and concessional funds are becoming scarcer, so the private sector is increasingly being asked to support the financing of renewable energy projects. Studies show that the type of financing provided by the private sector may depend on a number of factors: investment objectives and strategies; levels of risk appetite; return expectations of the investor; and investment horizons. Thus, the particular instrument adopted may be equity-based, debt-based or a combination of both (mezzanine), and these instruments may be adopted at all phases of the project development phase (FS–UNEP, 2014b).

According to the World Bank and Climate Investment Finance Fund (2013), public finance instruments for renewable energy projects should be used in order to incentivize private actors to complement the amount of public financing provided. Furthermore, financial instruments that are funded from public sources should not (only) aim at funding renewable energy projects, but also aim to address barriers and risks that either constrain or inhibit private investment. The financing instruments that are being used to support renewable energy developments can be divided into three categories (also see Figure 4.2):

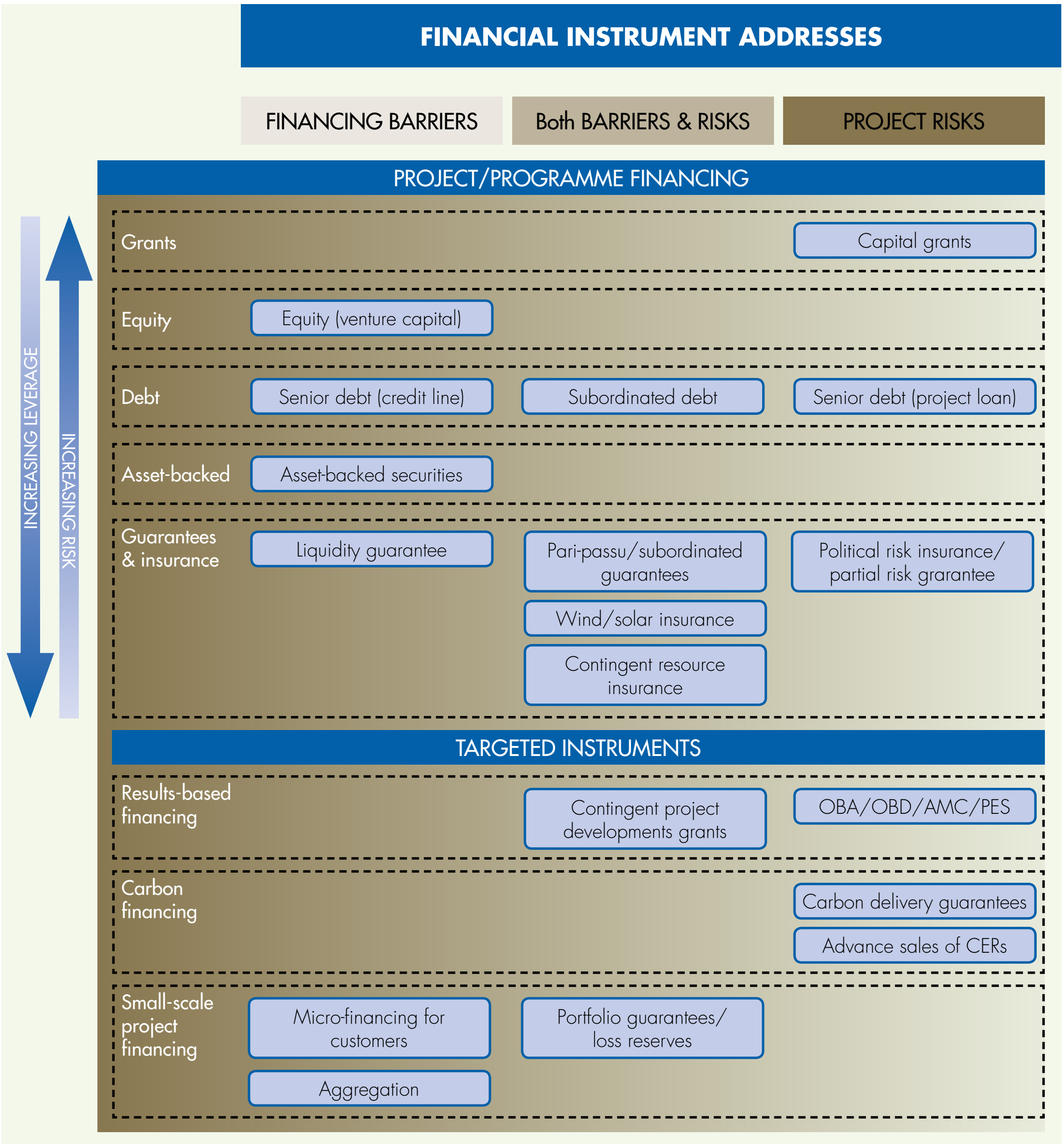
- Instruments that address barriers;
- Instruments that address specific risks of investment; and
- Instruments that address both barriers and risks.

As shown in Figure 4.2, the various financial instruments can be further differentiated by two factors:

- the level of risk assumed by the public sector institution funding the instrument; and
- the level of leverage[14] involved.

14 Leverage is the additional funding that is mobilized by the instrument concerned.

Figure 4.2: Range of financial instruments



Source: (World Bank and Climate Investment Funds, 2013)

Figure 4.2 lists some of the instruments available for project financing. It must be noted that the aim of this section is not to conduct an extensive review of available instruments, but to give a brief overview of the financial instruments in order to determine whether they are adequate to drive investments in the renewable energy sector. Information gathered from literature and from interactions with funding agencies in Ghana indicated that, of the instruments listed, the most common in Ghana are debt financing and grants.

Debt financing is a method of financing in which an entity receives a loan and provides a promise to repay the loan. There are many variants of debt financing, from private sector sources but also from public sector sources, also known as senior debt (World Bank and Climate Investment Fund, 2013). Its main purpose is to provide concessionary loans that may be combined with more expensive funding from commercial sources to reduce the cost of the project and provide longer-term financing. Providing senior debt financing may also be used to establish credibility among private financiers for longer-term lending to the renewable energy sector. Senior debt can be realized by advancing direct loans to project companies or by providing credit lines through Climate Finance Institutions (CFI).

Grants usually aim to provide partial funding for renewable energy projects, in order to reduce the ultimate financial cost of the project to an affordable and competitive level. Grants are the riskiest instrument, because they do not provide control over the funded projects. Also, there is no incentive for the project developer to deliver a viable project.

Further information regarding the pros and cons of different financial mechanisms available for developing renewable energy projects can be found in Appendix H.

4.4 Funding sources

Funding sources for renewable energy projects can be grouped under three broad headings: local financing sources, bilateral financing sources and multilateral financing sources. Over the years, Ghana's energy sector has received financial support from bilateral and multilateral agencies mostly in the form of loans and grants. Ghana has been a beneficiary of these financial instruments because the country met the eligibility requirements of respective funding agencies.

4.4.1 Local financing sources

Local financing comes mostly from Government statutory funds, or from private commercial and development banks. A selection of potential sources is listed below.

a) Government funds for renewable energy projects include, but are not limited to, the following:

- Government of Ghana budgetary allocation to the Ministry of Power for the development of the electricity sector.
- The Ghana Energy Fund, which was set up in 1997 by the Energy Commission Act (Act 541) with the mandate to mobilize funds from the government levy on petroleum products, electricity and natural gas, in order to enable the Energy Commission to perform its functions and grants.
- The Ghana Renewable Energy Fund, established in 2011 by the Renewable Energy Act (Act 832) but not yet active, will provide financial resources for the promotion, development, sustainable management and utilization of renewable energy sources. Once active, the fund will provide financial incentives, feed-in-tariffs, capital subsidies, production-based subsidies and equity participation to the renewable energy sector.
- The Government of Ghana set up the Ghana Infrastructure Investment Fund (GIIF) in 2014 by Act 877, to focus on strategic infrastructure development in partnership with the private sector. The implementation of this fund will provide opportunities to use national resources in novel ways in order to upgrade critical national infrastructure. It is expected that the fund will also be used for project financing where necessary and applicable. The potential sources of funding for the GIIF include appropriations by Parliament, escrowed and on-lent funds from prior investments, private or public domestic and foreign funds from multilateral institutions and development banks, capital markets (including stock exchange) and pensions, among others.
- Quasi-public institutions such as the Social Security and National Insurance Trust (SSNIT), which is the owner of the Tema CENIT Thermal Power Plant.

b) Private financing could be obtained from local commercial banks and development banks, but such funds are provided only in the short term, and have significantly higher rates (typically, 27–32 per cent over five years).

Table 4.1 provides a summary overview of local funding sources for renewable energy financing.

Table 4.1: Local funding sources

Classification of sources	Investment support scheme		Financing instrument/ mechanism	Examples of projects
	Managers	Source (institutions/funds)		
Government of Ghana	Ministry of Power	Budgetary Allocation	Not accessible to individuals and private organizations	
	Energy Commission	Energy Fund		
		Renewable Energy Fund		
	Ministry of Roads and Transport	Road Fund (Street Light Levy)		
	Ministry of Finance	Ghana Infrastructure Investment Fund (GIIF)		
	Quasi-public institutions			CENIT Power Plant
Private sector	Commercial banks		Market-based loans	
	Development banks			

4.4.2 Bilateral financing institutions

Bilateral financing institutions (BFIs) are financing institutions created and directed by various national governments for the purpose of giving aid or investing in targeted development projects and programmes in developing countries and emerging markets (see Table 4.2 for various examples of bilateral financing institutions). These institutions are mandated by their respective governments to provide long-term financing to the public and / or private sector, with specific value-added development objectives, but on a sustainable commercial basis. The funding mechanisms employed by BFIs include grants, concessional loans, market-based loans, credit lines, credit / risk guarantees and equity financing. Some BFIs also provide non-financial assistance to the beneficiary countries in the form of technical support.

The JICA and the AFD (including its subsidiary Proparco) are among the BFIs that are currently supporting various energy-related projects in Ghana. Others include the German development bank KfW, its subsidiary German Investment Company (DEG), the US Government's Overseas Private Investment Corporation (OPIC), and the UK's Department for International Development (DFID).

a) BFIs offer support to programmes / projects in beneficiary countries based on certain criteria, including:

b) Relevance to objectives of the funding agency;

c) Total funding sought;

d) Amount or percentage of co-financing;

e) Economic and financial viability;

f) Experience and capabilities of proposing entity;

g) Programme management plan;

h) Implementation plan; and

i) Evaluation plan.

Table 4.2 provides a comprehensive overview of financing instruments and eligibility requirements of selected key bilateral financing sources.

Table 4.2: Bilateral financing sources

Investment support scheme		Financing instrument / mechanism	Key eligibility requirements	Typical terms			Examples of projects
Managers	Name of scheme			Interest rate, %	Tenor, in years	% grant	
Japanese International Cooperation Agency (JICA)	Bilateral Assistance Scheme to Governments & SoE's	1. Technical cooperation 2. Official development assistance loan 3. Grant aid	1. Geographic and regional setting 2. Sector and technology covered 3. Qualifying project or programme 4. Type of financing (grant, concessional loans, etc.) 5. Project size 6. Size of targeted organization 7. Co-financing / cost-sharing requirements 8. Type of proposing entity (government, NGO, etc.) 9. Implementation timeframe	–	–	100	1. Provided assistance in the development of the Power Distribution System Master Plan for Ghana (2006) 2. Provided grant for rural electrification in the Upper Denkyira District 3. Supported the installation of solar PV systems at the Noguchi Memorial Institute for Medical Research, University of Ghana 4. Provided a grant to the GoG for the reinforcement and extension of the existing power distribution systems in Tamale and Sunyani 5. Supporting the ECG's training school for electrical engineers, in order to facilitate power distribution in the country.
Agence Française de Développement (AFD)	Bilateral Assistance Scheme to Governments and SoE's	1. Sovereign concessional loans 2. Non-sovereign concessional loans 3. Grants		2 to 5	20 to 30		1. Retrofitting of the Kpong Hydroelectric Power Station 2. Financing GRIDCo's upgrade of the 330 kV transmission line from Kumasi to Bolgatanga
French Development Finance Institution (Proparco)	Financial Assistance to the Private Sector	1. Concessional loans		2 to 5	20 to 30		1. Expansion work of the Takoradi International Company Ltd (TICo)
US Overseas Private Investment Corporation (OPIC)	Financial Assistance mostly to the Private Sector	1. Direct loans 2. Investment guarantees 3. Political risk insurance					
German development bank (KfW)	Bilateral Assistance Scheme to Governments and SoE's	1. Grants 2. Developmental loans 3. Promotional loans					
German Investment Company (DEG)	Financial Assistance to the Private Sector	1. Loans to the private sector					

4.4.3 Multilateral financing institutions

Multilateral financing sources include multilateral development banks (MDBs), special international agencies created by these MDBs (such as the Global Environment Facility – GEF), as well as various national governments and multilateral funds (see Table 4.3 for some examples of multilateral financing sources). Multilateral development institutions are an important source of development assistance and typically provide significant benefits and economy-wide support for sustainable development and emerging finance instruments. Funding mechanisms employed by these multilateral agencies include grants, concessional loans, market-based loans, credit lines, credit / risk guarantees and equity financing.

The MDBs, including the African Development Bank Group, the World Bank Group, the European Bank for Reconstruction and Development (EBRD) and the European Investment Bank (EIB), provide financial support in the form of grants, concessional loans, market-based loans, credit lines, credit / risk guarantees and equity financing to member countries. The eligibility requirements used by MDBs to provide financial assistance to development projects can be found in Table 4.3.

Special international agencies, like the GEF and the climate finance institutions set up by MDBs and other multilateral institutions, also provide financial support for developments in the power sector. These agencies provide grants to beneficiaries for project development based on certain eligibility criteria, exemplified by the GEF criteria that can be found in Table 4.3.

Table 4.3: Mutilateral financing sources

Classification of sources	Investment support scheme		Financing instrument/ mechanism	Key eligibility requirements	Typical terms			Examples of projects
	Managers	Name of scheme			Interest rate, %	Tenor, in years	% grant	
Multilateral Development Banks (MDBs)	World Bank Group	1. International Bank for Reconstruction and Development (IBRD) 2. International Development Association (IDA) 3. International Finance Cooperation (IFC)	1. Concessional loans 2. Interest-free loans 3. Guarantees 4. Risk management products 5. Grants	1. Geographic/regional setting 2. Sector/technology covered 3. Qualifying project/ programme 4. Type of financing (grant, concessional loans, etc.) 5. Size of project 6. Size of targeted organization 7. Co-financing cost-sharing requirements 8. Type of proposing entity (Government, NGO, etc.) 9. Implementation timeframe	5	20		1. Ghana Energy Development and Access Project (GEDAP)
	African Development Bank Group (AfDB)	1. African Development Bank 2. African Development Fund	1. Loans 2. Guarantees 3. Risk management products 4. Equity financing					1. T2 Expansion Project 2. Power system reinforcement project in Kumasi
	European Bank for Reconstruction and Development (EBRD)		1. Loans 2. Equity investment 3. Guarantees			15		
Special agencies	Global Environment Facility (GEF)	1. Least Developed Countries Fund (LDCF) 2. Special Climate Change Fund 3. Sustainable Energy Fund for Africa (SEFA)	1. Grants	1. Undertaken in an eligible country consistent with national priorities and programmes 2. Addresses one or more of the GEF Focal Areas, improving the global environment, or reducing risks to the global environment 3. Consistent with the GEF operational strategy 4. Seeks GEF financing only for the agreed-on incremental costs on measures to achieve global environmental benefits 5. Involves the public in project design and implementation 6. Is endorsed by the government(s) of the country or countries in which it will be implemented				

4.5 Public–private partnership (PPP) participation in renewable energy

In 2011, the Ghana Ministry of Finance launched a national policy on public–private partnerships in order to encourage private participation in infrastructure and services and to improve the quality of public services provided. The policy defines PPPs as "contractual agreements between a public entity and the private sector with clear agreement on shared objectives for the provision of infrastructure and services traditionally provided by the public sector". PPP participation has long existed in Ghana's energy sector, even before the introduction of the National PPP Policy (MoFEP, 2011). For example, the T2 and T3 thermal plants operated by the Takoradi International Company (TICo), the West African Gas Pipeline Company (WAPCo) and the Kpone Independent Power Project are cases of private sector participation in Ghana's energy sector through PPPs. PPPs are an important option for realizing infrastructure investment projects, including in the energy sector.

The risk rating presented in Figure 4.2 shows that the difficulty in securing favourable long-term financing for infrastructural projects in the energy sector can be largely attributed to a high perceived financing risk, which increases the cost of securing financing under favourable conditions for the renewable energy projects, which are characterized by very high up-front investment costs. PPP funds can help to overcome this barrier. In the case of the T2 and T3 thermal plants, the Abu Dhabi National Energy Company (TAQA) provided about 90 per cent of the funds and financed the day-to-day operation of the plant, while the Government as a key stakeholder provided a conducive business environment for operations. The National Policy on PPP provides detailed guidelines to enhance private sector participation in the energy sector.

4.6 Conclusion and recommendations

Ghana can boast of high renewable energy resources, especially solar, but investment in renewable energy is comparatively low. This is due to several factors, including challenges in securing favourable long-term financing. Among all the local financing sources discussed, the Ghana Infrastructure Investment Fund and the Renewable Energy Fund are the foremost funds that have been mandated to support the sector with loans. Although the funds have been provided for in the law, the responsible bodies are still defining modalities for their operations. At the same time, the international sources come with strict eligibility requirements and conditions, which applicants are expected to fulfil before funding is provided. This creates difficulties that chiefly stem from the (mostly economic) risks associated with renewable energy development. These risks need to be addressed in order to create the enabling environment that will drive investments in Ghana's renewable energy sector.

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5 Infrastructure approval process in Ghana, Burkina Faso, and the ECOWAS subregion

In many countries, there are established requirements mandated by regulatory frameworks, or guideline documents that need to be complied with, when constructing new electricity transmission lines. In many of these country frameworks, Environmental and Social Impact Assessments (ESIAs) are a key prerequisite for infrastructure construction projects. It is also becoming increasingly common for financing institutions to require potential beneficiaries of funds (i.e. project developers) to conduct an ESIA. Such assessments ensure that the undertaking of the project will have no avoidable negative environmental and social impacts. This section looks at the requirements and steps for approval of infrastructure construction projects in the ECOWAS subregion, and individual requirements in Ghana and Burkina Faso.

5.1 Approval process in the ECOWAS subregion

The West African Power Pool has been set up to ensure, in the medium- to long-term, an optimal and reliable electricity supply at an affordable cost to the population of the various member states, through the integration of national electricity networks in a unified regional market (WAPP, 2005). Accordingly, member states are expected to facilitate the realization of this goal through their participation in projects and their compliance with regulatory requirements. The WAPP Articles of Agreement, which were first adopted by the ECOWAS Ministers of Energy in 2005, were subsequently adopted by the ECOWAS Summit of Heads of States and Government in 2006, and have become the guiding framework for subregional energy cooperation between member states. By virtue of countries joining the organization, on a voluntary basis, they pledge to be part of the activities, comply with the rules, and support the operations of the WAPP.

The WAPP Master Plan, which is the framework within which cross-border infrastructure projects are implemented in the subregion, has been approved and adopted by the ECOWAS Heads of States and Governments. The plan envisions a contribution of 800 MW from solar and wind technologies to the subregional energy mix by 2025, and proposes interconnection projects for power evacuation and transmission. The approval process for cross-border transmission infrastructure is facilitated by the adoption of the WAPP Master Plan. Additionally, international project agreements are often signed with countries involved in particular WAPP infrastructure projects.

Under provision 23.1 of the Articles of Agreement (WAPP, 2005), member states are allowed to retain their existing regulatory jurisdiction and the authority of their agencies. Hence, the WAPP facilitates the construction of new infrastructure through its project implementation and coordination units, while member states remain directly responsible for executing such projects, controlling and operating the transmission lines, and maintaining them where necessary. Within the different country contexts, the domestic requirements for approving the construction of new transmission lines also have to be complied with. This may involve the conduct of an ESIA for infrastructure projects.

5.2 Approval process for the construction of new transmission lines in Ghana

Ghana's existing transmission system network is wholly owned and operated by the Ghana Grid Company (GRIDCo). The TSO is guided by Legislative Instrument (LI) 1934 of 2008. GRIDCo is presently the independent operator of the transmissions system. The establishment of GRIDCo was intended to develop and promote competition in Ghana's wholesale power market by providing all participants in the power market, particularly power generators and bulk consumers, with transparent, non-discriminatory and open access to the transmission grid, by making power delivery more efficient.

5.3 Third-party ownership of transmission system assets

Per the roles defined for utilities, GRIDCo, being the TSO, has the mandate to invest in electricity transmission lines from power plants to any part of the country. Due to financial constraints, however, GRIDCo may face delays in the construction of new transmission lines for effective power evacuation. For this reason, the owners of new plants, including solar energy plants, may be required to construct a new transmission line in order to connect to the nearest GRIDCo connection point.

A solar project developer who needs to construct a new transmission line is referred to as a 'third party' in the regulations. To construct new transmission lines, this third party must gain approval from the relevant agencies. The different steps of this approval process are presented in section 5.4.

According to LI 1934 (2008), even though a third party can in principle own a transmission line, GRIDCo is then delegated to grant and control connections to such assets in order to guarantee open, fair and non-discriminatory access to its transmission assets by other grid participants. As part of the preparation process for constructing new grid lines, the project developer may negotiate with GRIDCo about possible incentives. This may be in the form of reduced transmission costs for wheeling power through the GRIDCo-owned transmission lines, and the sharing of transmission charges if an electricity plant should connect to any point on the 'privately-owned' transmission line in the near future. Such arrangements can typically be spelled out in a PPP agreement, and can provide much-needed incentives for private actors to provide finance for grid infrastructure projects.

Due to the high costs of constructing transmission lines (approximately US$ 100,000 per km for a 161 kV line), this strategy proposal recommends that new solar plants are constructed within 5 km from the nearest GRIDCo connection point. The analysis of land availability (see section 3.1) for solar plants assumed this maximum distance.

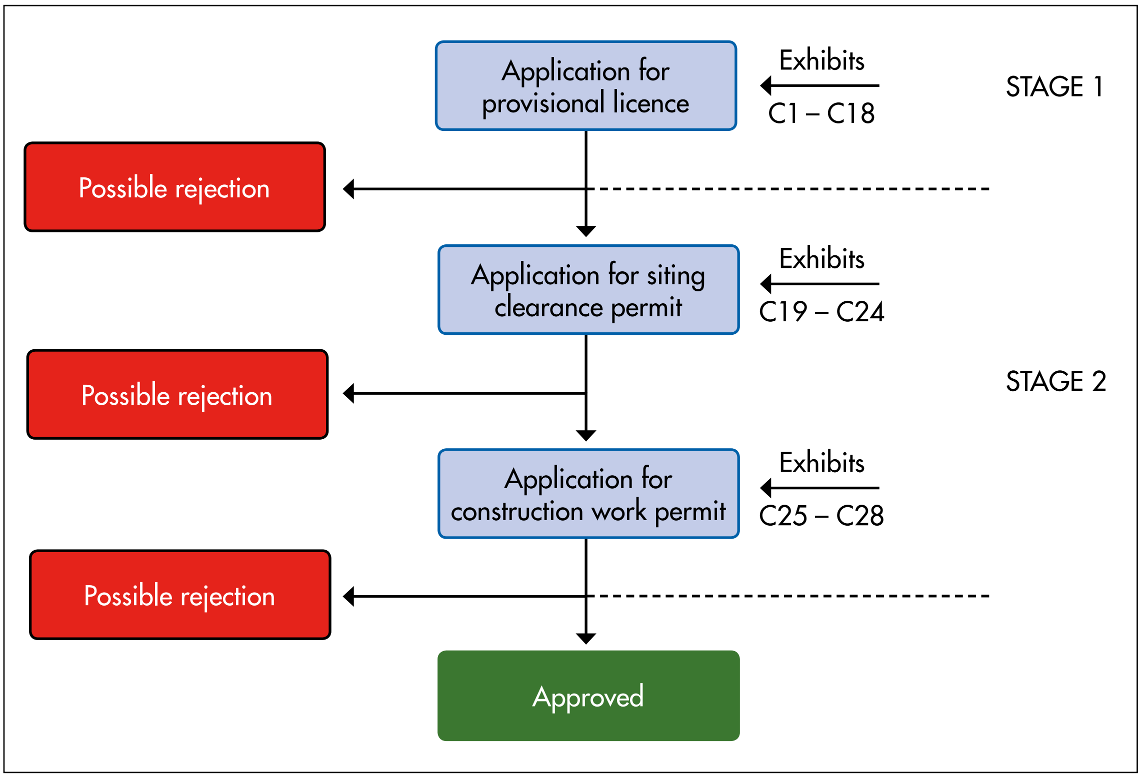
5.4 Licences required for transmission construction and operation

Two main licences are required for owners of transmission system assets: a technical licence from the Energy Commission and an environmental permit from the Environmental Protection Agency (EPA).

5.4.1 Technical licensing procedure

Details of the technical licensing procedure are spelled out in the 'Licence Application Manual for Service Providers in the Electricity Supply Industry' published by the Energy Commission (2012). The Energy Commission may issue a licence if it deems the applicant (an individual or company hoping to construct a new transmission line) to be suitable for it, and if the applicant meets the specified requirements for the licence. GRIDCo may play a major role in the process of granting licences to third-party applicants, as it is responsible for operating the national grid lines. Figure 5.1 summarizes the technical licensing procedure for infrastructure project applications.

Figure 5.1: Overview of technical licensing procedure



Source: Developed by authors

The relevant exhibits are also outlined in Appendix I of this document. The first stage is the submission of a formal licence application to the Office of the Executive Secretary of the Energy Commission. Applications are filed on forms approved and supplied by the Energy Commission. The completed application form is submitted together with all relevant supporting documentation (or exhibits) required, as specified in the application form. An application fee is paid at the time of submitting the application and covers all the stages in the licensing process. The Energy Commission should acknowledge receipt of the application within ten working days and indicate whether the applicant's submissions are deemed to fully satisfy the requirements expected for the licence. Applicants provide ten hard copies and one soft copy, if available, of the relevant exhibits (see Appendix I). The next stage in the process is the acquisition of a siting clearance and of a construction work permit, again with some exhibits.

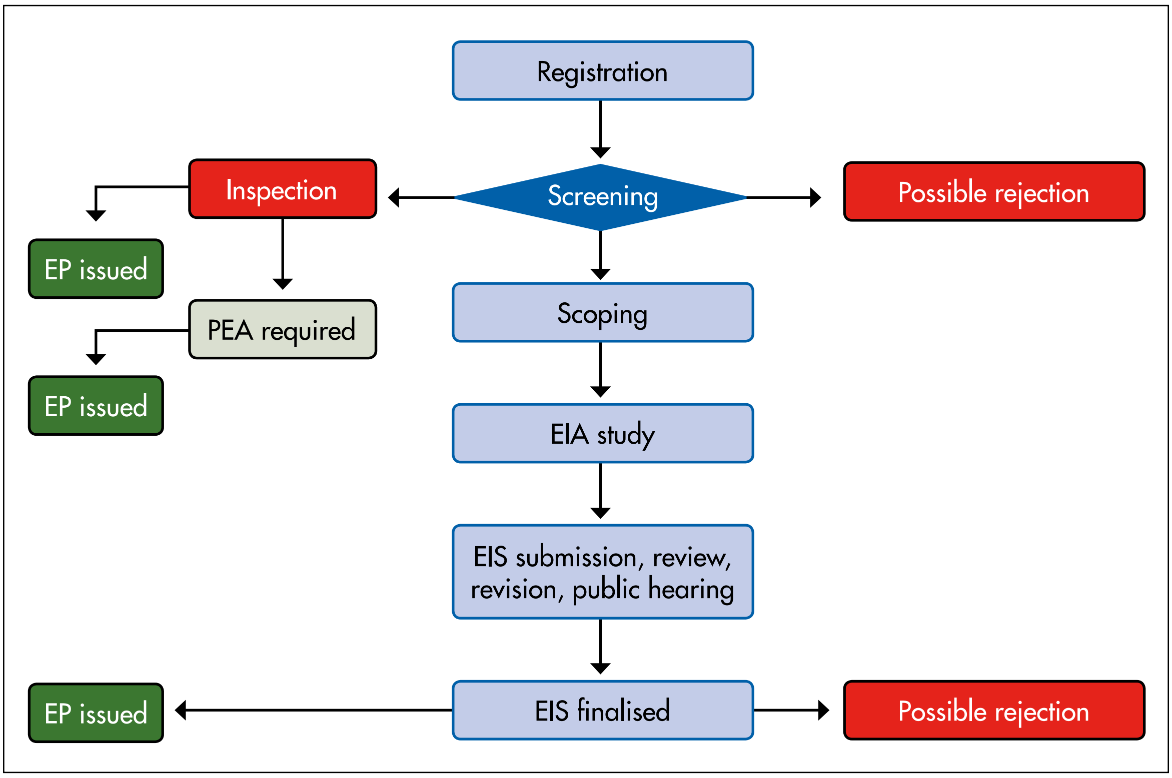
For the Energy Commission to issue a licence, it needs to be convinced that a safe, reliable and economic transmission of electricity will be guaranteed, and that the applicant has the capacity to adequately exercise system control functions and operations in an efficient, transparent and fair manner. The Commission should provide the applicant with a written notice of its decision within 60 working days after acknowledging receipt of the application.

5.4.2 Environmental permitting procedure

Projects that are deemed to have environmental consequences must be granted an environmental permit by the EPA, as part of the overall approval process. Whether or not a detailed Environmental Impact Assessment (EIA) is required is dependent on the perceived impacts of the project. Construction of power transmission lines in Ghana is regarded as a critical environmental project for which an EIA may be mandatory before an environmental permit can be granted. This is determined by factors such as the location and the length of the proposed transmission line.

The applicant goes through the initial stages with the EPA in order to determine whether an EIA is mandatory. The environmental permit forms part of the exhibits required by the Energy Commission for the issuance of a site clearance permit. The procedure for obtaining the environmental permit is summarized in Figure 5.2, and briefly explained in the next sections. Details can be found in the 'Ghana Environmental Impact Assessment Procedures' (Environmental Protection Agency, n.d.).

Figure 5.2: Environmental permitting procedure



Source: (Environmental Protection Agency, n.d.)

5.4.2.1 Registration

Application forms for the EIA are available at all offices of the EPA across the country, as well as the District, Municipal and Metropolitan Assemblies. The responsibility for registering the project lies with the applicant, but the responsibility for determining environmental impacts related to the construction of the transmission lines lies exclusively with the EPA.

5.4.2.2 Screening

Within 25 days from receipt, the EPA, assisted by a cross-sectoral technical committee including MESTI, will make a decision regarding the appropriate level of assessment. Consideration is given to a number of factors, including:

(i) The location, size and output of the project;

(ii) Concerns of the general public; and

(iii) Land use considerations.

A screening report will be prepared summarizing the decision reached, which can be one of the following:

(i) Objection to the undertaking;

(ii) No objection to the undertaking;

(iii) A Preliminary Environmental Assessment (PEA) will be required; or

(i) An EIA will be required.

The PEA is smaller in scope and is often used for projects whose environmental and social impacts are perceived to be minimal. A full EIA is required if the project is deemed to have more significant environmental and social impacts.

5.4.2.3 Scoping

If the initial registration of the project or a subsequent Preliminary Environmental Report (PER) from the PEA indicates that significant adverse environmental impacts are likely, the applicant will be required to conduct an EIA and, therefore, to submit an Environmental Impact Statement (EIS). For the applicant, the first step is to evaluate the project, and to consult with interested and affected parties, such as government officials, relevant ministries, local department authorities, traditional authorities and members of the public. The objective is to determine how the concerns of all groups will be addressed in the Terms of Reference (TORs) for the EIA. The scoping process also identifies key issues of concern to be addressed in the EIA.

5.4.2.4 Scoping Report / Terms of Reference

The applicant prepares a scoping report, including draft TORs for the EIA study, and submits ten copies to the EPA. As indicated in EPA (n.d.), the draft TORs should indicate that the EIS will include:

(i) A description of the project and an analysis of the need for it;

(ii) The objective of the project;

(iii) Other options for carrying out the project;

(iv) Alternatives to the project;

(v) A description of the present environment that would be affected, directly or indirectly;

(vi) A description of the future environment, predicting its condition if the project did not take place;

(vii) The impacts that may be caused to the environment by the project;

(viii) Proposed measures to prevent or mitigate all adverse impacts;

(ix) An evaluation of opportunities and constraints to the environment caused by the project;

(x) A proposal for an environmental management programme to cover constructional, operational and decommissioning stages of the project; and

(xi) Proposals for a programme for public information.

The draft TORs will be analysed by EPA and the cross-sectoral technical committee, and site visits will take place, if possible. This process of reviewing the draft TORs can either result in a rejection, a revision or an approval; the decision will be communicated to the applicant within 15 days upon receipt of the scoping report / TORs. Upon approval of the TORs, the applicant may start working on the EIA immediately.

5.4.2.5 Preparation of the Environmental Impact Statement (EIS)

Based on approval of the TORs, the applicant conducts an EIA. In the course of gathering data for the EIA, the applicant is required to initiate a public information programme for the area likely to be affected by the project. Through such programmes, local residents should be fully informed of the nature of the project and its direct and indirect expected effects on the environment. Public notice for the assessment process for the undertaking will be issued by the applicant through newspaper advertisements and / or by announcement posted in appropriate public places. Copies of all related reports must be made available to EPA. The concerns of the public must be recorded and addressed in the EIS.

5.4.2.6 Review of the Environmental Impact Statement (EIS)
Once the final draft of the EIS is completed, the applicant submits twelve copies to EPA. A cross-sectoral technical committee, including MESTI and other agencies, assists EPA in the review of the EIS. Copies are made available to the appropriate district, municipal or metropolitan assemblies. There is a 21-day public notice of the EIS publication, through newspaper advertisements and posting at appropriate places, to inform the public and to collect reactions, as part of the review process. The EPA then collates public views and undertakes a field / site verification exercise, if considered necessary.

5.4.2.7 Public hearing
If a strong public concern over the project is indicated and the expected environmental and social impacts are significant, the EPA will appoint a panel to organize a public hearing on the proposed undertaking. This panel should consist of three to five members. The chairman will not be a resident of the area affected by the construction, but at least a third of the panel's membership must be residents of the geographic area where the transmission lines are to be constructed. If a public hearing is held on a proposed project, the processing of the application may extend beyond the normal 90-day period for processing an application.

5.4.2.8 Environmental Permitting Decision (EPD)

a. Environmental Impact Statement (EIS)
If the draft EIS is found to be acceptable, the applicant shall be notified and will be allowed to finalize the EIS. If the draft EIS is found not to be acceptable, the applicant may be allowed to submit a revised statement at a later date, or to conduct further studies in order to modify the statement as necessary.

b. Validity of the Provisional Environmental Permit
The Provisional Environmental Permit is the initial environmental approval that allows any proposed development to commence. There is a time limit on the validity of the environmental decision. The decision is effective for a period of 18 months from the day the applicant is notified of the decision. If works have not started after expiry of these 18 months, the original decision becomes void and the undertaking must be registered again. The Provisional Environmental Permit does not preclude other licenses required for constructing the transmission line, such as those required by the Energy Commission.

c. Provisional Environmental Permit
The Provisional Environmental Permit is regularized within a time-span up to 24 months of its issuance and project commissioning. The basic requirements for the regulations of granting an Environmental Permit include evidence and / or confirmation of:

- Satisfactory commencement of construction;
- Observance of relevant permitting and approval conditions; and
- Compliance with nominated mitigation and other responsibilities outlined by the EPA.

5.5 Approval process for the construction of new transmission lines in Burkina Faso

In Burkina Faso, SONABEL holds a monopoly on the construction of new transmission lines. There is currently no document that spells out the requirements for approving the upgrade or construction of new transmission lines. However, a direct engagement with SONABEL staff revealed that an application for transmission upgrade by private individuals would have to be submitted to SONABEL. The application submitted must sufficiently demonstrate the need for a new power line and include a technical assessment and related information, including line voltage, main equipment and insulators, among others. An ESIA will then have to be conducted. A designated Director of the Ministry of Environment usually approves the ESIA. Upon approval of an ESIA, Engineering, Procurement and Construction (EPC) for the project may begin.

iStock: © didoi

6 Requirements for a solar-ready, cross-border grid line between Ghana and Burkina Faso: step-by-step proposal

This section draws on findings from the technical, financial and procedural analyses regarding the integration of variable sources of renewable energy into the grid systems, and the export of power from Ghana to Burkina Faso. It proposes a flow chart for selecting, financing and approving the installation of a solar-ready, cross-border grid line between Ghana and Burkina Faso. It also aims to facilitate close cooperation with project developers and financiers for further developing the nascent solar PV segment.

Two possible scenarios may call for the construction of a transmission line by a solar project developer or an independent entity. The first scenario assumes an intended grid-connected solar PV plant that is not located in close proximity to the GRIDCo network. Within the context of this analysis, therefore, a need could arise for the construction of a transmission line of up to a length of 5 km.

The second scenario is a cross-border transmission line linking Ghana with Burkina Faso. Power trade between the two countries, from VRA to SONABEL, is approximately 10 MW on the existing five cross-border transmission lines. As mentioned in Sections 1.0 and 3.9, a 225 kV transmission line is currently under construction to increase power trade between the two countries, and there is also a planned 225 kV line from the same Bolgatanga substation, through Burkina Faso to Mali. Upon completion, these two lines combined are expected to wheel approximately 400 MW of power in the medium- to long-term. Given SONABEL's contract with VRA for the supply of 100 MW of power through the new line (upon completion), there is sufficient vacant grid capacity to be accessed by IPPs, using technologies like solar PV.

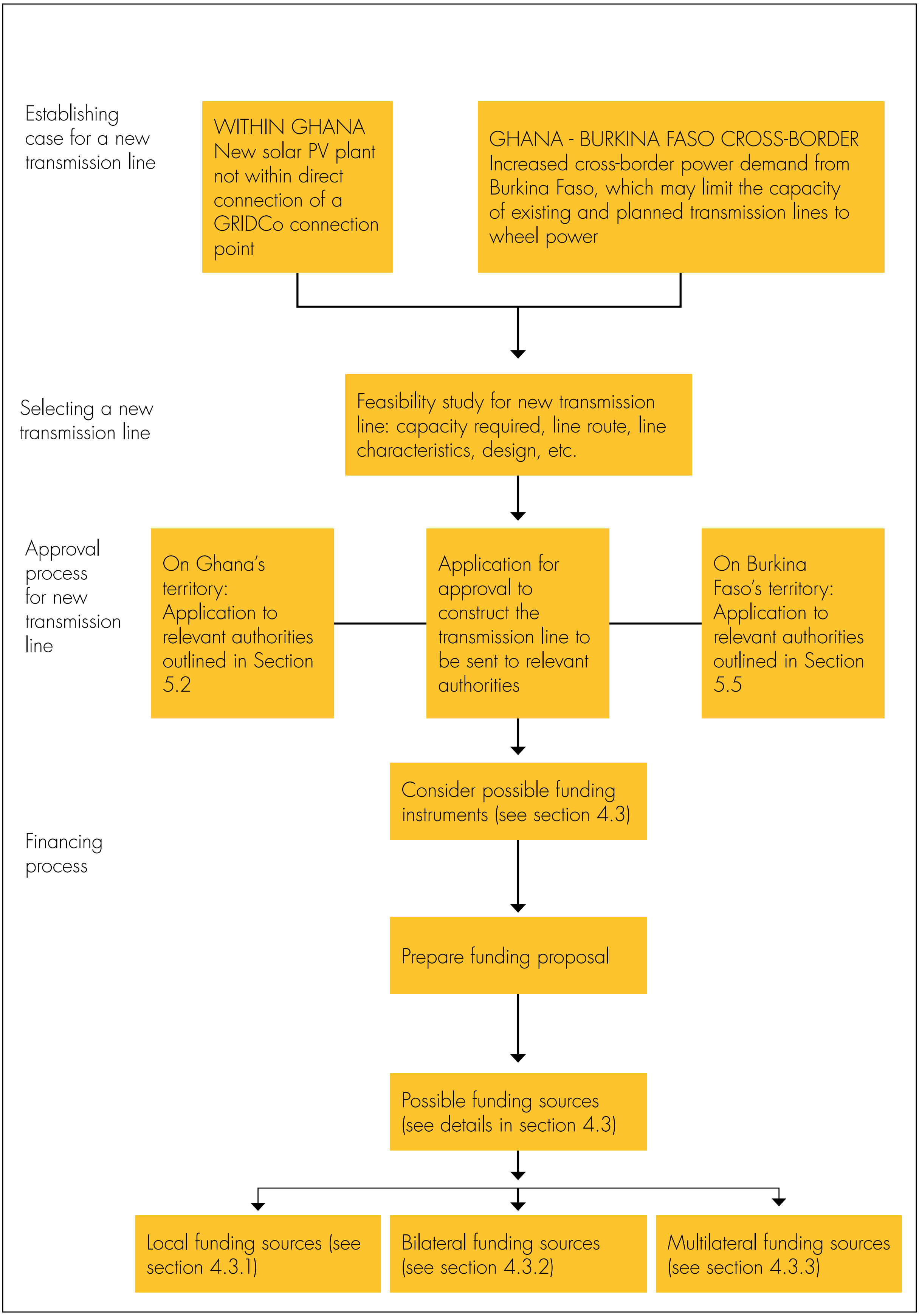
Beyond the two 225 kV lines planned and under construction, there are two drivers that could call for the construction of a new transmission line. The first is economic (if it is cheaper to construct a new transmission line) and the second is technical (in case there is not enough capacity on the existing line). In the short- to medium-term, the economic driver appears to be more relevant. A new transmission line could connect to the 225 kV substation at Bolgatanga in Ghana, or link directly to a line in Burkina Faso.

If it becomes necessary to construct a new line, Figure 6.1 shows the steps required towards selecting, seeking approval for, and financing new transmission lines, based on the analysis provided in chapters 3, 4 and 5 of this Strategy Proposal.

Once the need for a new transmission line has been established, a feasibility (or prefeasibility) study is required to establish system design parameters and other important factors, such as line route and space availability. When the feasibility study is completed, the next stage is to obtain a permit application from the relevant authorities. To construct a local transmission line in Ghana, approval is required from the Energy Commission and the EPA, as detailed in Section 5.2. For a cross-border line between Ghana and Burkina Faso, approval for part of the line running through Ghana is sought from authorities in Ghana, whereas the line segments located in Burkina Faso are to be approved by SONABEL. If the project is pursued under the umbrella of the WAPP initiative, WAPP and ERERA will facilitate the process.

Once approval is obtained, the developer needs to find financing for the project. Details of relevant financial instruments are presented in Sections 4.2 and 4.3. This Strategy Proposal assumes that investment requirements for constructing new transmission lines for solar energy projects will qualify for support under schemes that are oriented towards promoting clean and renewable energy, international and intra-regional trade (in particular South–South), as well as general infrastructure investments in the energy sector.

Figure 6.1: Steps to select, seek approval for, and finance cross-border transmission lines



6.1 Suggestions for further research and analysis

It was beyond the scope of this Strategy Proposal to establish how much variable renewable energy Ghana's grid can accommodate in the medium- to long-term. Consequently, the authors propose that an academic study be conducted that models a far-future scenario for ascertaining what transmission network upgrades will be required in order to haul renewable power from Ghana to neighbouring countries without compromising the grid.

Further, a regionally tailored capacity-building programme, including a training course via e-learning and compulsory face-to-face meetings, is required to foster awareness, understanding and capacity of stakeholders in the energy sector, to harness opportunities from regional integration of (renewable) energy markets under WAPP. Such capacity-building programme would need to focus on potential and opportunities at regional level, related technical requirements, regulatory tools and processes, WAPP support schemes, and regional support funds and financing options. It could be linked to and complement similar regional activities by the Africa Renewable Energy Initiative (AREI) and IRENA-ECREEE.

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Appendices

Appendix A: Attendees to GE-TOP Ghana Financial Working Group

15 July 2015 – Energy Commission, Accra

SN	Name	Institution
1	Noah Gaikpah	Ghana Investment Promotion Council
2	Seth Agbeve Mahu	Ministry of Power
3	Kwabena Out-Danquah	Energy Commission
4	Joshua B. Mabe	Japan International Cooperation Agency
5	Dennis Apreku	Ministry of Finance
6	Osei Oteng-Asante	Ministry of Finance
7	Salifu Addo	Energy Commission
8	Yawovi Negbegble	ECOWAS Regional Electricity Regulatory Authority
9	Kennedy Amankwa	Energy Commission
10	Prosper A. Amuquandoh	Energy Commission
11	Vitus Tankpa	Energy Commission
12	Joseph Essandoh-Yeddu	Energy Commission
13	Lena Dzifa Mensah	The Energy Center
14	Julius Nyarko	Energy Commission
15	David Ato Quansah	The Energy Center
16	Ebenezer Nyarko Kumi	University of Energy and Natural Resources
17	Francis Kemausuor	The Energy Center

Appendix B: Attendees to GE-TOP Ghana Technical Working Group

16 July 2015 – Energy Commission, Accra

SN	Name	Institution
1	Jabesh Amissah-Arthur	Arthur Energy Advisors
2	Doris Dushie	Environmental Protection Agency
3	Charles Dzikunu	Northern Electricity Distribution Company
4	Ato Mensah	Northern Electricity Distribution Company
5	Gabrielle Osei	University College of London
6	Noah A. Gaikpa	Ghana Investment Promotion Council
7	Vitus Tankpa	Energy Commission
8	Joyce Ocansey	Energy Commission
9	Godfred Mensah	Electricity Company of Ghana
10	Yawovi Negbegble	ECOWAS Regional Electricity Regulatory Authority
11	Ethel Mensah	Energy Commission
12	Joseph Essandoh-Yeddu	Energy Commission
13	Seth Agbeve Mahu	Ministry of Power
14	Salifu Addo	Energy Commission
15	Kwabena Otu-Danquah	Energy Commission
16	Lena Dzifa Mensah	The Energy Center
17	David Ato Quansah	The Energy Center
18	Edward Quarm	The Energy Center
19	Ebenezer Nyarko Kumi	University of Energy and Natural Resources
20	Francis Kemausuor	The Energy Center
21	Samuel Danquah	The Energy Center
22	George Appiah	The Energy Center
23	Khouru Boutrous	The Energy Center

Appendix C: Attendees to third national GE-TOP Ghana Workshop

3 September 2015 – Institute of Statistical Social and Economic Research (ISSER), University of Ghana, Legon, Accra

NAME	INSTITUTION
Wisdom Togobo	Ministry of Power
Ethel Togobo	Wesley Girls High School
Seth Mahu	Ministry of Power
Lennart Kuntze	United Nations Environment Programme
Simon Bawakyillenuo	Institute of Statistical Social and Economic Research
Doris Dushie	Environmental Protection Agency
James Sukjoo Kim	Make Group
Soon Ji Hun	Make Group
Hye Jin Jang	Make Group
Hae Lin Kin	Make Group
Abdoulaye Sawadogo	SONABEL (Burkina Faso)
Emmanuel Kwaku Anto	Department of Electrical Engineering
Gabriel Takyi	The Energy Center
Dennis Apreku	Ministry of Finance
Papa Bartels	Ministry of Trade and Industry
Noah A. Gaikpah	Ghana Investment Promotion Council
Peter Dery	Ministry of Environment, Science, Technology and Innovation
Adolf Ashong	Energy Commission
Adam Joseph	Energy Commission
Jabesh Ammissah-Arthur	Arthur Energy Advisors
Godfred Mensah	Electricity Company of Ghana
Danladi Bukari	Volta River Authority / Northern Electricity Distribution Company
Gbemu Edmund	Volta River Authority / Northern Electricity Distribution Company
K.A Otu-Danquah	Energy Commission
Joseph Essandoh-Yeddu	Energy Commission
Josephine Oduro-Asare	Energy Commission
Oumar Bangoura	ECOWAS Regional Electricity Regulatory Authority
Osei Oteng-Asante	Ministry of Finance
Ekow Coleman	Ministry of Finance
Lena Dzifa Mensah	The Energy Center
Francis Kemausour	The Energy Center
Samuel Danquah	The Energy Center
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Reginald Quansah	School of Public Health
Ebenezer N. Kumi	University of Energy and Natural Resources
George Appiah	The Energy Center
Khouru Boutrous	The Energy Center
Marcus Amosah Henaku	The Energy Center

Appendix D: Candidate locations based on available land within 5 km of MV and HV network

Node	Subnode	Area (acres)	Minimum distance to High Voltage (km)	Minimum distance to Medium Voltage (km)	Maximum plant size (MW)
A	A1	966	0	97	140
B	B2	96.6	4.2	71	14
	B3	172.5	2.9	63	25
C	C4	1035	0	66	150
	C5	586.5	0	71	85
		48.3	0	14	7
		1035	0	31	150
		6.9	5	59	1
		27.6	1.7	54	4
		48.3	2.1	55	7
		103.5	1.2	39	15
		96.6	0.8	32	14
	C6	55.2	3	0	8
D	D7	69	34	0	10
E	E8	69	15	0	10
	E9	241.5	0	4	35
	E10	586.5	0.5	0	85
		345	0	16	50
	E11	690	4	0	100
	E12	966	4.7	0	140
		6.9	7	4.7	1
		1035	0	12.7	150
		241.5	0.3	19.3	35
		1035	0	14	150
		13.8	0	21.2	2
	E13	1035	0	8.8	150
	E14	1035	0	7	150
	E15	828	4.4	20	120
		1035	0	0	150
	E16	276	4.1	24.1	40
	E17	345	2.2	9	50
F	F18	69	27.7	0	10
G	G19	69	29.2	0	10

Node	Subnode	Area (acres)	Minimum distance to High Voltage (km)	Minimum distance to Medium Voltage (km)	Maximum plant size (MW)
H	H20	1035	0	28	150
		552	0	34	80
		1035	0	33	150
	H20	1035	0	32.8	150
		1035	0	32.6	150
		1035	0	36.7	150
		621	0	62.4	90
		586.5	3.3	72.6	85
		103.5	3.9	62.7	15
	H21	207	1.6	33	30
	H22	69	15.4	0	10
		69	49	0	10
		69	25	0	10
	H23	414	4	25	60
	H24	276	4	75	40
	H25	1035	0	78.5	150
		483	2.2	80	70
J	J26	172.5	4.6	32.2	25
		55.2	4.5	33.1	8
	J27	69	16.4	0.6	10
	J28	1035	0	0	150
		1035	0	0	150
	J29	276	0	0	40
	J30	1035	0	0	150
	J31	1035	0	0	150
		1035	0	20.5	150
		1035	0.1	20.9	150
	J32	690	0	9.8	100
		27.6	0.5	10.1	4
	J33	276	0	13	40
		1035	0	13.6	150
	J34	20.7	0.3	42.3	3
		1035	0.3	36.4	150
		345	4.3	35.6	50
		138	4.4	35.5	20
	J35	172.5	3.8	27.3	25
		103.5	3.8	27.9	15

Node	Subnode	Area (acres)	Minimum distance to High Voltage (km)	Minimum distance to Medium Voltage (km)	Maximum plant size (MW)
J	J36	207	3.5	48.7	30
		1035	0	38.5	150
		276	3.5	43.8	40
		1035	0	38.3	150
	J37	483	2.7	44	70
		621	3.5	32.7	90
		96.6	2.4	34	14
	J38	1035	1.6	0	150
		69	21.8	4.3	10
	J39	621	0.3	34.7	90
	J40	1035	0	0	150
		276	2.8	38.5	40
		1035	0	42.1	150
		1035	2.3	11	150
	J41	138	4.3	17.2	20
	J42	1035	1.2	21	150
	J43	1035	0	19.6	150
	J44	103.5	4.5	29.5	15
K	K45	69	27.4	2.8	10
		69	29	0	10
	K46	69	25.8	2.8	10
L	L47	69	17.1	0.5	10
		69	17.9	0	10
		69	17.8	0	10
	L48	69	12.7	0.6	10
		69	8.1	0	10
	L49	1035	0	0.5	150
	L50	69	5.2	1.9	10
M	L51	69	53.1	0	10

Appendix E: Generation schedule for 2016 – Base case (Scenario 1)

Power plant	Installed capacity	Output (MW)
Conventional		
Akosombo**	1020	420
Kpong GS	140	70
KarPower, Tema	225	120
CENIT	110	85
TT1PP	110	85
KTPP	220	100
Asogli	180	180
Bui	330	110
TICO, TAPCO	600	400
KarPower, Takoradi	225	120
APR	240	0
Aggreko	140	0
Non-conventional		
SW Solar PV	100	75
SE Wind Turbine	225	180

** Reserve Margin of 60 MW on the Akosombo Hydro Plant.

Appendix F: Generation schedule for 2016 with a total of 150 MWp solar PV in the north (Scenario 2)

Power plant	Installed capacity	Output (MW)
Conventional		
Akosombo	1020	420
Kpong GS	140	70
KarPower, Tema	225	120
CENIT	110	85
TT1PP	110	85
KTPP	220	100
Asogli	180	180
Bui	330	110
TICO, TAPCO	600	300
KarPower, Takoradi	225	120
APR	240	0
Aggreko	140	0
Non-conventional		
NW Solar PV	50	50
NE Solar PV	100	100
SW Solar PV	100	100
SE Wind Turbine	225	100

** Reserve Margin of 60 MW on the Akosombo Hydro Plant.

Appendix G: Short circuit levels

IEC 60909 SHORT CIRCUIT CURRENTS   TUE, JUL 14 2015 14:40

GRIDCO 2016

2016 LF END OF YEAR OFF-PEAK LOADING CONDITIONS

```
VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.100 seconds

                    <-SCMVA-> <-Sym I''k rms--> <-ip(B)-> <-ip(C)-> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                              /I/    AN(I)    /I/     /I/     /I/     /I/     /I/
X--------- BUS ---------X     MVA     AMP    DEG     AMP     AMP     AMP     AMP     AMP
 1280 [TAM-TM28   161.00] 3PH    420.10   1506.5  -67.60   2779.5   3288.3    49.3   1506.5   1507.3
                          LG     487.08   1746.7  -70.06   3334.7   3840.4   110.2   1746.7   1750.1
THEVENIN IMPEDANCE, X/R  (OHM)   Z+:/67.872/67.602, 2.42637  Z-:/67.890/67.589, 2.42487  Z0:/40.405/78.357, 4.85330
```

```
VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.100 seconds

                    <-SCMVA-> <-Sym I''k rms--> <-ip(B)-> <-ip(C)-> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                              /I/    AN(I)    /I/     /I/     /I/     /I/     /I/
X--------- BUS ---------X     MVA     AMP    DEG     AMP     AMP     AMP     AMP     AMP
 1290 [BOL-BG29   161.00] 3PH    309.41   1109.6  -67.99   2057.9   2394.3    18.8   1109.6   1109.7
                          LG     341.60   1225.0  -69.53   2321.2   2638.0    39.2   1225.0   1225.6
THEVENIN IMPEDANCE, X/R  (OHM)   Z+:/92.152/67.991, 2.47398  Z-:/92.168/67.982, 2.47285  Z0:/66.341/73.841, 3.45115
```

```
VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.100 seconds

                    <-SCMVA-> <-Sym I''k rms--> <-ip(B)-> <-ip(C)-> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                              /I/    AN(I)    /I/     /I/     /I/     /I/     /I/
X--------- BUS ---------X     MVA     AMP    DEG     AMP     AMP     AMP     AMP     AMP
 1345 [WA         161.00] 3PH    315.90   1132.8  -69.75   2153.3   2407.6    17.7   1132.8   1133.0
                          LG     503.43   1805.3  -64.09   3186.7   3406.2     0.0   1805.3   1805.3
THEVENIN IMPEDANCE, X/R  (OHM)   Z+:/90.260/69.753, 2.71099  Z-:/90.278/69.743, 2.70966  Z0:/20.297/-54.609, 1.40761
```

```
VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.100 seconds
<-SCMVA-> <-Sym I''k rms--> <-ip(B)-> <-ip(C)-> <DC Ib(C)> <Sym Ib-> <Asym Ib>
/I/   AN(I)   /I/   /I/   /I/   /I/   /I/
X--------- BUS ---------X   MVA   AMP   DEG   AMP   AMP   AMP   AMP   AMP
1346 [NWPV   161.00] 3PH   302.83   1086.0   -69.66   2061.4   2303.3   14.6   1086.0   1086.1
LG   487.76   1749.1   -63.41   3063.1   3238.6   0.0   1749.1   1749.1
THEVENIN IMPEDANCE, X/R  (OHM)   Z+:/94.154/69.658, 2.69729  Z-:/94.171/69.649, 2.69602  Z0:/23.652/-56.615, 1.51746
```

```
VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.100 seconds
<-SCMVA-> <-Sym I''k rms--> <-ip(B)-> <-ip(C)-> <DC Ib(C)> <Sym Ib-> <Asym Ib>
/I/   AN(I)   /I/   /I/   /I/   /I/   /I/
X--------- BUS ---------X   MVA   AMP   DEG   AMP   AMP   AMP   AMP   AMP
1470 [TUM-TU47   161.00] 3PH   287.32   1030.3   -69.17   1942.4   2199.3   13.6   1030.3   1030.4
LG   470.68   1687.9   -55.71   2737.2   2787.1   1.6   1687.9   1687.9
THEVENIN IMPEDANCE, X/R  (OHM)   Z+:/99.240/69.173, 2.62875  Z-:/99.256/69.164, 2.62758  Z0:/47.556/-48.047, 1.11246
```

```
VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.100 seconds
<-SCMVA-> <-Sym I''k rms--> <-ip(B)-> <-ip(C)-> <DC Ib(C)> <Sym Ib-> <Asym Ib>
/I/   AN(I)   /I/   /I/   /I/   /I/   /I/
X--------- BUS ---------X   MVA   AMP   DEG   AMP   AMP   AMP   AMP   AMP
12861 [NEPV   161.00] 3PH   342.38   1227.8   -68.58   2295.5   2666.2   27.0   1227.8   1228.1
LG   350.28   1256.1   -70.51   2414.0   2701.3   24.9   1256.1   1256.4
THEVENIN IMPEDANCE, X/R  (OHM)   Z+:/83.278/68.578, 2.54878  Z-:/83.295/68.567, 2.54743  Z0:/77.926/74.651, 3.64308
```

Appendix H: Pros and Cons of Financial Instruments

Instrument	Pros	Cons
Grants	• Relatively simple to implement; • Do not require ongoing administration.	• High risk in terms of achieving objectives; • Public sector involvement may lead to poor performance and crowding out of private financing; • Low leverage; • Low return on capital.
Equity (venture capital)	• Pays for itself; • Strong incentives for project viability.	• High returns are needed to compensate for the risk; • Low levels of leverage; • Developed financial markets are needed.
Senior debt	• Obligation to repay creates incentives for making project viable; • Repayment of principal frees funds for further support to renewable energy projects; • Used to increase commercial finance institutions' involvement in renewable energy projects.	• High transaction costs due to the need for due diligence to verify the ability of the project to repay the loan; • Leverage is limited and may crowd out potential private providers of debt.
Subordinated debt	• High level leverage; • Crowd in senior debt by allowing projects to meet acceptable risk criteria for lenders.	• Usually high transaction cost because generally custom designed for each project.
Asset -backed securities	• Lower tenor and possibly lower cost than bank financing; • Ready means to refinance projects, freeing developer funds for further investments; • Potential to bundle projects together in a single security can reduce risk and, therefore, financing cost; • Can be a good tool for expanding capital market offerings, given the guaranteed off-take and relative low risk of some renewable energy technologies.	• Sophisticated markets required, to be able to analyse and price the risk associated with this type of security.

Instrument	Pros	Cons
Individual guarantees	• Guarantees are targeted to specific risks deterring private investment, thereby minimizing the risk of market distortions; • Effective means of crowding in private investment; • A high degree of leverage, as a relatively small commitment of funds can mobilize significant quantities of private investment; • No need for large up-front payment, making it easier to obtain political approval.	• High transaction cost, which generally are custom-designed for each project; • Significant risk is transferred to public financing agencies but with only limited ability to control these risks; • Appropriate accounting for and approval of the resulting contingent liabilities is required, but assessing the associated risks may be complicated; • Ability to avoid up-front funding may encourage excessive use of guarantees for political reasons and favoured projects.
Resource insurance	• Targeted on specific risks deterring private investment, thereby minimizing the risk of market distortions; • Effective means of crowding in private investment; • A high degree of leverage can be achieved, as a relatively small commitment of funds can mobilize significant quantities of private investment.	• A large number of projects on different locations is required for the insurer to be able to diversity its risk exposure away from any one project; • A large database of historic performance is required for the insurer to be able to assess price risks. For this reason, resource insurance either needs multinational insurers or large and sophisticated domestic financial markets combined with large volumes of existing renewable energy technology projects.
Result-based financing (payment against outputs)	• Linking payment of grants and subsidies to results creates strong incentives on developers to deliver; • Availability of local credit to implementing entities is boosted, if the funder of result-based financing is credible; • Crowding-out effects are limited, as developers must still arrange a large part of the up-front financing.	• The need for up-front financing by the developer means that results-based financing doesn't necessarily overcome financial market barriers – it may be difficult to obtain loans against expected future payments; • For small-scale projects, the cost of verification can be extremely high; • Without careful definition of the required outputs, incentives can be distorted.

Instrument	Pros	Cons
Result-based financing (contingent project development grants)	• RBF can leverage private financing by supporting the development of projects to a stage where private investors are willing to participate; • The use of loans that will be converted to grants provides incentives to developers to complete projects in a timely fashion; • The use of grants that will be converted to loans means developers are more willing to take on marginal projects, knowing that the costs of pre-investment activities are covered if the project is unsuccessful.	• The use of loans that will be converted to grants increases the risk for developers if the project is unsuccessful. • The use of grants that will be converted to loans can reduce incentives to complete projects of marginal viability.
Carbon financing	• A possible means of obtaining up-front financing secured against carbon revenues; • Used to refinance projects, thus freeing up resources for the development of new projects.	• There is only a small number of potential buyers of certified emission reductions; • Significant risk is transferred to the public financing agencies, if purchases are made ahead of project registration (under the Clean Development Mechanism) or if carbon revenues are uncertain; • The process of realizing carbon revenues can be complex and costly, particularly for first-of-a-kind projects, and reliance on these may delay project development substantially; • Front-end loading of carbon finance revenues has been difficult to realize in practice, given the regulatory and operational uncertainties of these projects; • Financing only covers part of the costs, and amounts received depend on carbon prices.

Instrument	Pros	Cons
Portfolio guarantees and loss reserves	• In the case of group projects, the reserves required against default can be reduced as a result of the diversification of risk compared to individual guarantees, allowing greater leverage; • Transactions costs for each project are reduced, as any project meeting the required criteria can be included in the guaranteed portfolio.	• A large number of similar projects are required for this funding to be effective. Project developers may include inappropriate projects in the portfolio, increasing the risk exposure of public financial agencies. Ideally, this requires a good database of similar projects to be able to assess the risk of guarantee of reserves being utilized; • Requires good accounting of contingent liabilities and may create scope for abuse; • Sophisticated institutional capacity is required to manage such programmes.
Aggregation	• The transaction costs for such projects are reduced as a result of the standardization of documentation.	• Commitment from developers, off-takers and financiers is required, so they do not amend standard documents; • A large number of similar projects is required in order for aggregation to be effective.

Source: (World Bank and Climate Investment Fund, 2013)

Appendix I: Exhibits required for the application process[15]

Exhibit label	Exhibit name	Description
Exhibits for first stage of the process (provisional license)		
Exhibit C1	Scope of operation	Written description of the operational nature of the applicant's business.
Exhibit C2	Service coverage areas	List and map of cities, towns and rural areas of service provision.
Exhibit C3	Company registration	Evidence of registration from the Registrar General's Department, including: Certificate of Registration, Certificate to Commence Business and Regulations 8 to 82; Second schedule to the Companies Code, 1963 (Act 179).
[…]		
Exhibit C17	Commercially sensitive information	The Commission may make the information included in the application public. If the applicant considers information contained in an application to be commercially sensitive, the applicant should clearly identify such information and state the reasons why the information should be regarded as commercially sensitive.
Exhibit C18	Description of NITS	Description of the National Interconnected Transmission System.
Exhibits for acquisition of site clearance permit (second stage)		
Exhibit C19	Site analysis	Detailed site analysis for the siting of electric power transmission and distribution facilities.
Exhibit C20	Land conveyance agreement	Approved documentation of proof of title to land, site plan, and relevant municipal permits for construction (i.e. Town & Country Planning Permit) etc.
[…]		
Exhibit C23	Environmental disclosure	Environmental Impact Assessment (EIA) report and an Environmental Permit or Permanent Environmental Certificate issued by the Environmental Protection Agency (EPA).
Exhibit C24	Site layout and right-of-way	Detailed site layout and "right-of-way" drawings. Programme for compensation payments (where relevant).
Exhibits for acquisition of construction work permit (second stage)		
Exhibit C25	Implementation agreements	Copies of licences, Memorandum of Understanding (MoU), etc. with agencies relevant to the implementation.
Exhibit C26	Detailed implementation schedule	Detailed timelines for the specific activities that must be performed to produce the various project deliverables, establishing interdependences and sequencing.
[…]		
Exhibit C35	Receipt of licence fee	Evidence of payment of the appropriate prevailing licence fee to the Energy Commission.

15 For the purposes of brevity only the key, selected few of the applicable exhibits are shown in this table. Details of all the exhibits required are available from the Application Manual (Energy Commission, 2012).

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