Technical Report

Reducing Mercury Emissions from Coal Combustion in the Energy Sector in Vietnam

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Acronyms and Abbreviations

µg	microgram
APC	Air pollution control device
As	arsenic
ASTM	American Society for Testing and Materials
BAT/BEP	Best Available Techniques and Best Environmental Practices
BOT	Build–operate–transfer
Br	bromine
Ca	calcium
CEM	Centre of Environment Monitoring
CEMS	Continuous Emission Monitoring System
CFB	Circulating fluidized bed
CIDP	Coal Industry Development Plan to 2020, vision to 2030 (Decision no 403/QD-TTg in February 14th, 2016 by Prime Minister)
Cl	chlorine
DONRE	Deparment of Natural Recources and Environment (in each city or province)
ESP	Electrostatic precipitator
EVN	VietNam Electricity
FGD	Flue gas desulfurization
Hg	mercury
Hg^0	elemental mercury
kWh	kilowatthour
mg/kg	milligram per kilogram
MOIT	Ministry of Industry and Trade
MONRE	Ministry of Natural Recources and Environment
MW	megawatt
Na	sodium
NAP	National Action Plan to reduce mercury emissions from coal-power

	plants
Nm^3	normal cubic meter
NOx	nitrous oxides
PC	Pulverized coal
PCD	Pollution Control Department
PDP VII	Power Plant Development Plan from 2015-2020, vision to 2030 (Decision no 1208/QD-TTg in July 21st, 2011 by Prime Minister)
PDP VII (revised)	Power plant Development Plan from 2015-2020, vision to 2030 (revised by Decision no 428/QD-TTg in February 18th, 2016 by Prime Minister)
PM	Particulate matter
PVN	PetroVietnam
RPD	Relative Percent Difference
Se	selenium
SO_2	sulfur dioxide
UBC	Unburned carbon content
UNEP	United Nations Environment Programme
US DOS	Unites States Department of State
US EPA	United States Environmental Protection Agency
VEA	Vietnam Environment Administration
VESC	Vietnam Energy Association
Vinachemia	Vietnam Chemicals Agency
Vinacomin	Vietnam National Coal - Mineral Industries holding corporation limited

I. Introduction of Project

I.1. Background

Emissions of mercury (Hg) from thermal power stations are a subject of increasing concern because of their toxicity, volatility, persistence, and long-range transport in the atmosphere. Hg has the tendency for bioaccumulation as methyl Hg and thus enters the food chain. Once released into the environment, Hg contaminates soil, air, surface and ground water. Hg is a neurotoxin and causes adverse health effects. Hg is a global pollutant that is emitted, deposited, and reemitted on both a local and global scale in both terrestrial and marine environments.

Toxic Hg emitted from coal-fired power plants originates from the Hg present in coal. Burning of large quantity of coal for power generation makes it the second largest anthropogenic source of Hg emissions at a global level.

The Pollution Control Department (PCD) and United Nations Environment Programme (UNEP) have entered into a Small-Scale Funding Agreement to undertake a project titled “Reducing Mercury Emissions from Coal Combustion in the Energy Sector in Vietnam”. In accordance with UN Environment Governing Council priorities, identified in Decisions 24/3 and 25/5, and with the goal of reducing Hg emissions from the coal partnership area under the UN Environment Global Mercury Partnership, the project aims to present national information on:

- coal types and coal usage;
- characterize coal-fired power sector in Vietnam;
- develop an emission inventory for the coal fired energy sector; and
- present other relevant information to improve accuracy of future emission inventories for the sector.

I.2. Project objectives

The above co-operation has a number of specific objectives:

- Assessment of the Hg content of coals fed to coal fired power plants; this includes in-country coals as well as imported coals;
- Provide a forecast for coal consumption (up to 2025);
- Characterization of existing coal-fired power plants with regard to electricity production and air pollution control technologies;
- Direct measurements of Hg in the flue gas of selected power plants; plants should be selected based on the capacity, vintage, fuel type, emission

control systems, including speciation of Hg in flue gas and partitioning of Hg in the combustion products;

- Estimation of the Hg emission factors based on the information that was gained during this project and comparison with relevant published emission factors;
- Calculation of Hg emissions from the coal fired power sector in Vietnam based on developed emissions factors;
- Capacity building activities and information seminar; and
- Development of a proposal for a national plan on how to reduce emissions from the coal-fired power sector.

I.3. Main Tasks

I.3.1. Collection of Coal Information

Information was collected on the amount of coal consumption (for electricity production) by coal source and by power plants; available information on coal analysis on dry basis (including proximate and ultimate analysis, heating value, as well as Hg, arsenic [As], selenium [Se], chlorine [Cl], bromine [Br], calcium [Ca], and sodium [Na] content).

Information was collected to estimate coal use for electricity generation for the target year 2025.

Analyses of untreated coal samples in Vietnam:

1. Collection of coal samples from 8 coalfields in Vietnam (with 37 samples) and from 6 power plants (with 33 samples) – 70 samples in total.

2. Samples were analyzed for determination of Hg, As, Se, Na, Ca, Br, and Cl content. Analyses were inter-calibrated on 5 coal samples.

I.3.2. Collection of Power Plant Information

Coal power plant information was collected on existing power plant capacity and electricity generation by coal combustion, including the approximate locations of power plants; projections on power plant capacity and electricity generation for the target year 2025.

Information was collected on any existing configuration of air pollution control equipment and its typical operational efficiency.

Hg emission was monitored at 3 selected power plants for solid and gaseous sampling according to internationally accredited methods.

Measurements were carried out on one boiler unit of a power plant (representative unit size for Vietnam).

In addition to Hg measurement at each power plant, the following samples were collected:

- Coal samples as mined from coalfields and from power plants: 70 samples

- Power plant samples (where Hg stack measurements were done): 23 samples

- Power plant samples (including coal from mill feed and combustion by products): 11 samples

Total number of samples collected and analyzed: 104 samples

I.3.3. Mercury emission inventories and future estimate

- The Hg emission factors were developed based on data sets from selected power plants. The result of Hg emission inventories was presented to a network of experts and stakeholders in Vietnam for comments.

- Development of future Hg emission estimate (scenario up to 2025).

I.3.4. Capacity building and national action plan

Capacity building activities were carried out to inform stakeholders about the goals, progress, and intended outcomes of the project in the context of developing a national action plan in Vietnam. Activities included a Technical Training Workhop on the United States Environmental Protection Agency (US EPA) toolkit and US EPA Method 30B and a National Workshop on Assessing Mercury Emissions from the coal-fired power sector in Vietnam. These workshops were attended by policy makers and representatives from the electricity sector as well as from coal power plants.

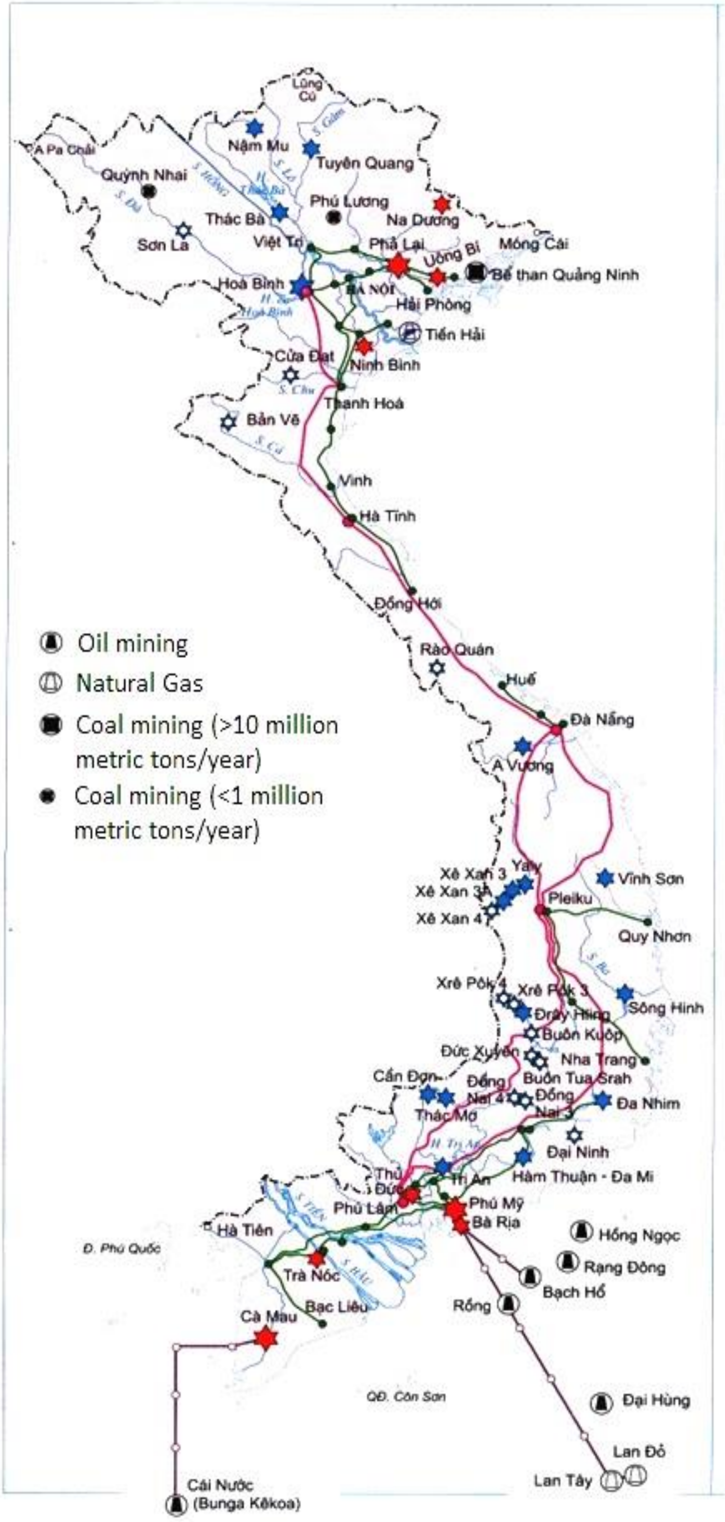
A preliminary plan on how to reduce Hg emissions from the coal-fired power sector was developed. The preliminary plan included target Hg emission reduction from the sector and the timeline for achieving the reduction.

II. Coal Reserve in Vietnam

II.1. Coal mining information

Vietnam is a country with significant potential coal resources. According to the Coal Industry Development Plan (CIDP), Vietnam's total coal resources are about 48.88 billion metric tons, including 2.26 billion metric tons of reserve. The northeastern coal basin (Quang Ninh, Thai Nguyen, Da River, Nong Son) is the biggest reserve with over 2.21 billion metric tons and other local coal minings are about 41.7 million metric tons.

Until December 2015, total coal resources documented in Vietnam were about 46.6 billion metric tons. This included: the northeast coal basin - about 4 billion metric tons; the Red River coal basin - about 42 billion metric tons; local mines -about 164 thousand metric tons and peat mines - 336 thousand metric tons. Total coal resources in confident and reliable exploration are about 1.2 billion metric tons and total coal resources in the estimate and in the forecast, are about 45.2 billion metric tons. Summary of coal resources is shown in Table 1.



(Source: Atlas Vietnam)

Figure 1. Vietnam coal mines location

Table 1. Summary of coal resources (in thousand metric tons)

Area	Total coal resources	Reserve	Total Coal Documented
Dong Bac Coal Basin	6,287,077	2,218,617	4,068,460
Red River Delta Coal Basin	42,010,804		42,010,804
Domestic Coal (Managed by Viet Nam Coal [Vinacomin])	206,255	41,741	164,514
Local Coal	37,434		37,434
Peat Coal	336,382		336,382
Total	48,877,952	2,260,358	46,617,594

Source: CIDP

Total output of coal mining by two methods: open-pit and underground (including 24 surface mines and 49 underground mines) is derived mainly in Quang Ninh, northern Vietnam, with the ratio of 50/50. The share of coal from underground mining has increased from 2014 and is projected to account for 70% of total coal output in 2020. Mines are being modernized through technological innovation, new equipment, and advanced mining techniques. Mechanized underground mining in particular has contributed to the increased productivity and cost savings.

Recently, open coal mining has had the leading role in providing the output of the coal industry. According to the Vinacomin (2011), the output of open mining in recent years accounted for about 55-65% of the entire coal industry. Vietnam has 5 large open mines with the capacity of each mine of about 2 million metric tons of per year (Cao Son, Coc 6, Deo Nai, Ha Tu, Nui Beo), 15 mid-sized open mines with the capacity of each mine from 100 to 1,000 thousand metric tons per year, and small mines with capacity of each mine about 100 thousand metric tons per year.

In addition to open mines, there are more than 30 underground mines in Vietnam. This includes 10 mines with large output of over 1 million metric tons/year: Mao Khe, Nam Mau, Vanh Danh, Hong Thai, Ha Lam, Nga Hai (Quang Hanh), Khe Cham, Khe Tam (Duong Huy), Lo Tri (Thong Nhat) and Mong Duong mine. Most other mines have the average output from 0.5 - 1.0 million metric tons/year. There also are small mines (output <0.5 million metric tons/year) such as Bac Coc Sau, Tay Bac Khe Cham, Dong Vong-Uong Thuong mine, Tay bac Nga Hai. These small mines with narrow mining exploration area and small reserves generally are not capable of increasing their output or mechanizing their mining technology. According to Vinacomin, the amount of raw coal produced from 2003-2010 is shown in Table 2.

Table 2. Total amount of coal produced per year (in million metric tons)

No	Coal	2003	2004	2005	2006	2007	2008	2009	2010	Total
1	Surface mines	12.98	17.33	22.06	26.10	26.78	25.33	25.76	26.52	182.86
2	Underground mining	6.81	9.78	12.48	14.71	16.3	17.6	18.17	20.44	116.32
	Total Coal	19.79	27.11	34.54	40.81	43.11	42.93	43.93	46.96	299.18

Source: Vinacomin, 2011

According to CIDP, the planned output of commercial coal production of the entire sector is as follows:

- In 2020: 47-50 million metric tons.
- In 2025: 51-54 million metric tons.
- In 2030: 55-57 million metric tons.

An overall assessment of the current situation of the mining industry indicates a strong growth trend from 2001. For example, the output of the entire coal mining industry increased significantly from 19.8 million metric tons in 2003 to 46.96 million metric tons in 2010.

II.2. Coal consumption

II.2.1. Coal demand for electricity production

In recent years, coal demand for electricity production accounted for a high proportion of total domestic coal demand. It was 30.8%, 34.1%, 33.5%, 33.5%, and 32.4% in 2005, 2006, 2007, 2008, and 2009, respectively (Vinacomin, 2011). According to the Power Plant Development Plan (PDP-VII), coal demand for coal-fired power plants will be 67.3 million metric tons in 2020 and will rise to 171 million metric tons in 2030.

However, in 2016, PDP-VII (revised) has changed the electricity development plan and coal demand for coal-fired power plants. Coal demand for coal-fired power plants according to PDP-VII (revised) is presented in Table 3.

Table 3. Coal demand for coal-fired power plants up to 2020 and 2030

Targets by PDP VII (revised)	Year		
	2020	2025	2030
Capacity (mega watts [MW])	26,000	47,600	55,300
Coal demand (million metric tons)	63	95	129

Sources: PDP-VII (revised)

Due to the limitations of domestic coal production, there are some new coal-fired power plants such as: Duyen Hai, Long Phu, Song Hau, and Long An which use imported coal.

II.2.2. Coal demand for cement industry

Currently in Vietnam, cement is produced either in blast furnaces or in rotary kilns. A total design capacity of the existing cement factories in 2009 was 57.4 million metric tons of cement per year. The total capacity of the existing cement factories, those under construction, and planned for the period 2012 - 2030 is 140 million metric tons of cement per year.

Arcording to CIDP, coal demand for the cement industry will increase to 6.2 million metric tons in 2020 and continue to increase to 6.9 million metric tons in 2030.

II.2.3. Coal demand for other sectors

In recent years, coal types used in other sectors (metallurgy, fertilizers, chemicals, construction materials industry, etc.) are mainly Anthracite (type: 4b, 5) and brown coal (type: 2b, 4, 5). Total coal consumption in these sectors was 8.27 million metric tons in 2007. It increased to 8.534 million metric tons in 2008 and to 9.64 million metric tons in 2009 with the tendency to increase in recent years. Coal consumption for households was 2.1 million metric tons in 2009 and increased to 7.9 million metric tons in 2010 (Vinacomin, 2011).

Coal demand for these sectors is determined based on the average growth rate through each period in Table 4.

Table 4. Demand for coal for industries per year

No	Industries	Coal demand by year (million metric tons/year)			
		2016	2020	2025	2030
1	Coal-fired power	33.2	64.1	96.5	131.1
2	Fertilizers	2.4	5.0	5.0	5.0
3	Cement	4.7	6.2	6.7	6.9
4	Metallurgy	2.0	5.3	7.2	7.2
5	Others	5.2	5.8	6.1	6.4
	Total	47.5	86.4	121.5	165.6

Sources: CIDP

III. Development of Coal-fired Power Plants in Vietnam

Acording to the PDP VII (revised), until 2030, Vietnam will have 64 coal-fired plants in total with 56.325 MW of total capacity. This number has been by reduced 11 coal-fired plants with 21.795 MW of total capacity compared to PDP VII.

The PDP VII (revised) has two specific goals:

- Firstly, electricity production and imports (in 2020: approximately 265-278 billion kilowatt hours [kWh] and in 2030: around 572-632 billion kWh) will be less than the electricity planning in PDP VII (2020: approximately 330-362 billion kWh, and in 2030: approximately 695-834 billion kWh).

- Secondly, developing electricity production from renewable energy sources (approximately 7% in 2020 and more than 10% in 2030), higher than the electricity planned in PDP VII (2020: 4.5% and in 2030: 6%).

III.1. Capacity and electricity generation

III.1.1 Installed capacity and electricity generation

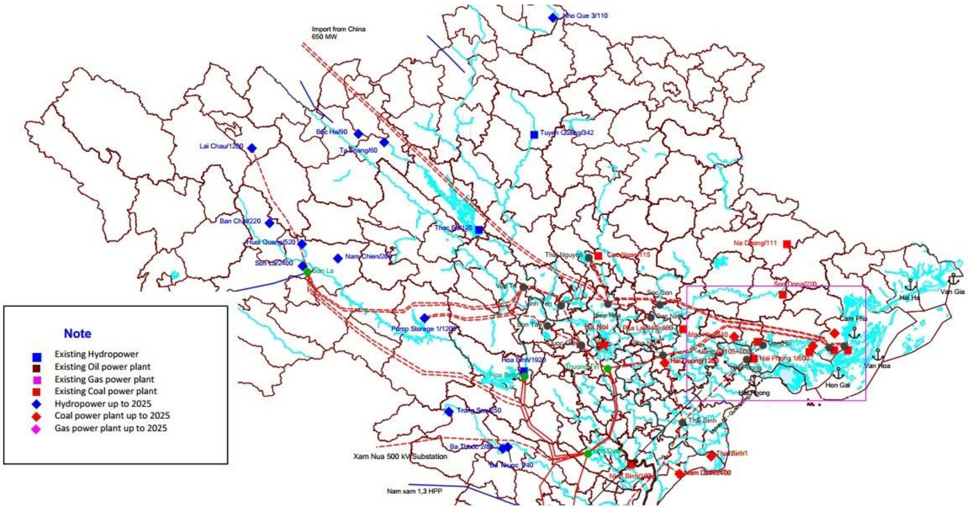
In 2016, 26 coal-fired power plants were operated with 13,810 MW of total capacity. This capacity included 14 VietNam Electricity (EVN) power plants with a total capacity of 8,400 MW; 7 Vinacomin power plants with a total capacity of 1,505 MW; 1 Petrovietnem (PVN) power plant with the capacity of 1200 MW; 4 independent power producer and build-operate-transfer (BOT) small power plants with the total capacity of 2,705 MW. The existing coal-fired power plants in Vietnam are shown in Table 5.

Table 5. The existing coal-fired power plants in Vietnam

No.	Name of coal-fired power plant	Capacity (MW)	Investor
1	Ninh Binh	4 x 25	EVN
2	Uong Bi 5 + 6	50 + 55	
3	Uong Bi 1	1 x 300	
4	Uong Bi 2	1 x 330	
5	Pha Lai 1	4 x 110	
6	Pha Lai 2	2 x 300	
7	Hai Phong 1	2 x3 00	
8	Hai Phong 2	2 x 300	
9	Quang Ninh 1	2 x 300	
10	Quang Ninh 2	2 x 300	
11	Nghi Son 1	2 x3 00	
12	Vinh Tan 2	2 x 600	
13	Duyen Hai 1	2 x 625	
14	Mong Duong 1	2 x 540	
15	Na Duong 1	2 x 50	TKV
16	Cao Ngan	2 x 57.5	
17	Son Dong	2 x 110	
18	Cam Pha 1	1 x 300	
19	Cam Pha 2	1 x 330	
20	Mao Khe	2 x 220	
21	Nong Son	1 x 30	
22	Vung Ang 1	2 x 600	PVN
23	An Khanh 1	2 x 57.5	An Khanh thermal power joint stock company
24	Formosa Dong Nai 1,2,3	3 x 150	Hung Nghiep Formosa Nho Trach Ltd Company
25	Formosa Ha Tinh 1,2,5,6,7,10	6 x 150	Hung Nghiep Formosa Ha Tinh Industrial Ltd Company
26	Mong Duong 2	2 x 620	Electricity Co., Ltd. Mong Duong AES-TKV

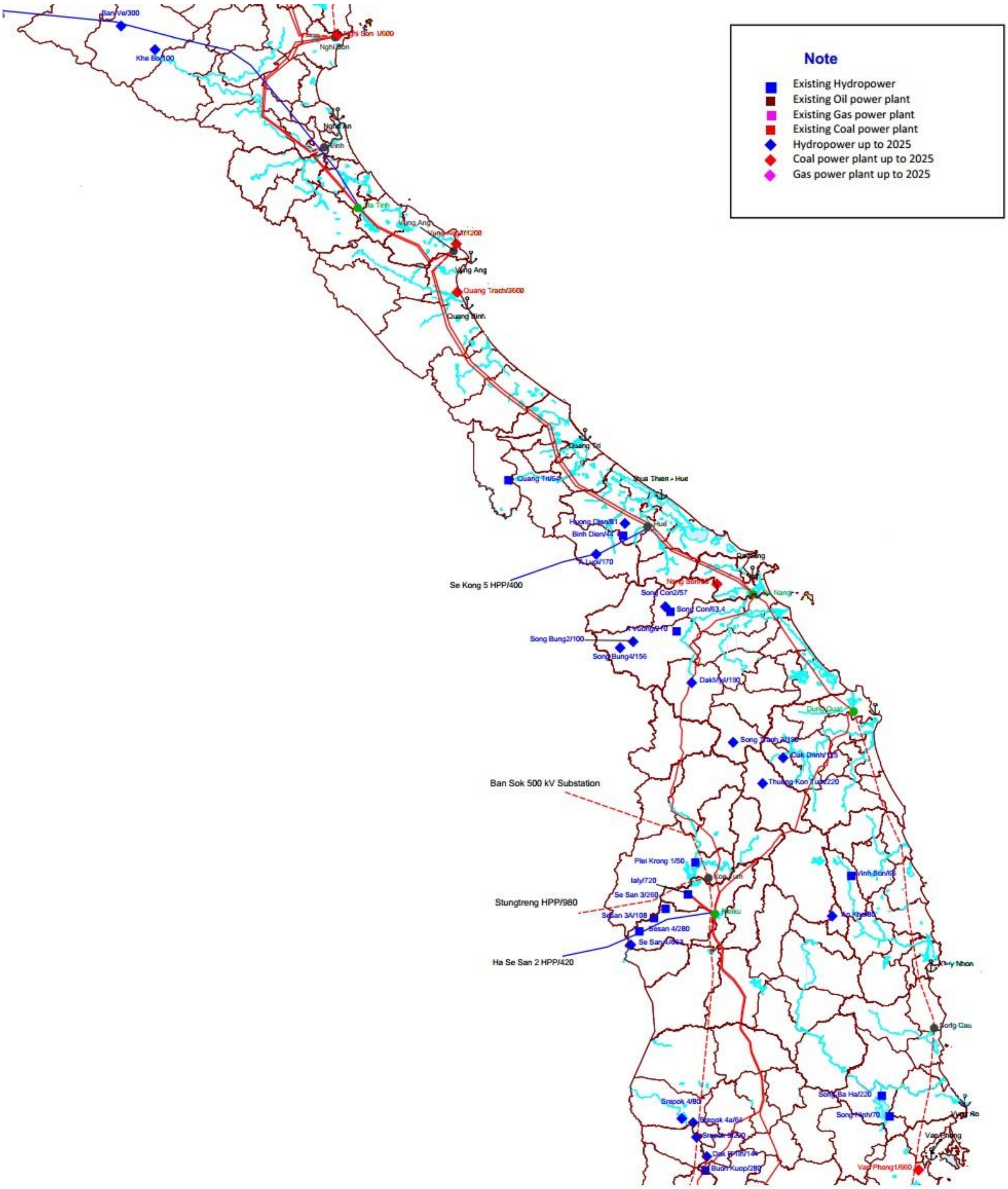
Source: Vietnam Energy Association (VESC)

Coal-fired power plants in Vietnam are located throughout three major regions: northern, central, and southern. The map of coal-fired power plants, including other sources of power, in each region is shown in Figures 2, 3, and 4.



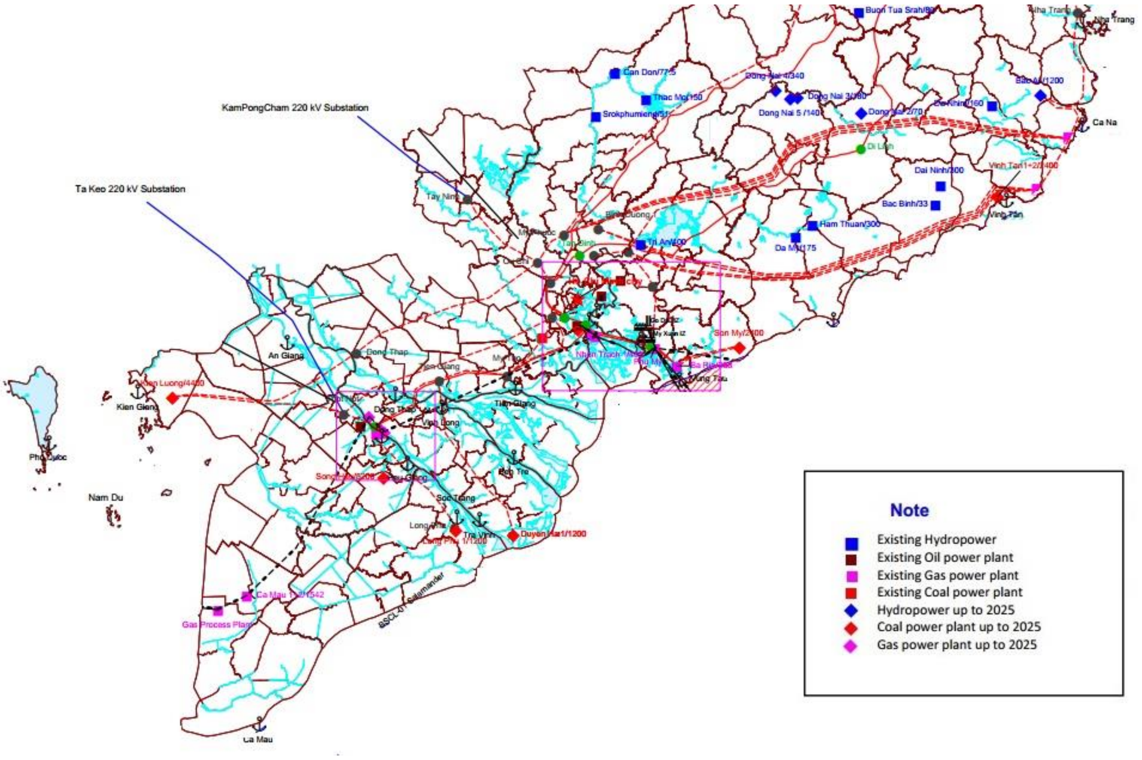
Source: Vietnam Energy Association (VESC)

Figure 2. Map of power plants in Northern Vietnam



Source: Vietnam Energy Association - VESC

Figure 3. Map of power plants in Central Vietnam



Source: Vietnam Energy Association - VESC

Figure 4. Map of power plants in Southern Vietnam

III.1.2. Coal-fired power plants under construction

Arcording to PDP-VII (revised), there are 15 coal-fired plants under construction with a total capacity of 14,575 MW. These plants under construction are shown in Table 6.

Table 6. Coal-fired power plants under construction

	Name of coal-power plants	Capacity (MW)	Investors
1	Duyen Hai 3	2 x 622.5	EVN
2	Vinh Tan 4	2 x 600	
3	Duyen Hai 3	1 x 660	
4	Thai Binh 1	2 x 300	
5	Na Duong 2	11 x 110	TKV
6	Quynh Lap 1	2 x 600	
7	Thai Binh 3	2 x 600	PVN
8	Long Phu 1	2 x 600	
9	Song Hau 1	2 x 600	
10	Quang Trach 1	2 x 600	
11	Thang Long	2 x 300	Thang Long thermal power joint stock company
12	Cong Thanh	1 x 660	Cong Thanh thermal power joint stock company,
13	Vinh Tan 1	1 x 660	A joint venture of TKV, China Southern Power Grid and China Power International Holdings
14	Nghi Son 2	2 x 600	Marubeni – Kepco (Korea)
15	Hai Duong	2 x 600	JAKS Resources Bhd (Malaysia).

Source: Vietnam Energy Association - VESC

In addition, there are 13 plants with 16,540 MW of total capacity in the planning stage, including:

- EVN has 1 plant: Vinh Tan IV expansion (1 x 600 MW).

- PVN has 1 plant: Long Phu III (3 x 600 MW).

-TKV has 2 plants: Cam Pha III (2 x 220 MW); Hai Phong III (2 x 600 MW).

Furthermore,BOT will apply for 9 other plants with a total capacity of 12,500 MW as shown in Table 7.

Table 7.Thermal power plants under construction by BOT

No.	Name of coal-power plants	Capacity (MW)	Investors
1	Nam Đinh 1	2 x 600	TaekWang - Acwa
2	Duyen Hai 2	2 x 600	Janakusa Malaysia
3	Long Phu 2	2 x 600	Tata Power India
4	Vung Ang 2	2 x 600	VAPCO
5	Vinh Tan 1	3 x 660	VTEC
6	Song Hau 1	2 x 1000	Toyo Ink Malaysia
7	Van Phong 1	2 x6 60	Sumitomo Japan
8	Quang Tri 1	2 x 600	EGATI Thailand
9	Vung Ang 3 (Unit 1,2)	2 x 600	Samsung C&T Korea

Source: PDP VII (revised)

III.2. Plans for coal-fired power plants in Vietnam up to 2020 and vison to 2030

Acording to PDP VII (revised) up to 2030, Vietnam will develop the generation capacity of power plants to 129,500 MW and total electricity production and imports will be 572 billion kWh. As a result, coal-fired plants will constitue 42.6% of total electric capacity and 53.2% of total electric power production.

The total capacity and total electricity production for coal-fired power plants up to 2030 are summarized in Table 8.

Table 8. Coal-fired power industry in PDP VII (revised)

Target year	2020	2025	2030
Total capacity (MW)	26,000	47,600	55,300
Total electricity production (billion kWh)	131	220	304
Percentage of total electric power industry (%)	49.3	55.0	53.2
Coal consumption (million metric tons)	63	95	129

Source: PDP VII (revised)

According to the PDP VII (revised), in 2020, the total capacity of coal-fired power plants will increase from 33.4% to 42.7%. Although capacity was decreased by 5.3%, compared to the PDP VII, coal-power plants will still play an important role in the national power system up to 2030. Therefore, while considering the mitigation of coal-fired power, other solutions should be promoted. The PDP VII (revised) proposed the development of renewable power up to 2030 with 21% of renewable sources, included small hydropower, wind power, solar power and biomass power. The details of planned installed power generation for 2020 and 2030 are presented in the Table 9.

Table 9. Projected profile of the installed capacity for 2020 and 2030

TT	Power Sources	Year 2020		Year 2030	
		Capacity (MW)	Percentage (%)	Capacity (MW)	Percentage (%)
1	Hydro	21,600	30.1	21,886	16.9
3	Coal-fired	26,000	42.7	55,167	42.6
4	Thermal (using Compressed Natural Gas)	9,000	14.9	19,037	14.7
5	Renewable	1,650	9.9	27,195	21.0
6	Nuclear	-	-	4,662	3.6
7	Imported	1,750	2.4	1,554	1.2
	Total	**60,000**	**100**	**129,500**	**100**

Source: PDP-VII (revised)

In 2020, compared to PDP VII, coal-fired power capacity in PDP VII (revised) will decrease by 5.3% and by 9% in 2030. Several coal-fired power plants were eliminated such as: Uong Bi III, Hung Yen, Bac Giang, and Kien Luong. Simultaneously, the government also requires developing thermal power plants following the appropriate rate as well as the ability to supply and distribute fuel. The development of renewable power sources is also encouraged; from 5.6% in PDP VII to 9.9% in PDP VII (revised) in 2020.

III.3. Status of air pollution control

Basically, coal-fired power plants in Vietnam use two basic coal combustion technologies, pulverized coal (PC) and circulating fluidized bed (CFB). Air pollution control (APC) systems of thermal power plants mostly use electrostatic precipitators (ESPs) and flue gas desulfurization (FGD) with limestone for PC plants. For plants using CFB technology, the removal of sulfur dioxide (SO_2) from flue gas is accomplished by directly injecting pulverized limestone into the boiler.

By limitation of national technical standards for thermal plant emissions (QCVN 22: 2009), there are no regulations for Hg concentrations in the exhaust gas from thermal power plants. Accordingly, there are no power plants in Vietnam applying technical measures or technological equipment to control Hg emissions. The APC technology currently deployed in coal-fired power plants is presented in detail in the sections below.

II.3.1 Dust emission control by ESP

ESP, shown schematically in Figure 5, is a system for filtering out small size particles from the flue gas flowing through the filter chamber on the principle of charging and separating dust out of gas when they pass through areas with a large electric field. All coal-fired power plants in Vietnam use dry-ESP. Only some of coal gasification plants with capacity smaller than 50 MW use wet-ESP.

Coal-fired power plants in Vietnam using ESP achieve dust removal efficiency of more than 95%.

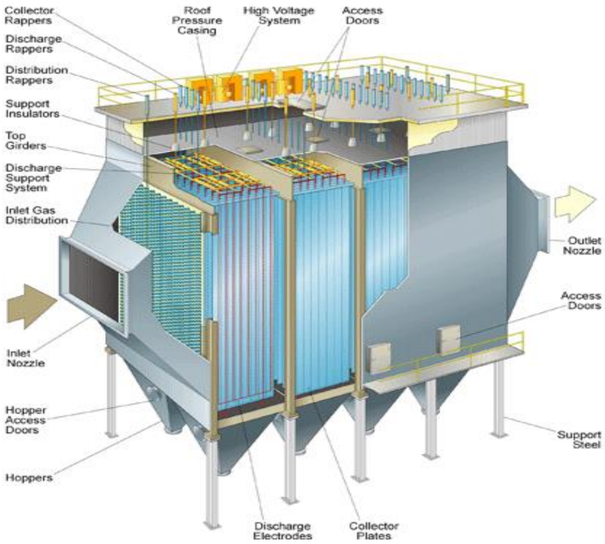


Figure 5. ESP schematic

II.3.2 SO_2 and NO_x control equipment

Almost all PC power plants in Vietnam use wet FGD to control SO_2 emission with the main method using limestone, shown in Figure 6.

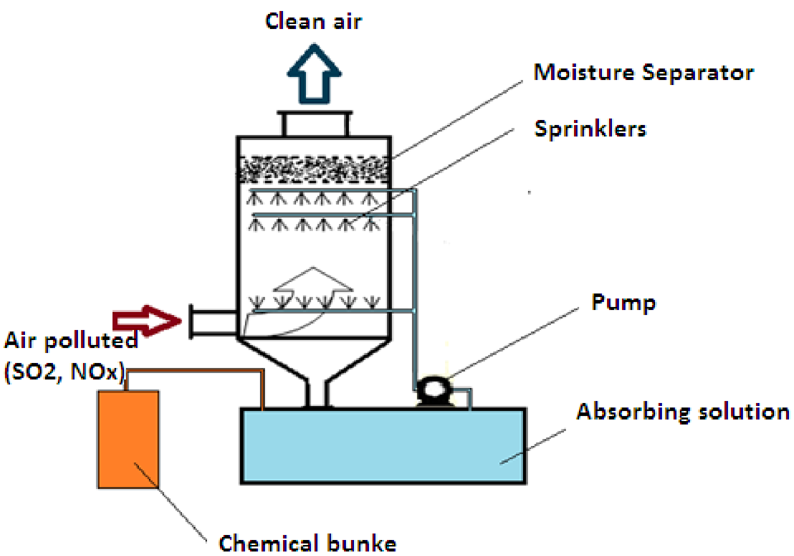


Figure 6. FGD Schematic

Recently, only Duyen Hai 1 and Vinh Tan 2 plants installed seawater a FGD and SCR system with ammonia for SO_2 and nitrogen oxides (NOx) emission control. Summary of emission control equipment being used at coal-fired power plants is given in Table 10.

Table 10. Air pollution control technology at coal-fired power plants in Vietnam

No.	Name of plant	Design capacity (MW)	Operation year	Boiler type	APC installed
1	Pha Lai 1	440	1986	PC	ESP
2	Pha Lai 2	600	2002		ESP + FGD
3	Uong Bi (Unit 5&6)	107	1978	PC	ESP + FGD
4	Uong Bi expanded (Unit 7)	300	2009		ESP + FGD
5	Uong Bi expanded (Unit 8)	330	2013		ESP + FGD`
6	Ninh Binh	100	1976	PC	ESP
7	Na Dương	111	2005	CFB	ESP
8	Cao Ngan	115	2006	CFB	ESP + limestone injection
10	Formosa 1	150	2004		ESP + FGD
9	Formosa 2	150	2011		
11	Hai Phong (Units 1 and 2)	600	2011	PC	ESP + FGD
12	Hai Phong (Unit 3)	300	2014		ESP + FGD
13	Hai Phong (Unit 4)	300	2014		ESP + FGD
14	Quang Ninh	600	2011	PC	ESP + FGD
15	Quang Ninh (Unit 3)	300	2014		ESP + FGD
16	Quang Ninh (Unit 4)	300	2014		ESP + FGD
17	Cam Pha (Unit 1)	330	2010	CFB	ESP + limestone injection
18	Cam Pha (Unit 2)	330	2011		
19	Son Đong	220	2009	CFB	ESP + limestone injection
20	Đong Trieu (Unit 1)	220	2012	CFB	ESP + limestone injection
21	Đong Trieu (Unit 2)	220	2012		
22	Vung Ang 1	600	2013	PC	ESP + FGD
23	Vung Ang 2	600	2014		
24	Nghi Son 1	600	2013	PC	ESP + FGD

No.	Name of plant	Design capacity (MW)	Operation year	Boiler type	APC installed
25	Mong Duong	560	2014	PC	ESP + FGD
26	Vinh Tan 2	1,244	2014	PC	ESP + FGD

Note: some plants may use low-NOx burners for NOx control

Source: General Department of Energy, 2015

IV. Mercury Emissions from Coal-fired Power Plants in Vietnam

IV.1 Previous work

In 2009, the Vietnam Environment Administration (VEA) conducted a small-scale project on risk assessment of mercury emissions in industries, including coal-fired thermal power. The results of Hg concentrations in coal, fly ash, bottom ash and flue gas are shown in Table 11.

Table 11. Hg emissions in Pha Lai and Uong Bi (2009)

Coal-fired plant	Hg concentration				
	Coal (mg/kg)	Fly ash (mg/kg)	Bottom ash (mg/kg)	Flue gas (µg/Nm^3)	Ambient air (µg/Nm^3)
Pha Lai	0.05-0.17	0.40-1.64	0.31	0.25-0.48	0.07-0.11
Uong Bi	-	0.31-0.95	0.41	0.39-0.49	0.079

mg/kg – milligrams per kilogram

Source: VEA, 2009

µg/Nm^3 – micrograms per normal cubic meter

Base on coal consumtion and the average of Hg concentrations in coal input of some thermal power plants in 2009, Hg emissions estimated from coal-fired thermal power plants was about 225.72 kg.

In 2015, the Ministry of Industry and Trade (MOIT) has coordinated with the United Nations Industrial Development Organization to carry out the "Initial Evaluation of the Minamata Convention in Vietnam" project. Arcording to the survey report, Hg emissions estimated from coal combustion activities in 2014 is about 5,373.3 kg.

IV.2. Collection and analysis of coal samples

IV.1.1. Coal sampling and analysis

The PCD and Centre of Environment Monitoring (CEM) co-operated to conduct a survey and sampling at 8 coal mines including: Uong Bi, Hon Gai, Nui Beo, Ha Tu, Ha Lam, Mao Khe, Vang Danh, and Nam Mau. The samples are representative for all type of coals (anthracite class 4a, 4b, 5a, 5b, 6a and 6b) which are used in the Vietnamese power sector. Coal samples were analyzed for mercury concentration and other components (Ca, Na, Se, As, and Cl).

Representative coal samples were taken from coal warehouses at mines that were managed by coal mining companies Vinacomin Group and Dong Bac Corporation.

There are large numbers of coal-mines in the northern coal basin, supplying coal to coal-fired power plants in Vietnam. PC boilers mainly use Anthracite coal class 4a to 6b. Samples were collected in coal-mines, as shown in Figure 7.

Figure 7. Map showing coal mines where samples were collected

Coal samples were analyzed in the laboratory according to the methods described in Table12.

Table 12. Methods used for coal sampling and analysis

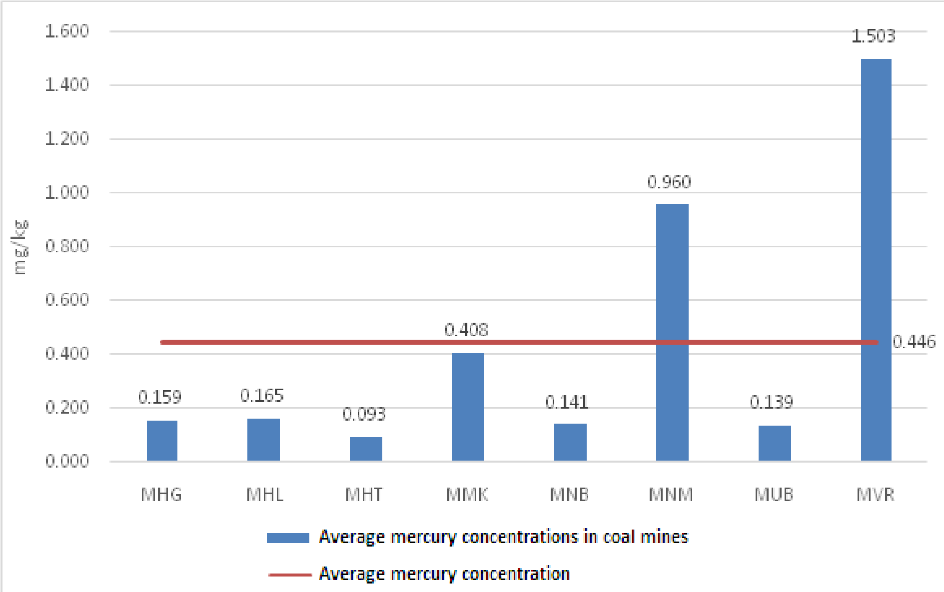
Activity	Methodology
Coal sampling:	TCVN 1693:2008 Coal - craft sampling
Analysis:	
- Calcium (Ca)	US EPA 200.8: Identify elements in water and waste by plasma spectrometry
- Sodium(Na)	American Society of Testing and Materials (ASTM) D 2795-95: Methods of coal and ash analysis
- Selenium (Se)	ASTM D 4606-95 – Standard Test method for determination of Arsenic and Selenium in coal by the Hydride Generation/Atomic absorption method

Activity	Methodology
- Arsenic (As)	ASTM D 4606-95: Methods for determination of Arsenic and Selenium in coal by Atomic absorption method
- Chlorine (Cl)	ASTM D 2361: Method for determination of Chlorine in coal
- Mercury (Hg)	US EPA Method 30B: Measuring total vapor phase mercury (Hg) emissions from coal fired combustion sources using sorbent trap sampling
- Mercury (inter-laboratory comparison samples)	ASTM D 6414: Standard Test Methods for determination of mercury in coal and coal combustion residues

IV.1.2 Mercury and other chemicals in coal

a) Coal sample analysis

Collected samples of coal were stamped with information including time, location, type of coal, analytical parameter, observers and other special information. Coal samples were contained in plastic bags (with two layers



including a plastic bag outside and a tin bag inside). Average Hg concentration of coal samples acquired from the 8 mines in Quang Ninh is listed in Table 13.

Table 13. Average Hg concentration in coal samples from mines in Quang Ninh

No.	Name of mine	Coal type	Number of samples	Average Hg (mg/kg)
1	Hon Gai (MHG)	Anthracite	6	0.159
2	Ha Lam (MHL)	Anthracite	3 plus 1 QC sample	0.165
3	Ha Tu (MHT)	Anthracite	4 plus 1 QC sample	0.093
4	Mao Khe (MMK)	Anthracite	6	0.408
5	Nui Beo (MNB)	Anthracite	3 plus 1 QC sample	0.141
6	Nam Mau (MNM)	Anthracite	3 plus 1 QC sample	0.960
7	Uong Bi (MUB)	Anthracite	2 plus 1 QC sample	0.139
8	Vang Danh (MVR)	Anthracite	2 plus 1 QC sample	1.503
	Average			0.446

The average Hg concentration in coal of 8 mines is shown in Figure 8 (details are given in Appendix 1).

Figure 8. The average Hg concentration in coal from 8 mines

Figure 8 showed that Hg concentration measured at Vang Danh mine (1.503 mg/kg) is 3.37 times higher than the average value (0.446 mg/kg) and 16.11 times than in Ha Tu mine. Vang Danh and Nam Mau coal-mines are located closely to Uong Bi district and Hg concentrations in the coal are much higher than for other mines.

The average Hg concentration in coal collected from some mines in

Quang Ninh (0.446 mg/kg) is at the level similar to concentartions measured in other countries. However, in comparison with coals in Europe, Africa and South America, the Hg concentration in anthracite coal in Vietnam is relatively higher, as shown in Table 14.

Table 14. Comparison of Hg concentration in coal in Vietnam and some other countries

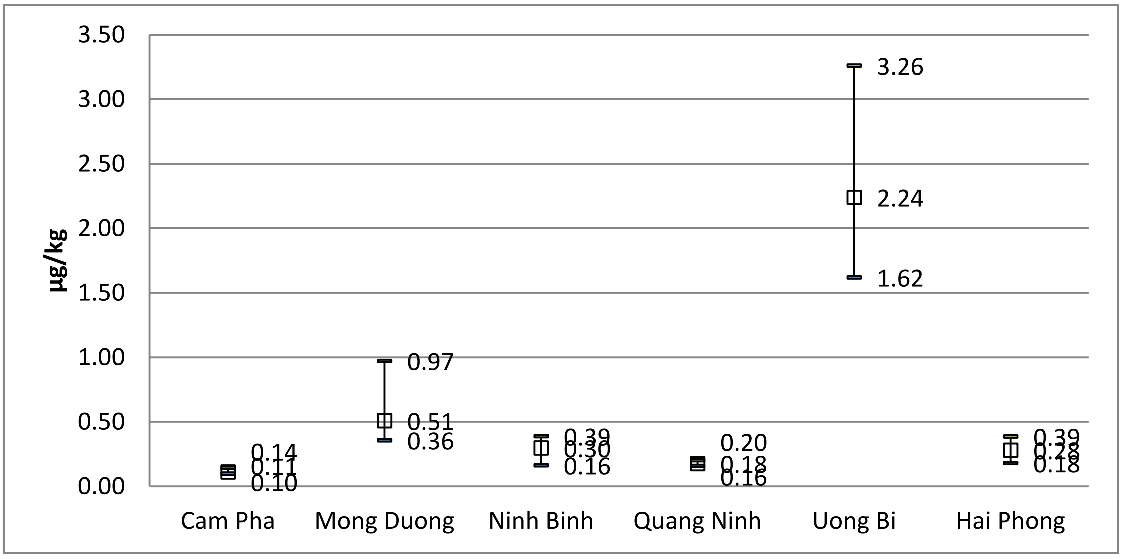
Country	Coal type	Average Hg in coal (mg/kg)	Range (mg/kg)	Source
Vietnam	Anthracite	0.446	0.08-1.51	This study
China	Bituminous	0.147	0.009-1.134	Tsinghua University, 2011
China	Subbituminous	0.145	0.008-2.248	
China	Anthracite	0.15	0.009-0.541	
China	Lignite	0.28	0.030-1.527	
Philippines	Bituminous	0.04	<0.04-0.1	Pirrone et al., 2001
Thailand	Lignite	0.12	0.02-0.57	Finkelman, 2004
Indonesia	Lignite	0.11	0.02-0.19	Finkelman, 2003
Indonesia	Subbituminous	0.03	0.01-0.05	US EPA, 2002
Australia	Bituminous	0.215	0.03-0.4	Pirrone et al., 2001
Turkey	Bituminous	0.11	0.03-0.66	Finkelman, 2003
Ukraine	Bituminous	0.07	0.02-0.19	Pirrone et al., 2001
Czech Rep	Bituminous	0.25	<0.02-0.73	Finkelman, 2003
Egypt	Bituminous	0.12	0.04-0.36	Finkelman, 2003
New Zealand	Anth + Bit.	0.31	0.02-0.6	Finkelman, 2004
Romania	Bituminous	0.21	0.07-0.46	Finkelman, 2003
Russia	Bituminous	0.11	<0.02-0.84	Finkelman, 2004
Slovak Rep	Bituminous	0.08	0.03-0.13	Pirrone et al., 2001
Yugoslavia	Lignite	0.11	0.07-0.14	Finkelman, 2004
Peru	Subbituminous	0.27	0.04-0.63	Finkelman, 2004
South America	Bituminous	0.08	0.01-0.95	
Tanzania	Lignite	0.12	0.04-0.22	

Country	Coal type	Average Hg in coal (mg/kg)	Range (mg/kg)	Source
Zambia	Bituminous	0.6	<0.03-3.6	
Zimbabwe	Bituminous	0.08	<0.03-0.5	
Botswana	Bituminous	0.09	0.04-0.15	
USA	Subbituminous	0.1	0.01-8.0	US EPA, 1997
USA	Lignite	0.15	0.03-1.0	
USA	Bituminous	0.21	<0.01-3.3	
USA	Anthracite	0.23	0.16-0.30	
Colombia	Subbituminous	0.04	>0.02-0.17	Finkelman, 2004
Argentina	Bituminous	0.1	0.03-0.18	
Brazil	Bituminous	0.19	0.04-0.67	

b) Hg concentration in coal used at coal-fired plants

In addition to coal sampled at coal mines, some of the coal samples from thermal power plants were collected and evaluated for assessment of Hg concentration. Coal-fired plants have collected coal samples including Cam Pha, Mong Duong, Quang Ninh, Uong Bi, Hai Phong and Ninh Binh.

The Hg concentration in input coal at these plants is between 0.11-0.51 mg/kg. Particularly, Uong Bi has Hg concentrations in coal (1.62-3.26 mg/kg) higher than other plants, which is probably a result of using coal supplied from the Vang Danh and Mao Khe mines. Other plants are using mixed coal from different areas of Quang Ninh. The results of the Hg concentration



measurements in the input coal of these plants are shown in Figure 9. (details are presented in Appendix 2).

Figure 9. Hg concentration in the input coal of selected coal-fired power plants

c) Halogen and some metals content in coal

At high temperatures in the boilers of coal-fired plants, Hg exists in coal in the form of mercury elements (Hg^0). Pollution control devices (ESP, FGD) have very little ability to control elemental mercury (Hg^0) because these devices can not react or dissolve elemental mercury. However, in addition to mercury, halogen is also present in coal, which may lead to conversion of mercury oxide to Hg-halogen complexes such as $HgCl_2$ and $HgBr_2$.

In addition to Hg concentrations, As, Se, Na, Ca, and Cl were also analyzed for coal samples from each mine. The average concentration of Cl and metals in coal samples are shown in Table 15 (The details are in Appendix 1).

Table 15. Average of Cl and metals concentrations in 8 coal mines

Concentration/ Element	Unit	Min	Max	Mean
Ca	%	0.01	0.56	0.15
Na	%	0.01	0.27	0.09
Se	mg/kg	0.76	7.74	2.81
As	mg/kg	3.41	48.14	16.71
Cl	g/kg	0.02	2.17	0.60

Table 15 shows the coal at Ha Tu mine has the highest Ca concentration (0.56%), while the Hon Gai mine has the highest Na concentration in coal (0.27%). Coal at Mao Khe mine has Se (7.74 mg/kg) and As (48.14 mg/kg) concentrations which are higher than other mines. The As concentration in the coal sample at Vang Danh mine is in the range of 3.41-6.52 mg/kg.

Cl contcentration in the coal sample at Ha Lam coal-mine has the highest result of 2.17 g/kg. The average Cl concentration at 8 mines (0.69 g/kg) is similar to other countries such as Cl in coal from China: 0.31 g/kg (Tsinghua University, 2011), coal from India: range 0.33-1.4 g/kg (CIMFR, 2014).

d) Interlaboratory comparison

The total of 5 samples from 5 mines were sent to the laboratory operated by VinaControl (the organization has the certificate Villas 202) for Interlaboratory comparison. Based on the analytical results of the laboratories for 5 coal samples, the percent difference is assessed. The formula to calculate relative percent difference (RPD) is as follows:

$$\% \text{ RDP} = \frac{|\text{A-B}|}{(\text{A+B})/2} X\ 100$$

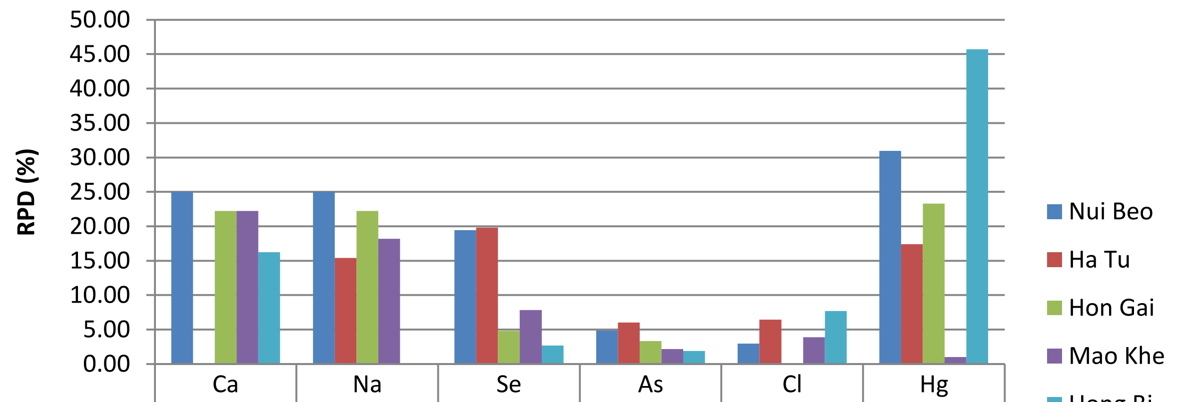
Where:

RPD: Relative percent difference (%)

A: Measured value of the first duplicate

B: Measured value of the second duplicate

The analytical results for interlaboratory comparison samples are shown in Figure 10.



	Ca	Na	Se	As	Cl	Hg
Nui Beo	25.00	25.00	19.44	4.85	2.94	30.97
Ha Tu	0.00	15.38	19.79	6.01	6.45	17.39
Hon Gai	22.22	22.22	4.80	3.35	0.00	23.30
Mao Khe	22.22	18.18	7.84	2.17	3.87	1.00
Uong Bi	16.22	0.00	2.68	1.88	7.69	45.70

Figure 10. RPD value (%) of the interlaboratory in 5 coal mines

Figure 10 shows almost all the RPD of the analysis results were lower than 30%. However, the RPD values of Hg concentration in coal samples of Nui Beo and Uong Bi mines are 30.97% and 45.7% (higher than 30%), respectively. The relatively high RPD value has been discussed and understood that it is may be due to the different methods of Hg analysis applied at the laboratories (US

EPA Method 30B and ASTM D 6414-99). The results of Interlaboratory comparison samples are detailed in Appendix 3.

IV.2 Mercury measurement in 3 coal-fired power plants

IV.2.1 Equipment and Methodology

a) Equipment for mercury measurement

The US EPA Method 30B is applied - This method is designed to measure the mass concentration of total vapor phase Hg in flue gas using carbon sorbent traps.

The equipment was brought to the location, including vacuum pump, consoles, sample tube, and carbon sorbent traps for in-the-filed analysis. Four different types of sorbent traps were used.

Two unspiked sorbent traps (A and B): have the same structures, used for total mecury testing. Hg concentration in flue gas will be taken as the average value of the A and B traps. One spiked sorbent trap (C): to satisfy strict quality assurance/quality control procedures outlined in the method. The average recovery must be between 85 and 115% at each of the two spiked concentration levels.

One special sorbent trap (D): this trap has two parts in which one sorbent trap collects only oxidized mercury (Hg^{2+}) while the other one collects the elemental mercury (Hg^0).

Before sampling, a leak check of the sampling system with the sorbent trap in place must be performed. The flow rate of sampling is nomally maintained at 1 liter/min and each sample takes 30 minutes. After the sampling is complete, the sample pump is turned off, the probe with sorbent traps is removed, the end of each sorbent trap is carefully sealed and another leak check of each sampling train with the sorbent trap in place is performed.

The Hg concentration is determined in the field by the sorbent trap Hg analyzer through the thermal desorption mechanism at 650ºC. According to the principle of the analyzer, it can also measure the Hg concentration of solid samples (coal) or waste products (fly ash, bottom ash).

For sampling and analyzing Hg in flue gas, the following monitoring equipment is used:

- Equipment for Hg sampling: Apex Instruments 30B - Model XC-260. This equipment is shown in Figure 11 and was funded by the United States Department of State (US DOS) in 2015.

Figure 11. Equipment used for Hg emission sampling

- Sorbent trap Hg analyzer: Ohio LUMEX-USA. The principle used for analysis was thermal desorption at 650 ºC.

All chemicals for sampling and analysis and equipment were donated by US DOS in March 2015. CEM's technical staffs were trained by US DOS' experts to use the monitoring equipment (Figures 12 and 13).

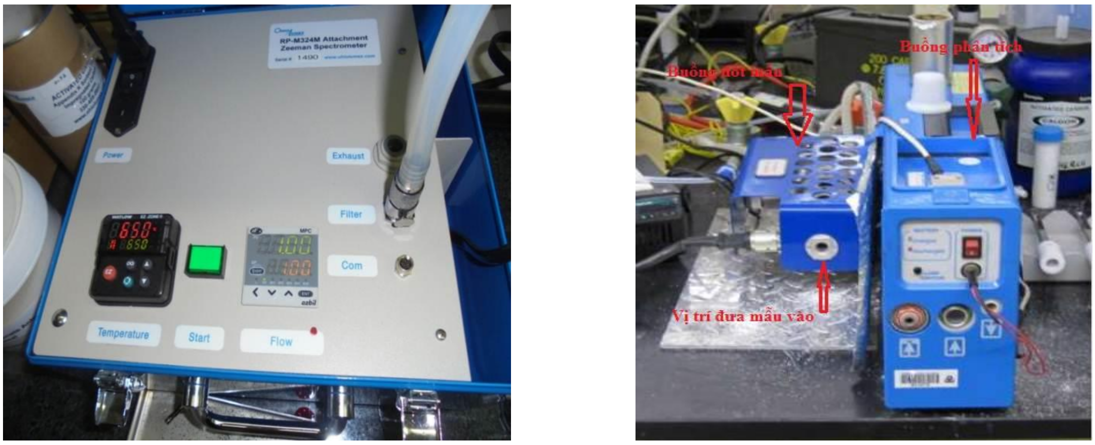


Figure 12. Ohio Lumex Hg analysis equipment

Figure 13. Chemicals used for analysis

b) Equipment for PM monitoring

The particulate matter (PM) sampling method was implemented according to the guidance on isokinetic emission sampling and following technical instructions by US EPA Method 5. The equipment is shown in Figure 14.

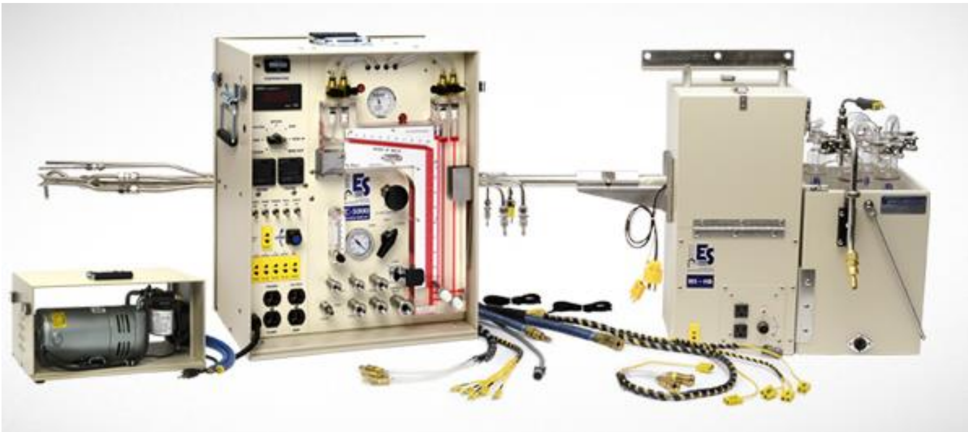


Figure 14. The equipment for PM sampling

Monitoring methods to measure PM and Hg in flue gas, fly ash, and bottom ash are listed in Table 16.

Table 16. Methods used to measure Hg in flue gas, fly ash, and bottom ash

ID.	Measurement	Methodology
1	Hg in fly ash and bottom ash	US EPA Method 30B: Measuring total vapor phase Hg emissions from coal-fired combustion sources using sorbent trap sampling
2	Particulate matter (PM)	US EPA Method 5 - Determination of dust in emissions
3	Hg in exhaust gas	US EPA Method 30B: Measuring total vapor phase Hg emissions from coal-fired combustion sources using sorbent trap sampling

IV.2.2 Selection of Coal-power plants

For selection of coal-power plants to conduct Hg measurement, PCD and CEM surveyed 6 coal-fired power plants in the North taking into account the following selection criteria:

- Stability of power plant operation
- Air pollution control systems (ESP, FGD, or other)
- Convenience and safety of emission measurement
- Feasibility of installation of the Hg and PM monitoring equipment.

Based on the survey results, 3 coal-fired power plants were selected for Hg monitoring. All 3 coal-fired power plants selected used anthracite from Quang Ninh, Vietnam. General information about the selected plants is presented below.

1. Quang Ninh power plant

Quang Ninh coal-fired power plant has a capacity of 4 x3 00 MW and was designed, installed, built, and tested by Shanghai Electric Group Company - China. Most of the equipment was manufactured by Shanghai Electric Group Company - China. General design was created by Northwest Electric Power Design Institute Co., Ltd. PC boilers were designed by ALSTOM Corporation (France).

Quang Ninh Joint Stock Company (a partnership that is majority-owned by Electricity of Vietnam) is located in Ha Khanh Ward, Ha Long City, Quang Ninh province which has the biggest coal reserves of Vietnam. This location is advantageous for producing and suppling electrical power for the national electricity system.

Quang Ninh power plant operates two units, namely Quang Ninh-1 and Quang Ninh-2, with the total capacity of 1,200 MW. The annual power output is expected to reach 7.2 billion kWh/year.

Quang Ninh 1 and 2 have existing individual APC systems, including ESP and wet FGD. Quang Ninh 2 has a flow of about 104.7 m^3/h. The continuous emission monitoring system (CEMS) was installed to measure concentrations of O_2, CO_2, CO, NO_X, SO_X, and PM. Monitoring results from the CEMS will be used to improve the boiler efficiency and exhaust gas treatment systems according to the Air Emission Standard for thermal-power plants (QCVN 22:2009).

Figure 15. Stack of Quang Ninh coal-fired power plant

2. Pha Lai power plant

Pha Lai coal-fired power plant is the one of the largest coal-fired power plants in Vietnam located in Pha Lai, Chi Linh District, Hai Dương Province, located north-east of Hanoi, next to Luc Dau Giang river with a total area of 300 hectares. The plant has two lines. The construction of the first line was started in 1980 with a capacity of 440 MW including 4 units (each unit has 100 MW). In 1998, the second line was constructed with funds from Japan's Official

Development Assistance. The capacity of this line is 600 MW with 2 units of 300 MW each.

There are 2 types of coal used in the plant, namely Vang Danh coal and coal mixture (from diffrent mines in Quang Ninh province). Both coal types have high ash and sulfur contents and low nitrogen content as shown in Table 17.

Table 17. Content of compounds in coal of Pha Lai power plant

Content of compounds (%)	**Vang Danh coal**	**Coal Mixture**
Ash	32.7	30.5
Sulfur	1.1	0.69
Nitrogen	0.56	0.69

Source: Pha lai report (2016)

3. Ninh Binh power plant

Ninh Binh coal-fired power plant is located in Thanh Binh ward, Ninh Binh city. The plant was built in 1974; it was one of the first power plants in Vietnam. The area of the plant is 144,496 m^2 and the slag dump area is 97,176 m^2.

Ninh Binh plant has a Chinese technology design from the early 1970s. The plant design capacity is 100 MW with 4 units (4 x 25 MW). The plant technology is based on the steam turbine and boilers using PC combustion technology. Currently, Ninh Binh plant is using Anthracite coal from the Hon Gai coal mine. The annual amount of coal used at Quang Ninh is shown in Table 18.

Emission control equipment for Ninh Binh plant (for 4 units) includes the ESP system; there is no FDG for SO_2 emission reduction.

Table 18. The amount of coal used annually at Ninh Binh plant

Year	Coal used (Metric tons)	Coal Source
2014	393,553	Anthracite coal from Hon Gai coal mine (Cam Pha, Quang Ninh)
2015	244,570	Anthracite coal from Hon Gai coal mine (Cam Pha, Quang Ninh)
2016 (Estimate)	250,000	Anthracite coal from Hon Gai coal mine (Cam Pha, Quang Ninh)

Source: Ninh Binh report (2016)

Monitoring plans for Quang Ninh, Pha Lai, and Ninh Binh coal-fired power plants are given in Table 19.

Table 19. Monitoring plan at three coal-fired power plants

No	Content	Location
I	**Quang Ninh power plant**	
	Hg emissions	The height of 60m above the ground, stack No. 3 (after ESP systems)
	PM emissions	The height of 60m above the ground, stack No. 3 (downstream of ESP)
	Coal from mill feed	From bunker before injection into the furnace
	Fly ash	From silos of ESP
	Bottom ash	From bunker at the output of furnaces
II	**Environmental monitoring at the Pha Lai power plant (3 days) August 15-17th, 2016**	
	Hg emissions	The height of 35m above the ground, stack No. 2 (downstream of FGD)
	Coal from mill feed	From bunker before injection into the furnace No.2
	Fly ash	From choppers of ESP
	Bottom ash	From bunker at the output of furnaces
III	**Ninh Binh power plant**	
	Hg emissions	The height of 25m above the ground, stack No. 3 (downstream of ESP)
	PM emissions	The height of 25m above the ground, stack No. 3 (downstream of ESP)
	Coal mill feed	From bunker before injecting into the furnace No.4
	Fly ash	From choppers of ESP
	Bottom ash	From bunker at the output of furnaces

The number of samples planned to be taken in each plant was 30, of which 10 samples for Hg, 10 for PM, 4 coal, 3 fly ash, and 3 bottom ash samples. However, Pha Lai power plant did not have the site to collect the PM sample and the moisture of gas was very high, so the number of samples was reduced. Details on the number of samples collected at the 3 power plants are presented in Table 20. Sampling locations are shown in Figure 16.

Table 20. The number of samples at three power plants.

No	Location	Number of samples	Sample Codes
I	Quang Ninh power plant		
	Hg emissions	10	QN-1, QN-2, QN-3, QN-4, QN-5, QN-6, QN-7, QN-8, QN-9, QN-10
	PM emissions	15	PM-1, PM-2, PM-3, PM-4, PM-5, PM-6, PM-7, PM-8, PM-9, PM-10, PM-11, PM-12, PM-13, PM-14, PM-15
	Coal from mill feed	4	TQN-7, TQN-8, TQN-9, TQN-10
	Fly ash	3	AQN-1, AQN-2, AQN-3
	Bottom ash	3	XQN-1, XQN-2, XQN-3
II	Pha Lai power plant		
	Hg emissions	3	PL1, PL2, PL3
	PM emissions	0	TPL-1, TPL-2, TPL-3, TPL-4
	Coal from mill feed	4	APL-1, APL-2, APL-3
	Fly ash	3	XPL-1, XPL-2, XPL-3
	Bottom ash	3	PL1, PL2, PL3
III	Ninh Binh power plant		
	Hg emissions	10	NB-1, NB-2, NB-3, NB-4, NB-5, NB-6, NB-7, NB-8, NB-9, NB-10
	PM emissions	15	PM-16, PM-17, PM-18, PM-19, PM-20, PM-21, PM-22, PM-23, PM-24, PM-25, PM-26, PM-27, PM-28, PM-29, PM-30
	Coal from mill feed	4	TNB-1, TNB-2, TPL-3, TPL-4
	Fly ash	3	APL-1, APL-2, APL-3
	Bottom ash	3	XPL-1, XPL-2, XPL-3

Hg and PM monitoring in Quang Ninh Thermal Power Plant

Hg monitoring in Pha Lai Thermal Power Plant

Hg and PM monitoring in Ninh Binh Thermal Power Plant

Figure 16. Location for Hg and PM sampling at three power plants

IV.2.3 Mercury measurement

In this research, 30 PM samples, 23 Hg samples, 12 coal samples (anthracite), 9 fly ash samples, and 9 bottom ash samples from 3 coal-fired plants were analyzed to determine Hg concentrations.

a) Mercury concentrations in coal, fly ash and bottom ash

In 2015, with the supporting of UNEP and the US DOS, Pha Lai plant was chosen for measurements of Hg emissions combined with hands-on training. At that time, 2 coal samples, 3 samples of fly ash and 1 sample of bottom ash were also taken for Hg concentration analyses. Results of Hg measurements are shown in Table 21.

Table 21. Hg concentration in coal, fly ash, and bottom ash of Pha Lai in 2015

Samples	Hg concentration (mg/kg)
TPL-1	0.212
TPL-2	0.173
TPL-3	-
TPL-4	-
APL-1	1.244
APL-2	1.139
APL-3	1.214
XPL-1	<0.100
XPL-2	-
XPL-3	-

Notes:
TPL - Coal samples
APL - Fly ash samples
XPL - Bottom ash samples

In 2016, samples were taken from 3 power plants to determine Hg concentrations in coal, fly ash, and bottom ash. The results are shown in Table 22.

Table 22. Hg concentrations in coal, fly ash, and bottom ash (mg/kg)

No.	Name of power plant								
	Quang Ninh			Pha Lai			Ninh Binh		
	Coal	Fly ash	Bottom ash	Coal	Fly ash	Bottom ash	Coal	Fly ash	Bottom ash
1	0.140	1.610	<0.003	1.590	2.000	<0.003	0.198	1.210	<0.003
2	0.169	1.567	<0.003	1.620	1.951	<0.003	0.181	1.230	<0.003
3	0.165	1.456	<0.003	0.920	2.002	<0.003	0.234	1.106	<0.003
4	0.124			0.950			0.261		
Average	0.150	1.544	0	1.207	1.983	0	0.219	1.183	<0.003

As shown in Table 22, the average Hg concentration in coal (anthracite) measured at 3 coal-fired plants ranged between 0.150-1.207 mg/kg, which is consistent with data provided from a coal sampling campaign in the Quang Ninh mine. In this sampling campaign, a total of 35 coal samples have been analyzed and Hg concentrations ranged from 0.093-1.503 mg/kg with an average concentration of 0.446 mg/kg. The average Hg concentration in coal samples of Pha Lai in 2016 was 1.207 mg/kg, which is relatively high compared to data in 2015 and in other plants.

b) Mercury concentration in flue gas

The results of flue gas Hg sampling at 3 power plants are shown in Table 23. The average Hg concentration at Pha Lai is 43.8 µg/Nm^3 in 2016, higher than 14.7 µg/Nm^3 measured in 2015 and Hg concentration measured at Quang Ninh and Ninh Binh. This may be due to the Hg concentration in coal of Pha Lai (2016) being much higher than Hg measured in 2015 and high moisture of flue gas measured in Pha Lai (detail is in Part a) as mentioned above). The lowest concentration of flue gas Hg was measured at Quang Ninh coal-fired power plant of 1.51 µg/Nm^3. Table 23 shows variability of measured Hg concentrations in flue gas at 3 plants.

Table 23. Measured Hg concentrations in flue gas

Coal-fired plant	Sample										Average (µg/Nm^3)
	1	2	3	4	5	6	7	8	9	10	
Pha Lai (2015)	14.4	15.1	15.7	8.4	7.9	20.7	17.9	17.4	15.1		14.7
Pha Lai (2016)	52.9	33.6	45.1	-	-	-	-	-	-	-	43.8
Quang Ninh	1.5	1.6	1.5	1.2	1.3	1.6	1.6	1.6	1.4	1.4	1.5
Ninh Binh	22.0	21.3	22.4	18.8	19.7	20.4	17.5	18.4	19.0	20.9	20.0

Hg concentrations in flue gas at 3 coal-fired power plants measured in 2016 are shown in Figure 17.

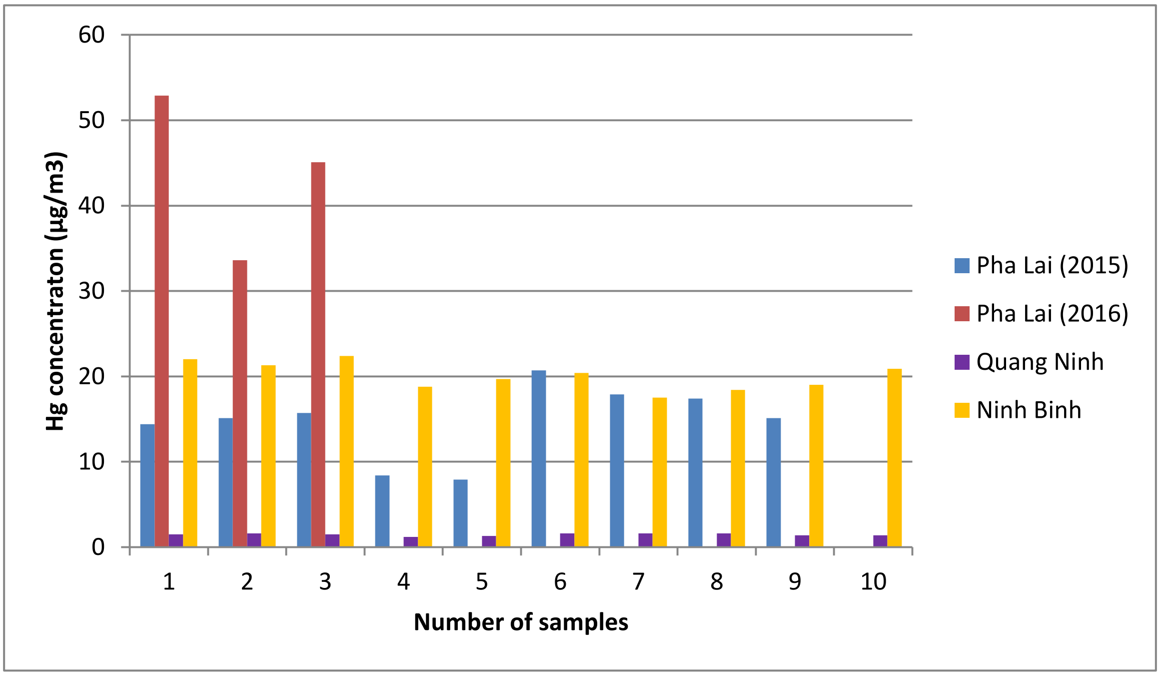


Figure 17. Hg concentration in flue gas at 3 power plants (µg/Nm^3)

In Figure 17, Pha Lai Thermal Power (2016) had the highest concentration of Hg in the flue gas (average 43.8 µg/Nm^3), compared to measured Hg concentration in coal (average Hg in coal 1.207 mg/kg). The lowest Hg concentration was measured at Quang Ninh power plant (average of 1.5 µg/Nm^3). It agrees with the fact that Hg concentration in coal input of Quang Ninh is the lowest among the three plants (average 0.150 mg/kg). These results demonstrate the relationship between Hg concentration in coal input and Hg concentration in the flue gas (Hg emission rate for a plant).

c) Particulate matter concentrations in flue gas

A total of 30 PM samples were taken in Quang Ninh and Ninh Binh coal-power plants. The PM concentration in flue gas at each power plant is shown in Table 24 and in Figure 18.

Table 24. PM concentrations in flue gas (mg/Nm^3)

Samples	Quang Ninh power plant	Ninh Binh power plant
1	209	209
2	299	163
3	272	207
4	215	195
5	212	187
6	185	141
7	328	170
8	255	112
9	196	123
10	214	151
11	361	121
12	242	104
13	178	162
14	238	152
15	237	170
Average	**238.5**	**157.8**

Note: PM concentration numbers are not available for Pha Lai because the monitoring position was not suitable for isokinetic sampling.

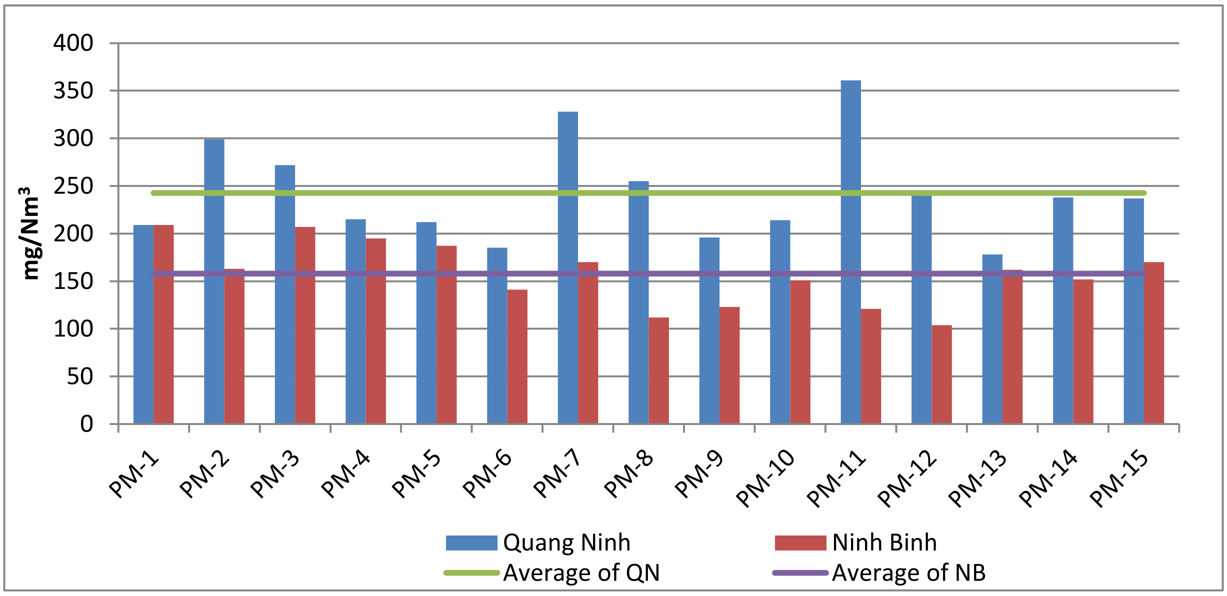


Figure 18. PM concentrations at Quang Ninh and Ninh Binh power plants

Overall, PM concentration in Quang Ninh ranged from 209 - 361 mg/Nm^3 and in Ninh Binh ranged from 104 - 209 mg/Nm^3. Average PM concentrations in 2 coal-fired power plants are 238.5 mg/Nm^3 and 157.8 mg/Nm^3, respectively.

IV.2.4 Comparison of Hg emission

When comparing mercury analysis of three plants to other coal-fired thermal power plants in other countries such as India, South Africa, and Russia, our results showed that the Hg concentrations in coal input, fly ash, bottom ash and in the exhaust gases of these factories are similar. Comparison results of Hg concentrations in coal and waste components of the factories are shown in Table 25.

Table 25. Comparision of Hg analyses in coal-fired plants

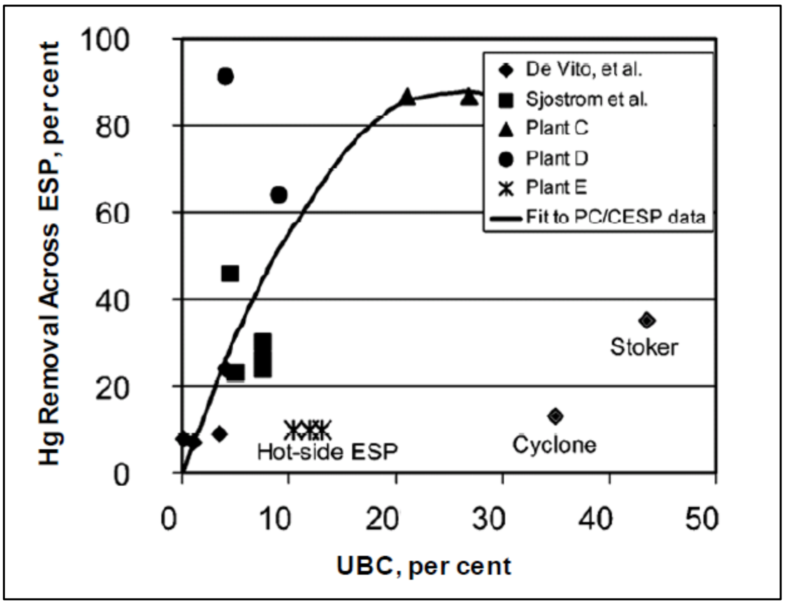
No.	Coal-fired plant	Capacity (MW)	APC	Coal type	Hg in coal input (mg/kg)	Hg in fly ash (mg/kg)	Hg in bottom ash (mg/kg)	Hg in flue gas (μg/Nm³)	Source
1	Pha Lai 2 (Vietnam-2015)	600	ESP + FGD	Anthracite (mix from Quang Ninh)	0.173 - 0.212	1.139 - 1.244	<0.003	7.97 - 20.73	This study
2	Pha Lai 2 (Vietnam-2016)				0.92 - 1.62	1.951 - 1.997	<0.003	33.6 - 52.9	
3	Quang Ninh (Vietnam-2016)	1200	ESP + FGD		0.124 - 0.169	1.46 - 1.61	<0.003	1.24 - 1.67	
4	Ninh Binh (Vietnam - 2016)	100	ESP		0.181 - 0.261	1.11 - 1.23	<0.003	17.5 - 22.4	
5	Kendal (South Africa)	4,116	ESP + FF	-	0.167 - 0.361	0.030 - 0.157	-	39.02 - 49.13	U.S. Geological Survey, 2014
6	Duvha (South Africa)	3,600	ESP + FF	-	0.137 - 0.306	0.13 - 0.687	-	4.09 - 40.37	
7	Talcher STPP, NTPC (India)	500	ESP	sub-bituminous and bituminous	0.173 - 0.229	0.097	0.006	14.84	Central Institute of Mining & Fuel Research, 2014
8	Korba (W) CEB (India)	210	ESP		0.176	0.158	0.011	11.5	
9	Budge Budge CESC (India)	250	ESP		0.05 - 0.183	0.242	0.143	4.24	
10	Cherepetskaya Thermal Power Plant (Russia)	300	ESP	-	0.0847	0.192	-	1.930-3.700	VTI, IOC, 2014

Table 25 shows that Hg concentrations measured in bottom ash of 3 plants in Vietnam is very low (<0.003 mg/kg) and are similar to other plants in India (0.006-0.017 mg/kg).

The Hg concentration in flue gas of 3 coal-fired plants in Vietnam (1.24-52.9 µg/Nm^3) is relatively higher than the Cherepetskaya plant of Russia (1.93-3.70 µg/Nm^3) and similar to some South Africa and Indian plants, except the Hg concentration in flue gas of Quang Ninh is quite low (1.24 - 1.67 µg/Nm^3).

However, Hg concentration measured in fly ash of 3 plants of Vietnam ranges from 1.11–1.997 mg/kg and is considerably higher compared to other countries such as India (0.097-0.242 mg/kg Hg), South Africa (0.03-0.68 mg/kg), Russia (1,930-3,700 mg/kg) and some plants of China (0.010-0.295 mg/kg), (EC, 2016). This might be due to incomplete combustion taking place in the boilers, resulting in relatively high unburned carbon content (UBC).

Higher UBC content in fly ash can increase Hg removal efficiencies in ESPs, likely to be associated with the increasing halogen content of UBC (UNEP, 2014). The relationship between UBC content in fly ash and Hg removal efficiencies in ESPs is described, as depicted in Figure 19. As shown, UBC content of about 5-10% can result in about 20-40% Hg removal efficiencies, whereas UBC content of 15-20% can increase ESP Hg removal efficiencies of up to 80%, thus having a positive effect on reducing Hg emissions to air from coal-fired power plants.



Source: UNEP (2010), p. 35

Figure 19. Hg capture across ESP as a function of the UBC amount

According to reports of each plant, the UBC in fly ash of the Ninh Binh plant is about 15-20%, and the Pha Lai plant is 14.9%, which is relatively high compared with the normal level of unburnt carbon in fly ash of below 5–10 % (EC, 2016).

The efficiency of coal used also indicated the potential UBC release in fly ash. According to coal consumption of 26 of Vietnam's coal-fired plants, (Table 29) showed that the efficiency of coal used in a PC boiler is about 426-819 g/kWh and for CFB is 597-918 g/kWh. The average of coal used in PC coal-fired plants in Vietnam is 560 g/kWh (Nguyen Thi Thu Huyen, 2015) and is higher than some plants in the world today (380 g/kWh), (IEA, 2012).

Thus, anthracite coal used has high ash content and lower efficiency than bituminous and sub-bituminous. The low coal used rate may cause the relatively high concentration of Hg in the fly ash and improve the ability of Hg removal rate of the APC system in 3 coal-fired plants of Vietnam.

IV.3. Mercury emission estimate

The UNEP Toolkit for Identification and Quantification of Mercury Releases (Level 2) provides a standardized methodology to estimate Hg emissions from coal-fired power plants. The methodology is based on a mass balance approach, assuming "all Hg in" equals "all Hg out". The calculation flow for estimating Hg emissions is depicted in Figure 20 and the corresponding parameters are described below.

Input factor (concentration of Hg in the coal types used at plant)	*	**Activity rate** (amount of each type of coal burned per year)	*	**Distribution factor** for each pathway (by coal type and filter types present)

Figure 20. Estimation of Hg emissions based on UNEP Toolkit Level 2

Input Factor: The Hg input factor is determined by the concentration of Hg in the type of coal burned. For anthracites, two different input factors may be used as depicted in Table 26. Input factors for Scenario 1- Based on UNEP Toolkit default factor for anthracites in Vietnam, and for Scenario 2- based on average Hg concentration measured in Quang Ninh anthracites.

Table 26. Hg factors for Vietnam input anthracite coal

Scenario	Coal type	Mean Hg concentration (mg/kg)	Range of Hg concentration, (mg/kg)	Source
1- UNEP Default Factor	Anthracite-Vietnam	0.28	<0.02-0-14	UNEP Toolkit Level 2
2- Measured in Quang Ninh mine	Anthracite – Quang Ninh mine	0.446	0.093 – 1.503	Based on the average of Hg concentration in coal of 08 Quang Ninh mines

Note: Scenario -1 is based on UNEP Toolkit Level 2 (page 65)

Activity Rate: The activity rate is determined by the amount of each type of coal burned in power plants.

Distribution Factor: The outputs of Hg from coal-fired power plants are distributed between 1) air emissions, 2) accumulation on solid combustion residues and flue gas cleaning device residues, and 3) possible smaller releases to water (only via wet flue gas cleaning systems), as depicted in Table 27.

Table 27. Main releases and receiving media from combustion in large power plants

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Combustion	**X**	x	x	x	**X**	**X**

*Notes: **X** - Release pathway expected to be predominant for the sub-category; x - Additional release pathways to be considered, depending on specific source and national situation.*

Source: UNEP Toolkit Level 2 p. 61

The installation of APC systems can have a significant influence on Hg distribution pathways, as shown in Table 28. For Vietnam, Level 1 and Level 3 APC systems may be applicable for most of power plants.

Table 28. Default distribution factors for Hg outputs from coal combustion in power plants, based on UNEP Toolkit Level 2, p. 69

Level of APC system applied	Distribution factors, fraction of Hg input					
	Air	**Water**	**Land**[1]	**Products**[3]	**General waste**[2]	**Sector specific treatment/ disposal**[2]
Level 0: None	1					
Level 1: PM simple APC: ESP/PS/CYC	0.75					0.25
Level 2: PM (FF)	0.5					0.5
Level 3: Efficient APC: PM+SDA/wFGD	0.35					0.65
Level 4: Very efficient APC: PM+FGD+SCR	0.3					0.7
Level 5: Mercury specific	0.03					0.97

Notes:

(1) If coal washing is applied, the input Hg to combustion is the calculated output to "products" from coal washing. Outputs to water can take place if not all Hg in washing media is retained in residues.

(2) If residues are not disposed of carefully, Hg in residues could be considered released to land. Sector specific disposal may include disposal on special secured landfills, disposal on special landfills with leaching not secured and more diffuse use in road construction or other construction works. The actual distribution between disposal with general waste (ordinary landfills) and sector specific deposition likely varies much among countries and specific information on the local disposal procedures should be collected.

(3) Depending on the specific flue gas cleaning systems applied, parts of the Hg otherwise deposited as residue may follow marketed by-products (primarily gypsum wallboards and sulphuric acid).

According to data from the General Directorate of Energy on coal consumption and power generation capacity of 26 coal-fired power plants in operation in 2015, the Hg removal rate according to the UNEP Mercury Toolkit methodology is described in Table 29.

Table 29. Estimation of Hg removal rate by APC installed at coal-fired power plants in Vietnam and estmates of mercury emissions using the UNEP Toolkit level 2, for the year 2014.

No.	Coal-fired power plant	Coal consumption (metric tons/year)[1]	Electric production (MWh)[1]	Estimation of coal use efficiency (g/kWh)	Air pollution control equipment	Hg removal rate, % (UNEP Toolkit Level 2)	Estimation of Hg emissions (kg)	
							Using UNEP Default Factor (0.28 mg/kg)	Using Hg in coal of Quang Ninh (0.446 mg/kg)
1	Pha Lai (Unit 1)[3]	1,430,600	2,061,778.60	694	ESP	25	300.43	478.54
2	Pha Lai (Unit 2)[3]	1,923,080	3,632,930.77	529	ESP + FGD	65	188.46	300.19
3	Uong Bi (Unit 5 and 6)	346,020	422,662.94	819	ESP + FGD	65	33.91	54.01
4	Uong Bi extend (Unit 7)[3]	741,300	1,459,980.16	508	ESP + FGD	65	72.65	115.72
5	Uong Bi extend (Unit 8)[3]	690,830	1,319,123.80	524	ESP + FGD	65	67.70	107.84
6	Ninh Binh	393,550	485,342.01	811	ESP	25	82.65	131.64
7	Na Duong	492,520	618,661.45	796	ESP	25	103.43	164.75
8	Cao Ngan	436,930	577,047.00	757	ESP + boiler limestone injection	25	91.76	146.15
9	Formosa (Unit 1)[2]	488,850	622,189.00	786	ESP + FGD	65	-	-
10	Formosa (Unit 2)[2]	488,850	622,189.00	786			-	-
11	Hai Phong (Unit 1&2)[3]	1,644,590	3,631,561.43	453	ESP + FGD	65	161.17	256.72
12	Hai Phong (Unit 3)[3]	850,630	1,708,506.69	498	ESP + FGD	65	83.36	132.78
13	Hai Phong (Unit 4)[3]	538,220	1,074,040.77	501	ESP + FGD	65	52.75	84.02
14	Quang Ninh	1,492,550	2,824,867.86	528	ESP + FGD	65	146.27	232.99
15	Quang Ninh (Unit 3)[3]	653,980	1,295,337.70	505	ESP + FGD	65	64.09	102.09
16	Quang Ninh (Unit 4)[3]	762,800	1,503,903.61	507	ESP + FGD	65	74.75	119.07

No.	Coal-fired power plant	Coal consumption (metric tons/year)[1]	Electric production (MWh)[1]	Estimation of coal use efficiency (g/kWh)	Air pollution control equipment	Hg removal rate, % (UNEP Toolkit Level 2)	Estimation of Hg emissions (kg)	
							Using UNEP Default Factor (0.28 mg/kg)	Using Hg in coal of Quang Ninh (0.446 mg/kg)
17	Cam Pha (Unit 1)	1,101,230	1,762,745.30	625	ESP + boiler limestone injection	25	231.26	368.36
18	Cam Pha (Unit 2)	1,101,230	1,199,474.48	918			231.26	491.15
19	Son Dong	770,680	997,719.71	772	ESP + boiler limestone injection	25	161.84	257.79
20	Đong Trieu (Unit 1)	644,620	1,078,564.00	598	ESP + boiler limestone injection	25	135.37	215.63
21	Đong Trieu (Unit 2)	780,140	1,306,826.00	597			163.83	347.94
22	Vung Ang (Unit 1)[3]	274,230	643,189.00	426	ESP + FGD	65	26.87	42.81
23	Vung Ang (Unit 2)[3]	4,690	-	-			0.46	2.09
24	Nghi Son (Unit 1)	168,990	361,392.00	468	ESP + FGD	65	16.56	26.38
25	Mong Duong[3]	316,640	504,545.00	628	ESP + FGD	65	31.03	49.43
26	Vinh Tan (Unit 2)[3]	686,010	1,070,168.00	641	ESP + FGD	65	67.23	107.09
	Total	19,223,760					2,589.08	4,335.17

Notes:

(1) General Directorate of Energy, 2015

(2) Formosa (Unit 1&2) was used Bituminous imported from Russia and Indonesia in 2014 and does not have data of Hg concentration in coal

(3) Coal-fired power plants also used oil for electricity production

According to the PDP VII (revised), coal-fired power plant capacity will be added in 3 stages: 2016-2020; 2020-2025; 2025-2030. The number of coal-fired power plants and total capacity for each stage are shown in Table 30.

Table 30. Total planned capacity of coal-fired power plants up to 2030

Planning phase	Number of coal-fired power plants	Total capacity (MW)
Up to 2020	46	23,100
Up to 2025	83	46,675
Up to 2030	99	56,675

Assuming APC treatment systems of all coal-fired power plants consist of ESP and wet FGD installed to ensure compliance with current regulations on the exhaust gas treatment (QCVN 22:2009) and no additional measures to reduce Hg emissions from the combustion process, Hg emissions are estimated based on the data of thermal power sector in PDPVII (revised) as shown in Table 31.

Table 31. Estimation of Hg emissions from coal-fired power plants to 2030

Year	Total capacity (MW)	Coal consumption (thousand metric tons/year)	Estimation Hg removal rate (%)	Estimation of Hg emissions(kg/year)	
				Using UNEP Default factor (0.28 mg/kg)	Using Hg in coal of Quang Ninh (0.446 mg/kg)
2014[1]	-	26,400	-	3,484	-
2014[2]	10,030	19,223	25-65	2,589	4,335
2020[3]	23,100	63,000	65	6,174	9,834
2025[3]	46,675	95,000	65	9,310	14,830
2030[3]	56,675	129,000	65	12,642	20,137

Data Source Notes:

(1) Vinachemia, 2016

(2) General Directorate of Energy, 2015

(3) PDP VII (revised)

According to a report of Vietnam Chemicals Agency (Vinachemia, 2016), the total Hg emissions to air estimated from coal-fired plants in Vietnam in 2014 was about 3.484 metric tons and for other incinerators using coal was 1.413 metric tons. These emissions are estimated based on the amount of coal consumed in 2014 was about 26.4 million metric tons and not including the Hg removal rate of APC in the plants.

Using the UNEP Toolkit Level 2 with the average Hg concentration of Vietnamese coal analysed is 0.446 mg/kg and coal consumption of the 26 coal-fired power plants (data from General Directorate of Energy, 2015), the amount of Hg emission by coal-fired plants into the air in 2014 is about 4.3 metric tons. The UNEP Toolkit Level 2 default value (0.28 mg/kg) is significantly lower than our measured values, and would underestimate the emissions for the coal-fired power sector.

Comparison of Hg emissions in some countries shows the level of Hg emissions of Vietnam's coal-fired plants in 2014 still lower, just 1/9 of South Africa in 2009 (about 39.4 tons), (Dr Gregory Scott, 2011), 1/25 of China in 2005 (108.6 metric tons), (Tsinghua University, 2011) and 1/12 compared to India's Hg emission level (53.2 metric tons), (CIMFR, 2014). The results of comparing levels of Hg emissions in Vietnam's coal-fired plants with other countries are shown in Figure 21.

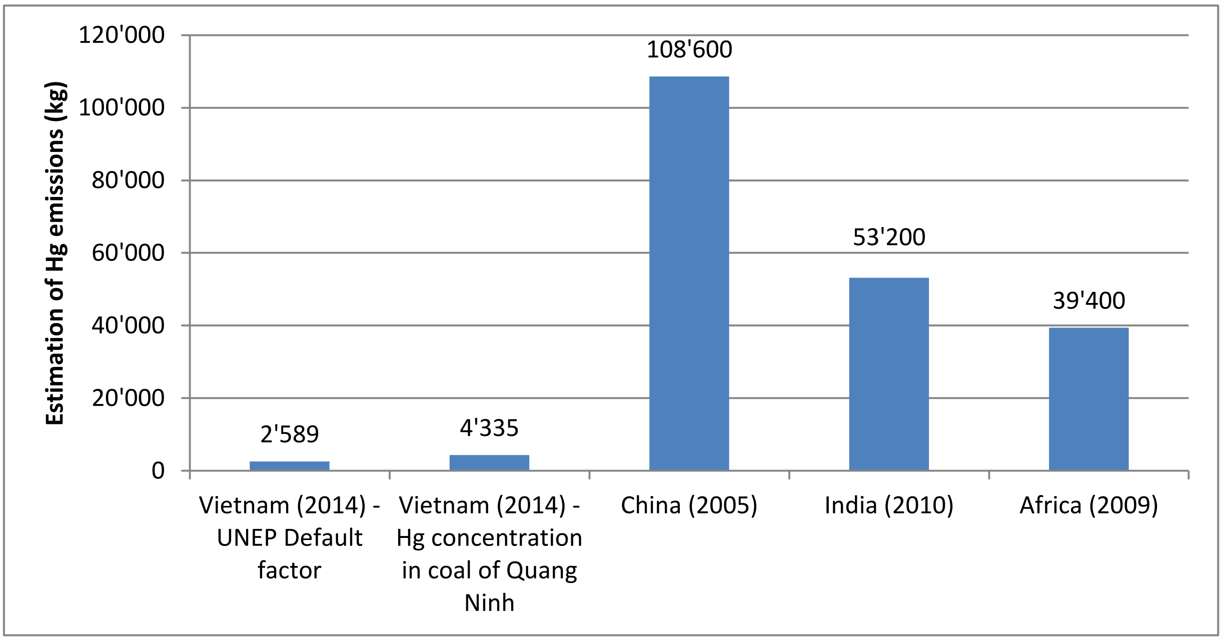


Figure 21. Comparison of Hg emissions from coal-fired power plants in selected countries

The result in Figure 21 is accordant with coal consumption in each country. While 26 plants in Vietnam used 19.2 million metric tons of coal in 2014, India consumed about 39 million metric tons by 2010 (CIMFR, 2014), China’s coal consumption was approximately 1 billion metric tons in 2005 (Tsinghua University, 2011) and South Africa consumed about 114.5 million metric tons (Gregory Scott, 2011).

V. Air Pollution Control Strategies and Technical Standards on Air Emissions from Coal-fired Power Plants

V.1. Technical standard for coal TCVN 8910:2011

This standard applies to all type of lump coal, bran coal, non-decentralized coal, and commercial peat. All coals must meet the quality standards and technical requirements after the process of sorting or processing that have been prescribed and used in all industrial sectors.

Accordingly, commercial coals must meet technical requirements in Table 32.

Table 32. Technical requirements for different coal types

Parameter	Requirements				Test Methodology
	Lump coal[1]	**Bran coal[2]**	**Peat[3]**	**Non-decentralized coal[4]**	
1. Particle size, mm	6-100	≤ 25	≤ 0.5	≤ 200	TCVN 251 (ISO 1953)
2. Ratio of Particle size, no larger, %	≤ 20	≥10	≥7	-	TCVN 4307
3. Dry ash (A^k), %	3.00-16.00	5.00-45.00	27.01-35.00	31.01-45.00	TCVN 173 (ISO 1171)
4. Total moisture (W^{tp}), no more than, %	6.00	23.00	25.00	16.00	TCVN 172 (ISO 589)
5. Dry volatiles (V^k), no more than, %	6.00	12.00	7.00	30.00	TCVN 174 (ISO 652)
6. Dry sulfur (S^k_{ch}), no more than, %	1.75	4.00	1.75	9.00	TCVN 175 (ISO 334)
7. Dry heat value (Q^k_{gr}), no less than, cal/g	6,700	4,200	5,000	3,750	TCVN 200 (ISO 1928)

Notes:

(1) Lump coal: coal size from 6-200mm and is often used for coal thermal power plants with fluidized boilers and other industries

(2) Bran coal: coal after crushing and screening, it is smaller in size than 25 mm and is often used for thermal power plants with pulverized coal boilers

(3) Peat: coal formed due to incomplete accumulation and degradation of residues under continuous anaerobic conditions; coal particle size is smaller than 0.5 mm; it is often used for fertilizer manufacturing.

(4) Non-decentralized coal: raw coal used with varying particle size

In addition, the standard is to provide specific technical criteria of each coal region for reference. The type of coal used for thermal power production (PC boilers) in Vietnam varies from level 4 to level 6, as shown in Appendix 4.

V.2. National Technical Regulation on emission of thermal power industry (QCVN 22: 2009/BTNMT)

The National Technical Regulation on Emission of Thermal Power Industry stipulates the maximum allowable concentration of pollutants in emissions from the thermal power industry when emitted into the atmosphere. Where the maximum allowable concentration of pollutants in emissions from thermal power industry is calculated as follows:

$$Cmax = C \times Kp \times Kv$$

where:

- Cmax is the maximum allowable concentration of pollutants in the flue gas of thermal power industry measured in milligrams per normal cubic meter of flue gas (mg/Nm^3)

- Kp is the power coefficient, as specified in Table 33.

Table 33. Power coefficient of thermal industry (Kp)

Design capacity of the thermal power plant, MW	Coefficient Kp
P ≤ 300	1
300 < P ≤ 1200	0.85
P > 1200	0.7

- Kv is the coefficient of region, as specified in Table 34.

Table 34. Values of regional coefficient (Kv)

Allocation of region, area		Coefficient Kv
Type 1	Inner city of urban city of special type(1) and urban city of type I(1): the specially-used forest areas(2), natural heritage areas, cultural, historic relics ranked(3); thermal power plants with a distance to the boundaries of these areas is less than 5 km.	0.6
Type 2	Inner city of urban city of type II, III, IV (1); suburbs of urban city of special type, urban city of type I with a distance to the boundary of Inner city is greater or equal to 5 km; thermal power plants with a distance to the boundaries of these areas is less than 5 km.	0.8
Type 3	Industrial zones; urban city of type V(1); suburbs of urban city of type II, III, IV with a distance to the inner city boundary is greater or equal to 5 km; thermal power plants with a distance to the boundaries of these areas is less than 5 km (4).	1.0
Type 4	Rural areas	1.2
Type 5	Mountainous rural areas	1.4

Notes:

(1)Urban area determined under the provisions of the Decree No.42/2009/ND-CP of May 7, 2009 of the Government on the classification of urban areas;

(2)Specially-used forest determined by the Law on Forest Protection and Development of December 14, 2004 include: National Parks; nature conservation areas; landscape protection area; forests for scientific research, experiments;

(3)Natural heritage, cultural, historical relics established and ranked by the United Nations Educational, Scientific and Cultural Organization, the Prime Minister or the governing ministry;

(4)In cases where the emission source hasa distance to two areas is more or less than 2 km, the coefficient of area/region is applied for the area with the smallest coefficient;

(5)The specific distance is calculated from the emission source.

- C is concentration of pollutants used as a basis for calculating the maximum allowable concentration of pollutants for emissions of thermal power industry and is specified in Table 35.

Table 35. Values of pollutant concentration (C)

No.	Pollutant	Value of concentration, C (mg/Nm^3)			
		A	B (by type of fuel used)		
			Coal	Oil	Gas
1	PM	400	200	150	50
2	Nitrogen oxide, NO_X (as NO_2)	1000	- 650 (for coal with a volatile content > 10%) - 1000 (for coal with a volatile content ≤ 10%	600	250
3	Sulfur dioxide, SO_2	1500	500	500	300

Notes:

- Column A specifies C concentration as the basis for calculating the maximum allowable concentration of pollutants for emissions from thermal power industry for units of thermal power plants which commenced their operations before October 17, 2005 with the application time utill December 31, 2014.

- Column B specifies C concentration as the basis for calculating the maximum allowable concentration of pollutants in the emission of thermal power industry for:

+ All units of thermal power plants operated from October 17, 2005.

+ All units of thermal power plants built after January 01, 2015.

V.3. Air pollution control strategies

On January 06, 2016, the Prime Minister approved the "National Action Plan on the Management of Air Quality up to 2020 and Vision to 2025". The objectives of the plan are to strengthen the management of air quality through controlling sources of emissions and ambient air quality monitoring, to improve the air quality and ensure human health. This focuses on the control of emission sources such as industrial emissions, energy and transport.

For control of industrial emission sources from now up to 2020, the focus is on 4 industrial sectors: thermal power, cement, chemical fertilizer, and steel production.

The Plan projected that: 80% of steel production facilities as well as chemical and chemical fertilizer facilities, 90% of thermal power production facilities, 80% of cement production facilities, and 70% of steel production facilities will achieve the requirements of the National Technical Regulations. Investment in installation of CEMS devices with parameters according to environmental technical regulations and inventory of emissions for 90% of thermal power plants, 80% of cement production facilities, 70% of steel production facilities, chemicals and chemical fertilizers.

To achieve these important goals and contribute to prevention and reduction of air pollution emissions, the Plan also provides practical solutions for implementation and focuses on the improvement of policy and legislative mechanisms and environmental standards for close emissions management.

During the period from 2019 to 2020, this plan will continue to revise and supplement regulations on the installation of a number of continuous automatic emission monitoring equipment, development and promulgation of guidelines for evaluation and identification of emission sources.

V.4. Development of the National Action Plan (NAP) to reduce Hg emissions from coal-fired power plants in Vietnam

In Vietnam, the thermal power sector is the major electricity industry (after hydropower). According to the PDP- VII (revised), the coal consumption of coal-fire plants in Vietnam will increase rapidly and therefore Hg emission will be one of the key issues for the environment in Vietnam. Therefore, a National Action Plan (NAP) to reduce and control Hg emissions is necessary in the future.

A NAP will satisfy the overall objectives to enhance control and reduction of Hg emissions from coal-fired power plants in order to meet the requirements of the Minamata Convention on Mercury. This also contributes to the protection of human health and the environment, and to sustainable development in Vietnam as well as international integration. The detailed objectives of the action plan include:

1) Strengthening capacity of institutional, legal framework to control Hg emissions.

2) Strengthening capacity of science and technology for the monitoring and analysis of Hg emissions from coal-fired power plants.

3) Applying Best Available Technology (BAT) and Best Environmental Practice (BEP) to reduce Hg emissions from coal-fired power plants.

4) Awareness rising of stakeholders on reduction of Hg emissions.

Objectives should be clearly linked to actions, as laid out in Table 36 below.

Table 36. Objectives and actions of the NAP

Objective	Action	Implementation
1. Institutional capacity, legal framework	1.1 Review existing regulations	Ministry of Natural Resources and the Environment (MONRE)
	1.2 Develop emission regulations	MONRE
	1.3 Coordination across governments/ministries	MONRE + MOIT + Department of Natural Resources and Environment (DONRE) + Coal thermal power plants
	1.4 Health and environmental impact assessments	MONRE
	1.5 Monitoring standards development	MONRE
2. Implementation	2.1 Analysis of financial resources, supply network	MF+ DONRE + Coal thermal power plants
	2.2 Timeline development	MONRE
	2.3 Project Plant selection	MONRE
	2.4 Analyze and apply BAT/BEP to selected project(s)	MONRE+ Coal thermal power plants
	2.5 Monitoring network, capacity building	MONRE+DONRE
3.Awareness raising	3.1 Information exchange, technology, policy, health effects.	MONRE + MOIT + NGO + Coal thermal power plants
	3.2 Public/professionals/local government	MONRE + DONRE
4. Action Effectiveness Evaluation	4.1 Monitoring data review	MONRE

Legal solutions should focus on the addition of Emission Limit Values for Hg emission and tightening for other pollutants such as PM, CO_2, NO_X, SO_2 of the coal-fired industry. The addition of the Emission Limit Values for Hg emission will ensure that coal-fired plants will improve the equipment and technology on Hg emission control. Besides, the supplementation of regulations on mercury levels in imported coal should be considered and implemented to prevent the import of coal with high concentrations of Hg to Vietnam.

The NAP is organized to be performed in three phases. The objective of each phase is to reduce Hg emissions. The specific technical activities to implement the NAP will be given for 3 phases: Phase 1 (2017 - 2020) with 10% reduction in Hg emissions; Phase 2 (2020-2025) with 30% reduction in Hg emissions; and Phase 3 (2025-2030) with 50% reduction in Hg emissions. The goal of each phase is described below.

Following legal regulation, technical activities are necessary and should be applied to adequately address the existing conditions at the plants. Specific technical activities will be conducted in three phases: Phase 1 (2017 - 2020) has a target to reduce 10% Hg emissions; Phase 2 (2020-2025) is 30% Hg emissions reduction; Phase 3 (2025-2030) is 50% Hg emissions reduction. Some specific technical activities in each phase include:

Phase 1 (2017-2020)

This phase mainly focuses on improving operational performance of the plants to not only increase production efficiency but also to reduce Hg emissions. On the other hand, developing continuous monitoring systems at thermal power plants to monitor the pollutants in the exhaust gases (PM, SO_2, NO_X), enhances the pollution control in coal-fired power plants and ensures the APC operate regularly and stably.

In addition, the implementation of inventory programs to assess and monitor Hg emissions from coal-fired power plants will support the implementation of the Minamata Convention.

These programs will assess the level of Hg emissions and identify which coal-fired plants should apply BAT/BEP to reduce Hg emissions in the next stage.

Phase 2 (2020-2025)

Phase 2 focuses primarily on improving the efficiency of coal input to reduce the impact of pollutants, including Hg. This could be achieved through measures that have effectively been applied in the world such as coal washing, coal blending and injection of additives for reducing Hg emissions by 30% from 2020 to 2025. The actions below aim at reducing the impact of coal burning on the environment.

a. Coal washing

Coal washing is an effective method that has been widely used around the world. Raw coal after mining, contains rock and clay, and should be prepared (sorting, processing, washing) to improve coal quality before being used as raw material for combustion at thermal power plants. According to a UNEP report, coal washing can reduce the ash content in coal from 40% to 20-30%. Improving the quality of the coal will not only enhance the productivity of plant operations but will also reduce emissions of harmful pollutants to the environment, such as Hg. According to the BAT/BEP Guidance of UNEP (2016), coal washing could help to remove Hg concentrations up to 37% in coal input.

b. Coal blending

Anthracite coal in Vietnam has the same energy value compared to bituminous coal in other countries but has higher ash and less flammability. Therefore, the rate of coal used in coal-fired plants is quite higher than other countries and the UBC will cause losses of energy and damage to the combustion chamber.

By using coal mixed with imported bituminous coal (low ash, higher energy and higher halogen content) will improve coal efficiency and the Hg removal rate of APC as well as reduce pollutants (SO_2, NO_X, PM) in the exhaust gases.

c. Injection of additives

Addition of halogen such as bromine, chlorine salt, hydrogen chloride, or ammonium chloride will increase the ability to form oxidized mercury (Hg^{2+}). These additives can be sprayed directly on coal or added as solids to a coal stream either upstream of the coal pulverizer or injected into the boiler. According to UNEP (2010), addition of bromine compounds will reduce the amount of elemental mercury by more than 80%.

Phase 3 (2025-2030)

This phase works towards improving the operational efficiency of the APC system to achieve the goal of reducing emissions up to 50%. By installing the entire ESP and FGD for all existing coal-fired plants, the efficiency of Hg treatment of APC equipment can reach 65% (UNEP, 2010).

In addition, the NAP should be a tool to increase the co-operation of environmental oganizations, the industry, plants and the community. Training programs are necessary to raise the awareness and technical level of stakeholders. The success of training programs will also greatly support the dissemination and replication of Hg emission control solutions at individual coal-fired plants.

VI. Summary

In 2016, by collaborating with UNEP, this research has assessed the Hg emission from coal-fired power plants in Vietnam. All types of anthracite which are used for coal-fired power plants were collected and analyzed. The results showed that the average concentration of Hg in coal from the 8 coal-mines in Quang Ninh region was 0.446 mg/kg. Compared with coal in Europe, Africa and South America, the Hg concentration in anthracite coal in Vietnam is relatively higher.

By using US EPA Method 30B, 3 coal-fired plants (Pha Lai, Quang Ninh and Ninh Binh) were monitored for Hg emission. The results showed the average of Hg concentration in flue gas of Pha Lai is higest (43.8 µg/Nm^3) and Quang Ninh is lowest (1.5 µg/Nm^3).

Based on information collected on coal consumption, APC systems of thermal power plants and using the UNEP Toolkit level 2, the study found that the total of Hg emissions from 26 Vietnam coal-fired power plants in 2014 is 4.33 metric tons.

According to PDP-VII (revised), coal consumption by coal-fired plants will be 95 million metric tons by 2025 and about 129 million tons by 2030. With the application of UNEP Tootkit level 2, Hg emissions estimated by Vietnam coal-fired plants will be about 14.83 metric tons in 2025 and continues to rise to 20.13 metric tons by 2030.

In fact, Hg emissions from coal-fired power plants depend on many factors, such as coal consumption, coal characteristics, APC installation and operation. To reduce the emissions of mercury from future coal-fired plants as well as to implement the Minamata Convention on Mercury, a NAP to reduce emissions has been proposed in the report. In addition to legislative solutions such as the establishment of Hg emission standards, the Hg threshold in coal, the BAT/BEP solutions have also been proposed based on the successful lessons from some coal-fired plants in the world. To effectively implement this plan, the organizations on environment, industry and power plants need to coordinate closely to meet two goals simultaneously on energy development and reducing Hg emissions in the future.

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Appendix 1: Results of coal analysis at coal mines

		Coal mine							
		Vang Danh	Nam Mau	Uong Bi	Nui Beo	Mao Khe	Ha Tu	Ha Lam	Hon Gai
Ca (%)	Sample-1	0.15	0.28	0.17	0.02	0.1	0.35	0.03	0.01
	Sample-2	0.15	0.27	0.15	0.07	0.06	0.51	0.03	0.17
	Sample-3	0.19	0.15	0.29	0.05	0.1	0.56	0.03	0.11
	Sample-4		0.24		0.04	0.1	0.15	0.03	0.11
	Sample-5					0.1	0.32		0.11
	Sample-6					0.04			0.05
Na (%)	Sample-1	0.15	0.08	0.04	0.03	0.1	0.07	0.01	0.01
	Sample-2	0.15	0.08	0.09	0.09	0.1	0.06	0.02	0.09
	Sample-3	0.19	0.09	0.08	0.06	0.1	0.08	0.08	0.1
	Sample-4		0.02		0.08	0.07	0.07	0.07	0.1
	Sample-5					0.13	0.05		0.27
	Sample-6					0.19			0.05
Se (mg/kg)	Sample-1	0.76	1.86	3.02	1.07	5.83	2.61	2.57	2.64
	Sample-2	1.18	1.44	3.44	1.75	4.79	2.77	1.02	5.48
	Sample-3	1	1.38	1.69	1.71	7.74	2.21	1.43	3.06
	Sample-4		1.68		0.9	4.22	2.17	1.95	5.17
	Sample-5					5.03	2.06		4.06
	Sample-6					3.82			4.88
As (mg/kg)	Sample-1	6.52	6.79	15.31	4.41	40.57	12.85	7.19	22.4
	Sample-2	3.41	8.3	14.53	9.3	40.4	9.9	6.19	44.02
	Sample-3	4.25	3.91	15.41	8.2	36.26	10.89	6.16	9.43
	Sample-4		6.84		6.96	48.04	11.81	5.3	8.33
	Sample-5					48.14	12.05		24.55
	Sample-6					42.15			23.99
Cl (g/kg)	Sample-1	0.37	0.1	0.27	1.03	0.76	0.15	2.17	1.38
	Sample-2	0.29	0.29	0.18	0.69	0.02	0.97	0.09	0.02
	Sample-3	0.38	0.75	0.37	0.1	1.49	0.97	0.37	0.28
	Sample-4		1.05		1.17	0.02	1.91	0.64	0.02
	Sample-5					0.02	0.12		0.75
	Sample-6					1.47			0.23
Hg (mg/kg)	Sample-1	1.508	1.22	0.157	0.122	0.505	0.126	0.18	0.145
	Sample-2	1.497	1.46	0.121	0.161	0.425	0.083	0.16	0.125
	Sample-3	1.49	1.32	0.122	0.139	0.455	0.078	0.204	0.168
	Sample-4		1.48		0.137	0.345	0.083	0.156	0.168
	Sample-5					0.356	0.081		0.168
	Sample-6					0.359			0.182

Appendix 2: Results of coal analysis at coal-fired power plants

		Coal-fired power plant					
		Cam Pha	Mong Duong	Ninh Binh	Quang Ninh	Uong Bi	Hai Phong
Ca (%)	Sample-1	0.31	0.23	0.22	0.16	0.21	0.13
	Sample-2	0.36	0.18	0.26	0.10	0.18	0.25
	Sample-3	0.35	0.16	0.27	0.14	0.19	0.24
	Sample-4	0.18	0.15	0.25	0.10	0.18	0.33
	Sample-5	0.34	0.19	0.37	0.13	0.23	0.35
	Sample-6			0.32		0.16	0.11
Na (%)	Sample-1	0.03	0.03	0.07	0.09	0.06	0.11
	Sample-2	0.08	0.08	0.12	0.04	0.04	0.12
	Sample-3	0.03	0.06	0.05	0.02	0.03	0.10
	Sample-4	0.04	0.03	0.05	0.07	0.11	0.10
	Sample-5	0.05	0.05	0.04	0.03	0.07	0.13
	Sample-6			0.04		0.05	0.05
Se (mg/kg)	Sample-1	1.54	1.95	2.04	1.84	1.54	2.15
	Sample-2	1.53	1.68	2.51	1.75	5.36	2.68
	Sample-3	1.60	1.79	2.66	1.87	3.48	2.64
	Sample-4	2.49	2.14	1.62	1.46	3.20	3.90
	Sample-5	5.00	2.38	3.06	2.21	2.60	3.36
	Sample-6			2.85		1.64	2.74
As(mg/kg)	Sample-1	8.32	1.43	1.53	8.51	1.05	1.64
	Sample-2	6.35	1.18	2.00	7.87	4.85	2.17
	Sample-3	6.29	7.08	2.14	8.57	2.96	2.13
	Sample-4	8.84	7.91	1.22	6.53	2.69	3.38
	Sample-5	8.36	8.82	2.55	7.18	2.08	2.85
	Sample-6			2.34		1.13	2.22
Cl (g/kg)	Sample-1	0.10	0.02	1.18	0.26	0.82	1.65
	Sample-2	0.27	0.26	2.37	0.28	1.64	1.32
	Sample-3	2.26	0.35	1.98	0.61	0.21	0.69
	Sample-4	0.63	1.20	0.16	0.26	1.23	0.74
	Sample-5	0.66	1.25	1.25	0.18	0.52	1.04
	Sample-6			1.74		0.75	1.95

		Coal-fired power plant					
		Cam Pha	Mong Duong	Ninh Binh	Quang Ninh	Uong Bi	Hai Phong
Hg (mg/kg)	Sample-1	0.143	0.406	0.311	0.186	1.620	0.180
	Sample-2	0.106	0.415	0.388	0.158	3.260	0.271
	Sample-3	0.113	0.973	0.372	0.203	2.220	0.316
	Sample-4	0.101	0.358	0.334	0.177	2.320	0.386
	Sample-5	0.099	0.390	0.164	0.160	2.020	0.342
	Sample-6			0.213		2.000	0.192

Appendix 3: Interlaboratory results

Coal mines	Analysis result	Element					
		Ca (%)	Na (%)	Se (mg/kg)	As (mg/kg)	Cl (mg/kg)	Hg (mg/kg)
Nui Beo	By CEM	0.07	0.09	1.75	9.3	0.69	0.161
	Interlaboratory	0.09	0.07	1.44	8.86	0.67	0.22
	RPD %	25.00	25.00	19.44	4.85	2.94	30.97
Ha Tu	By CEM	0.35	0.07	2.61	12.85	0.15	0.126
	Interlaboratory	0.35	0.06	2.14	12.1	0.16	0.15
	RPD %	0.00	15.38	19.79	6.01	6.45	17.39
Hon Gai	By CEM	0.05	0.05	4.88	23.99	0.23	0.182
	Interlaboratory	0.04	0.04	5.12	23.2	0.23	0.23
	RPD %	22.22	22.22	4.80	3.35	0.00	23.30
Mao Khe	By CEM	0.1	0.1	5.83	40.57	0.76	0.505
	Interlaboratory	0.08	0.12	5.39	39.7	0.79	0.5
	RPD %	22.22	18.18	7.84	2.17	3.87	1.00
Uong Bi	By CEM	0.17	0.04	3.02	15.31	0.27	0.157
	Interlaboratory	0.2	0.04	2.94	15.6	0.25	0.25
	RPD %	16.22	0.00	2.68	1.88	7.69	45.70

Appendix 4: Specific technical criteria of each coal region (TCVN 8910:2011)

Mine area	Coal type	Code	Paticle size (mm)	Dry ash (A^k %)		Total moisture (W^{tp} %)		Dry volatiles (V^k %)	Dry sulfur (S^k_{ch} %)		Dry heating value limit (Q^k_{gr} cal/g)
				Average	Range	Average	Limit	Average	Average	Limit	
Hon Gai–Cam Pha	Class 4a HG	HG 09A	≤ 15	21.00	19.01-23.00	8.00	12.00	6.50	0.65	0.90	6,400
	Class 4b HG	HG 09B	≤ 15	25.00	23.01-27.00	8.00	12.00	6.50	0.65	0.90	5,950
	Class 5a HG	HG 10A	≤ 15	29.00	27.0-31.00	8.00	12.00	6.50	0.65	0.90	5,600
	Class 5b HG	HG 10B	≤ 15	33.00	31.01-35.00	8.00	12.00	6.50	0.65	0.90	5,250
	Class 6a HG	HG 11A	≤ 15	37.50	35.01-40.00	8.00	12.00	6.50	0.65	0.90	4,800
	Class 6b HG	HG 11B	≤ 15	42.50	40.01-45.00	8.00	12.00	6.50	0.65	0.90	4,350
Uong Bi-Nam Mau-Vang Danh	Class 4a VD	VD 09A	≤ 15	21.00	19.01-23.00	8.50	13.00	3.75	1.10	1.75	6,000
	Class 4b VD	VD 09B	≤ 15	25.00	23.01-27.00	8.50	13.00	3.75	1.10	1.75	5,700
	Class 5a VD	VD 10A	≤ 15	29.00	27.01-31.00	8.50	13.00	3.75	1.10	1.75	5,400
	Class 5b VD	VD 10B	≤ 15	33.00	31.01-35.00	8.50	13.00	3.75	1.10	1.75	5,050
	Class 6a VD	VD 11A	≤ 15	37.50	35.01-40.00	8.50	13.00	3.75	1.10	1.75	4,650
	Class 6b VD	VD 11B	≤ 15	42.50	40.01-45.00	8.50	13.00	3.75	1.10	1.75	4,200
Mao Khe	Class 4b MK	MK 09B	≤ 15	25.00	23.01-27.00	8.00	12.0	5.00	0.80	1.20	5,700
	Class 5a MK	MK 10A	≤ 15	29.00	27.01-31.00	8.00	12.0	5.00	0.80	1.20	5,350
	Class 5b MK	MK 10B	≤ 15	33.00	31.01-35.00	8.00	12.0	5.00	0.80	1.20	5,000
	Class 6a MK	MK 11A	≤ 15	37.50	35.01-40.00	8.00	12.0	5.00	0.80	1.20	4,600

Mine area	Coal type	Code	Paticle size (mm)	Dry ash (A^k %)		Total moisture (W^{tp} %)		Dry volatiles (V^k %)	Dry sulfur (S^k_{ch} %)		Dry heating value limit (Q^k_{gr} cal/g)
				Average	Range	Average	Limit	Average	Average	Limit	
	Class 6b MK	MK 11B	≤ 15	42.50	40.01-45.00	8.00	12.0	5.00	0.80	1.20	4,200
Nui Hong	Class 4a NH	NH 09A	≤ 25	21.00	19.01-23.00	20.00	23.00	7.00	3.00	4.00	6,150
	Class 4b NH	NH 09B	≤ 25	25.00	23.01-27.00	20.00	23.00	7.00	3.00	4.00	5,850
	Class 5a NH	NH 10A	≤ 25	29.00	27.01-31.00	20.00	23.00	7.00	3.00	4.00	5,450
	Class 5b NH	NH 10B	≤ 25	33.00	31.01-35.00	20.00	23.00	7.00	3.00	4.00	5,150
	Class 6a NH	NH 11A	≤ 25	37.50	35.01-40.00	20.00	23.00	7.00	3.00	4.00	4,700
	Class 6b NH	NH 11B	≤ 25	42.50	40.01-45.00	20.00	23.00	7.00	3.00	4.00	4,350
Khanh Hoa	Class 4a KH	KH 09A	≤ 25	21.00	19.01-23.00	10.50	14.00	12.00	2.00	3.00	6,150
	Class 4b KH	KH 09B	≤ 25	25.00	23.01-27.00	10.50	14.00	12.00	2.00	3.00	5,750
	Class 5a KH	KH 10A	≤ 25	29.00	27.01-31.00	10.50	14.00	12.00	2.00	3.00	5,400
	Class 5b KH	KH 10B	≤ 25	33.00	31.01-35.00	10.50	14.00	12.00	2.00	3.00	5,050
	Class 6a KH	KH 11A	≤ 25	37.50	35.01-40.00	10.50	14.00	12.00	2.00	3.00	4,650
	Class 6b KH	KH 11B	≤ 25	42.50	40.01-45.00	10.50	14.00	12.00	2.00	3.00	4,200
Nong Son	Class 5a NS	NS 10A	≤ 25	29.00	27.01-31.00	10.00	12.00	7.50	2.50	3.50	5,300
	Class 5b NS	NS 10B	≤ 25	33.00	31.01-35.00	10.00	12.00	7.50	2.50	3.50	5,100
	Class 6a NS	NS 11A	≤ 25	37.50	35.01-40.00	10.00	12.00	7.50	2.50	3.50	4,650
	Class 6b NS	NS 11B	≤ 25	42.50	40.01-45.00	10.00	12.00	7.50	2.50	3.50	4,250

Mine area	Coal type	Code	Paticle size (mm)	Dry ash (A^k %)		Total moisture (W^{tp} %)		Dry volatiles (V^k %)	Dry sulfur (S^k_{ch} %)		Dry heating value limit (Q^k_{gr} cal/g)
				Average	Range	Average	Limit	Average	Average	Limit	
Na Duong	Class 1	ND10	≤ 200	33.00	31.01-35.00	12.00	16.00	30.00	7.00	9.00	4,350
	Class 2	ND 11A	≤ 200	37.50	35.01-40.00	12.00	16.00	30.00	7.00	9.00	4,050
	Class 3	ND 11B	≤ 200	42.50	40.01-45.00	12.00	16.00	26.00	7.00	9.00	3,750