REPORT
Analysis of future generation capacity scenarios for Vietnam

Hanoi, Oktober 18, 2017

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Executive summary

On 18/3/2016, the revised power development plan Nr.7 looking to 2030 (PDP VII rev) was released. Various development partners expressed concerns about this plan as the share of coal in this plan is still high, accounting for 43% of the capacity mix by 2030 with 31 new coal fired power plants planned. World Bank President Jim Yong Kim said if these coal plants were built, it would be a 'disaster' for the planet.
The PPD 7 rev is not compliant with the renewable energy targets as set out earlier in the Renewable Energy Development Strategy (REDS).
Meanwhile, in 2016 the National Assembly adopted a resolution on stopping to implement the Ninh Thuan nuclear power plant project due to economic reasons.
In light of those changes and commitments, on-going tendencies towards low carbon development and technology improvement, the PDP VII rev should be updated.
A least-cost model was developed to model the future electricity generation options for Vietnam to give inputs to this process. In this exercise, the system is divided into 3 sub-systems representing three geographic regions which are modelled separately but linked to each other by transmission grids.
Updated input data and assumptions including fuel price forecasts, specific investment cost for technologies and expected cost evolution were used. For renewable energies, updated inputs include resource potentials (categorized into resource quality categories) and their investment cost and trend.
From the modelling and analysis, the following broad conclusions could be drawn:

- Renewable energy technologies are getting less and less expensive. Solar PV as of 2020 and wind power as of 2025 could compete directly with fossil fuel based power.

- Development of renewable energy brings many benefits including cost, environment, and energy security….. Including just the environmental and social benefits into the production cost would make many renewable energy technologies, those even with poorer resources become cost-competitive to fossil fuel based technologies.

- Results from the modelling shows that share of renewable energy capacity could reach 27.8% in 2030. The higher share could be expected if a longer time horizon is studied as then a higher built rate for renewable energy technologies could be assumed.

- Along with renewable energy development, promoting of energy efficiency would be prioritized as it could lessen the burden on capacity addition. It is estimated that as much as 17 GW could be reduced - equivalent to 14 coal fired power plants by further promotion of EE. This, if combined with additional RE development would result in CO_2 emission reduction of up to 52%.

Hence, we recommend that:

- The power development plan considers energy efficiency properly. There is large capacity within Vietnam to implement greater energy efficiency, due to its high intensity of energy consumption. EE options can be modeled as generation technologies. In this case, these technologies avoid demand, rather than provide additional supply.

- It is recommended to use cost curve to present EE options. The cost curve shows the relations ship between cost of saving and the amount of saving that can be implemented.

- The "profile" of saving should be captured as this means greatly different for the system, to the cost that the system could avoid. If the savings are at peak times when the demand on the grid is highest and the most expensive generation has to be brought on-line, the avoided cost to the system could be many folds more than the similar at off-peak times.

- In the long-run, it might be worthwhile to evaluate the performance of the sectors in terms of their contribution to the economy and the resources, in particular energy resources. From the perspectives, restructuring of the economy might be proposed to improve the efficiency of the economy.

- Further on EE, attention should be paid to roof-top solar PV as it can reduce peak demand due to a high correlation of its power output profile and the system load curve, in particular in the southern provinces.

- In terms of power planning, the choice of power generation technologies/sources should be made from the view point of the economy. Ignorance of external cost would eliminate the possible contribution of renewable energy sources.

- It is recommended that the existing power development plan (PDP) be updated in the direction of reducing coal power and replaced it by renewable energies and gas power to ensure supply reliability.

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Abbreviations

BAU	Business As Usual
BOT	Build – Operation – Transfer
CCS	Carbon Capture Storage
CCGT	Combined Cycle Gas Turbine
CO_2	Carbon dioxides
CSP	Solar Power Plant
DO	Diesel Oil
EVN	Electricity of Vietnam
ESMAP	Energy Sector Management Assistance Program
FO	Fuel Oil
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GIS	Geographic Information System
GreenID	Green Innovation and Development Centre
GW	Gigawatt
IEA	International Energy Agency
ISEA	Industrial Techniques and Environment Agency
IMF	International Monetary Fund
INDC	Intended Nationally Determined Contribution
IPPs	Independent Power Plants
LCCA	Life-Cycle Cost Analysis
LCOE	Levelized cost Of Energy
LNG	Liquefied Natural Gas
MOIT	Ministry of Industry and Trade
NOx	Nitrogen oxides
NGGS	National Green Growth Strategy
OECD	Organization for Economic Cooperation and Development
O&M	Operation and Maintenance
PDP	Power Development Plan
PV	Photovoltaic
PVN	PETROVIETNAM
RE	Renewable Energy
REDS	Renewable Energy Development Strategy
SOx	Sulphur oxide
T&D	Transmission and Distribution
VBF	Vietnam Business Forum
VSEA	Vietnam Sustainable Energy Alliance
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wildlife Fund

1. Introduction

In late 2015, the Vietnam Sustainable Energy Alliance led by Green Innovation and Development (GreenID) conducted a study on the power source scenarios to provide constructive comments to the process of revising the Power Development Plan Nr. VII (PDP VII rev) by the Government. The PDP VII rev was approved by the Prime Minister on 18/3/2016. It cut down 20 GW of coal as compared to the original PDP as a result of using more realistic macro-economic assumptions for the demand forecast. However, the share of coal in the new generation plan is still high, accounting for 43% of the capacity mix by 2030 with 31 new coal fired power plants planned.
Therefore, various development partners have expressed concern about the PDP VII rev and accordingly conducted studies to suggest alternatives to generation development plan for Vietnam. For example,

- The World Wide Fund For Nature (WWF) commissioned a study that explores pathway for Vietnam to achieve 100% renewable energy by 2050. WWF published its study in 2016 (WWF, 2016).
- The Vietnam Business Forum (VBF) published the "Made in Vietnam Energy Plan" in 2016 that discusses solutions for Vietnam's future energy needs that stimulates investment in energy generation and to meet Vietnam's climate change obligations. It suggests to place a greater emphasis on cleaner domestic sources of energy including: renewables including biomass, wind and solar; sustainable energy efficiencies: and the increased development of Vietnam's offshore natural gas as they all reduce the effects on the environment and the need for imported coal (VBF, 2016).

Meanwhile, the Government has issued a number of decisions and policies relating to the power sector.

- Vietnam submitted its Intended Nationally Determined Contribution (INDC) report to the UNFCCC Secretariat in December 2015 prior to COP 21 in Paris. At the event, countries collectively agreed to keep global temperature rise this century well below 2 degrees Celsius and take further efforts to limit the temperature increase even further to 1.5 degrees Celsius above pre-industrial levels. Vietnam committed a voluntary CO_2 emission reduction of 8% by 2030 compared to the Business As Usual (BAU) level. The reduction will increase to 25% if receipt of international support (MONRE, 2015).
- The Government released the Renewable Energy Development Strategy (REDS) which sets an ambitious set of renewable energy targets, with the intention of raising the share of RE to 44% of the total primary energy consumption in 2050 (Decision No 2068/QĐ-TTg dated November 25, 2015).
- The National Assembly adopted a resolution on stopping to implement the Ninh Thuan nuclear power plant project (Resolution No 31/2016/QH14 dated November 22, 2016).
- The Government issued Decision No 11/2017/QĐ- TTG about the support mechanism for solar PV in April 2017 indicating its priority for clean energy.

In the context of these new government policies and concerns/contributions by development partners, GreenID and the Vietnam Sustainable Vietnam Sustainable Energy Alliance (VSEA) having granted with the mandate to contribute to sustainable energy development in Vietnam see the needs to update the study on power sources for its information and to advocate sustainable policies. The team is also inspired by the increasing competitiveness of solar PV technologies[1] and want to explore how much solar PV can be developed to meet the energy need of the country. Therefore, the objectives of the study are firstly to update the generation section with these policy changes and tendencies; and secondly to explore measures to achieve higher percentage of renewable energy in the generation mix than what is in the PDP VII rev.

The report is structured as follows. Section 2 provides an overview of the power sector followed by a review of recent key policies relating to future power sources. Section 3 and section 4 discusses the development of the MARKAL model, which is the tool used to analyse future generation mixes. Accordingly, various parameters and assumptions which enable the construction and investigation of the power system in Vietnam are described. A particular part is devoted to discussing renewable energies from available resources to exploitation technologies and modelling approach. In section 5, results of the model runs are evaluated. Finally, in section 6, conclusions of the analysis are summarized and policy implications are discussed.

2. Current situation of the sector and key development policies

At the end of 2015, total generating capacity of Vietnam was 38,553 MW, which comprised of 38.0% hydropower, 33.5% coal, 20.7% gas and the rest were oil and renewable energies.

Table 1: Power generation capacity as of the end of 2015

Power source	Capacity (MW)	Rate (%)
Hydropower	14,636	38%
Coal fired power	12,903	33.5%
Oil fired power	875	2.3%
Gas fired power	7,998	20.7%
Renewable	135	0.4%
Diesel and Small hydropower	2,006	5.1%
Total	**38,553**	**100%**

Source: EVN, 2016

EVN owns 61.2% of the generating capacity. Others are owned by PetroVietnam, Vinacomin (two other large state-owned corporations), IPPs and others.

Table 2: Power generation capacity by ownership as of the end of 2015

[1] Cost of solar PV has reduced significantly (80% reduction since 2008) and tends to continue to do so in the coming decade.

Owner	Capacity (MW)	Rate (%)
EVN	23,580	61.2%
PetroVietnam	4,435	11.5%
Vinacomin	1,785	4.6%
BOT and other investors	8,753	22.7%
Total	**38,553**	**100%**

Source: EVN, 2016

EVN acts as the single power purchaser from the generators. Total power production and purchase by EVN in 2015 was 159.68 billion kWh of which the power sale was 143.68 billion kWh. During 2011-2015, electricity generation output increased by 11% per year on average.

The latest power development plan is the revised PDP VII rev which looks to 2030 and was approved by the Prime Minister under Decision 428/QĐ-TTg 18/3/2016. It is the revised version of the PDP announced in 2011 under Decision 1208/QD-TTg. The PDP VII rev projected the electricity demand in 2020 to be 235-245 billion kWh, 352-379 billion kWh in 2025 and 506-559 billion kWh in 2030, equivalent to the annual average growth rate of 8.0-8.7% per year which is much lower than the forecasts in the original PDP[2] mainly due to using updated macro-economic assumptions and as a result, leading to less capacity (than the original PDP) to be built to meet the demand. To meet this new forecasted demand, generating capacity of the system is planned to increase to 60,000 MW in 2020 and 129,500 MW in 2030.

Table 3: Planned power generation capacity in 2020 and 2030[3]

Fuel types	2015	2020	2030
Natural gas	7,998	8,940	19,037
Coal	12,903	25,620	55,167
Nuclear		-	4,600
Hydro (large, PSH)	14,636	18,060	21,886
Oil	875	-	-
Solar	5	850	12,000
Wind	135	800	6,000
Other (Diesel, Small HH, biomass, waste to energy)	2,006	4,290	9,195
Import	500	1,440	1,554
Total	**39,058**	**60,000**	**129,500**

Source: PM, 2016

[2] The base demand scenario has an annual average growth rate of 10.0% from 2011 to 2030, leading to the demand in 2030 of 695 billion kWh. The high demand scenario has an annual average growth rate of 11.2%, leading to the demand in 2030 of 833 billion kWh.
[3] Capacity in this table is lightly higher than that in table 2 as it includes import and off-grid solar PV capacity

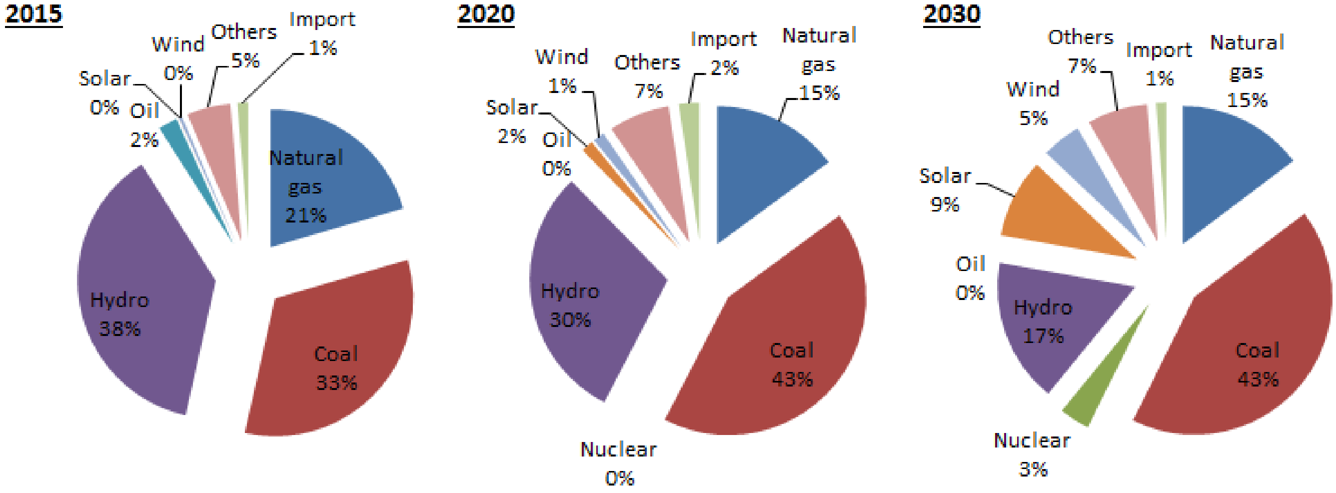


Figure 1: Share of power generation capacity by fuel type

As can be seen in Table 3 and Figure 1, along with increasing capacity, structure of generation capacity is expected to change significantly. Share of hydro power is expected to reduce from 38% in 2015 to 17% in 2030, natural gas from 21% in 2015 to 15% in 2030, whereas coal power is expected to grow strongly, from a share of 33% in 2015 to 43% in 2030 (from 12.9 GW to 55.1 GW with 31 new coal-fired power plants planned). Percentage of electricity production from coal is expected to increase from the current 34.4% to 49.3% in 2020 and 53.2% in 2030.

The share of renewable energy (excluding large hydro) installed capacity is expected to grow from 5.4% in 2015 to 9.9% in 2020 and 21% in 2030. In terms of electricity production, the percentage from renewables is set at 6.5% in 2020 and 10.7% in 2030 due to generally lower capacity factors of renewable energy power versus conventional power sources.

Another striking point in terms of future power source is the plan to build 2 nuclear power plants with the combined capacity of 4600 MW by 2030 in Ninh Thuan.

Along with power generation expansion, there is also a strong requirement for transmission network expansion as presented in Table 4.

Table 4: Power network expansion requirement

	Unit	2016-2020	2021-2025	2026-2030
500kV substation	MVA	26,700	26,400	23,550
220kV substation	MVA	34,966	33,888	32,750
500kV lines	km	2,746	3,592	3,714
220kV lines	km	7,488	4,076	3,435

Total capital requirement for the above investments is estimated at US$9.8 billion per year, a significant increase from the past figures (total investment in 2012 was around US$ 2.6 billion and slightly increased in 2013).

The focus of this plan on increasing coal power development has put Vietnam in an adverse situation because there is increasing global pressure to reduce greenhouse gas (GHG) emissions, particularly from the energy sector. In the landmark United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement in 2015, governments from nearly all countries agreed to keep global temperature rise this century well below 2 degrees Celsius and make efforts to limit the temperature

increase to 1.5 degrees Celsius above the pre-industrial level. Vietnam committed to 8% GHG emission reduction by 2030 compared to the BAU scenario in its Intended Nationally Determined Contribution (INDC) report submitted to the UNFCCC secretariat. The reduction would increase to 25% with international support.
In May 2016, World Bank President Jim Yong Kim said a decision by Vietnam to build the full 40 GW countrywide would be a 'disaster' for the planet.
The PPD 7 rev is not compliant with the renewable energy targets as set out earlier in the Renewable Energy Development Strategy (REDS) (Figure 2).
Meanwhile, in 2016 the National Assembly adopted a resolution on stopping to implement the Ninh Thuan nuclear power plant project due to economic reasons.

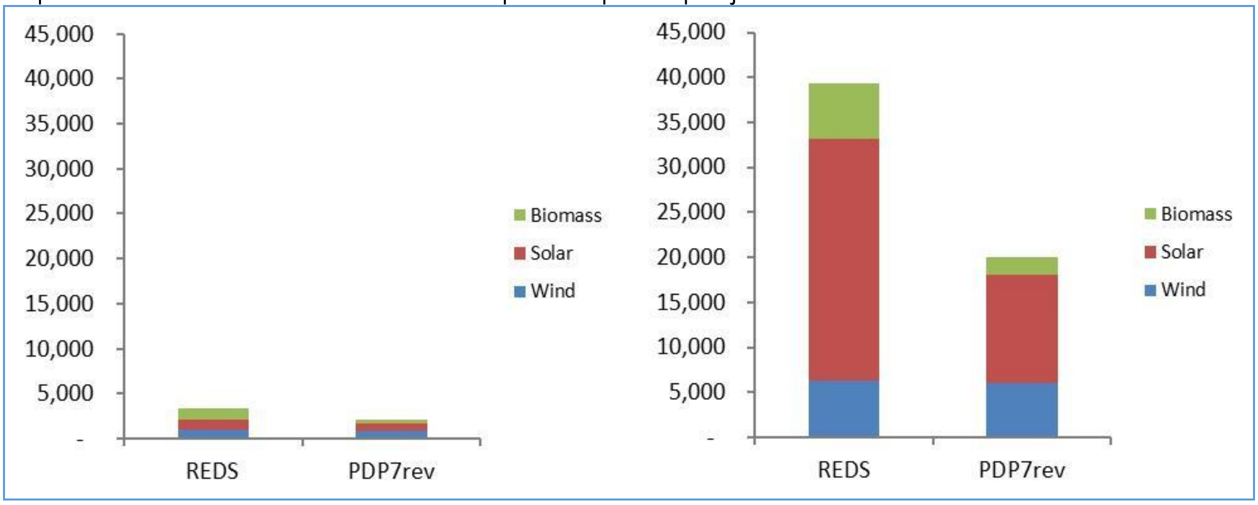


Figure 2: Renewable energy targets (MW) in the PDP VII rev and the REDS by 2020 and by 2030

3. Modeling approach

3.1 Introduction of MARKAL

MARKAL is used to model the future electricity generation mix for Vietnam. MARKAL is a dynamic, multi-period, linear programming bottom-up model. It was developed by a consortium of members of the International Energy Agency (IEA) in the early 1980s based on the general algebraic modelling system (GAMS). Since then, the model has evolved and has been applied to a wide range of energy and environmental issues in many countries other than IEA member countries. The issues that MARKAL has been successfully used to examine include:

- Energy security.
- New technology R&D portfolio prioritization.
- Impacts and benefits of environmental regulations.
- Greenhouse gas (GHG) emissions projections, *and*
- GHG project evaluation and estimates of the value of carbon rights.

There are a number of studies applying MARKAL. For example, in Vietnam, Khanh N.Q (2006) used MARKAL to examine the impacts of wind power generation and CO_2 emission constraints on the future choice of fuels and technologies in the power sector of Vietnam. Minh D.T (2011) used MARKAL to analyse future energy pathway for Vietnam.
MARKAL determines the power generation mix by using an optimization approach with total cost of the system as the objective function (in brief least cost model). This is similar to the STRATEGIST model which was used for deriving generation mix for the

PDP VII rev, so the results are by our understanding comparable. In the PDP VII rev, PDPAT2 was used in addition to STRATEGIST which simulated the dispatch for the power generation mix determined by STRATEGIST.

3.2 Modeling of Vietnam Power system

Currently, the distribution of power plants in Vietnam is heavily influenced by its natural geography and energy reserves. In the north, hydro and coal power plants dominate while in the south gas turbines represent the major power source. As such, there is a mismatch between demand and supply capability by region. There is surplus capacity in the north while there is a low reserve margin in the south (Table 5). To enable power exchange between regions, a 500 kV north-south transmission line was constructed in 1994. The second line was completed in late 2005. These two lines are now serving as the backbone for the power system of Vietnam. Presently, the load ability of the 500 kV transmission lines is 3500 MW for the South-Centre section and 1800 MW for the North-Centre.

Table 5: Reserve capacity by region

Region	2010			2015		
	Installed capacity	Peak power	Reserve capacity	Installed capacity	Peak power	Reserve capacity
North	8,698	6,547	*33%*	21,046	11,874	*77%*
Centre	2,371	1,648	*44%*	3,574	2,546	*40%*
South	9,447	7,566	*25%*	13,917	11,798	*18%*

Source: National Dispatching Centre

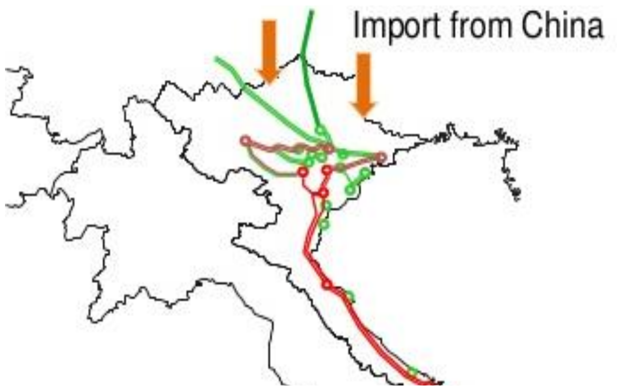


Figure 3: Transmission network

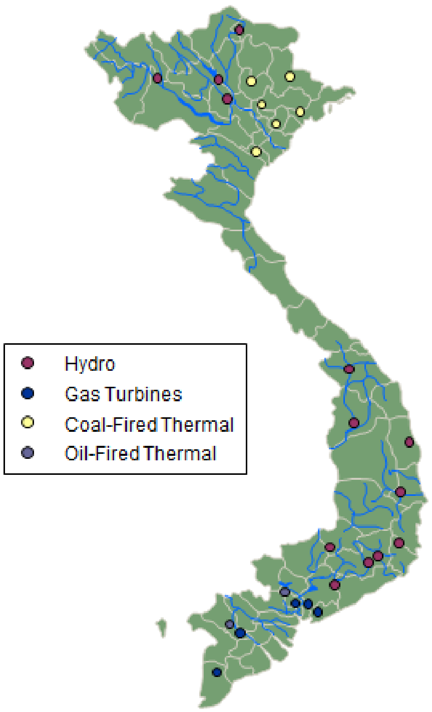
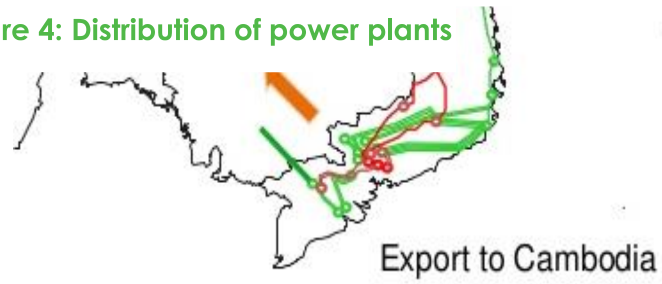


Figure 4: Distribution of power plants



By planning guidance, power plants should be located near the load centers to reduce transmission investment and losses and also because there is a limitation to the transfer capacity of the transmission network. Therefore, in the present study, the power system of Vietnam will be divided into 3 sub-systems representing three geographic regions which are linked to each other by the transmission grids. Transfer capacity of the transmission lines is subject to their load ability. Figure 5 illustrates the separation and Figure 6 presents the modelling approach.

By the official definition, the north includes provinces in the north up to Nghe An and Ha Tinh. Centre region includes 4 highland provinces (Gia Lai, Kon Tum, Daklak, Dak Nong) and provinces from Quang Binh to Khanh Hoa. The southern region includes the rest provinces.

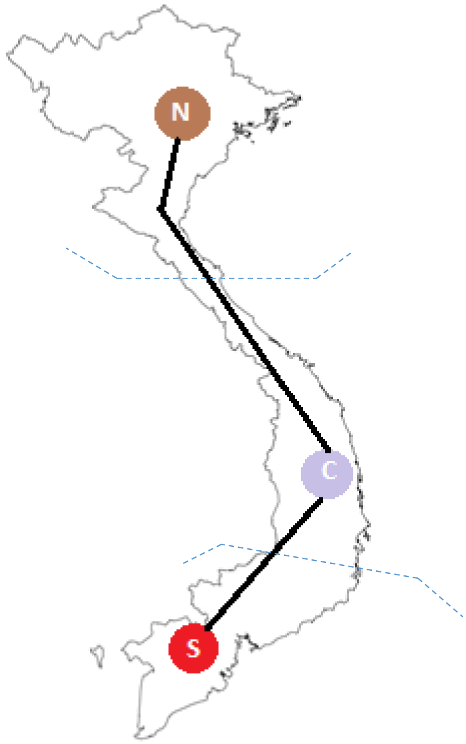


Figure 5: Modeling the power system of Vietnam

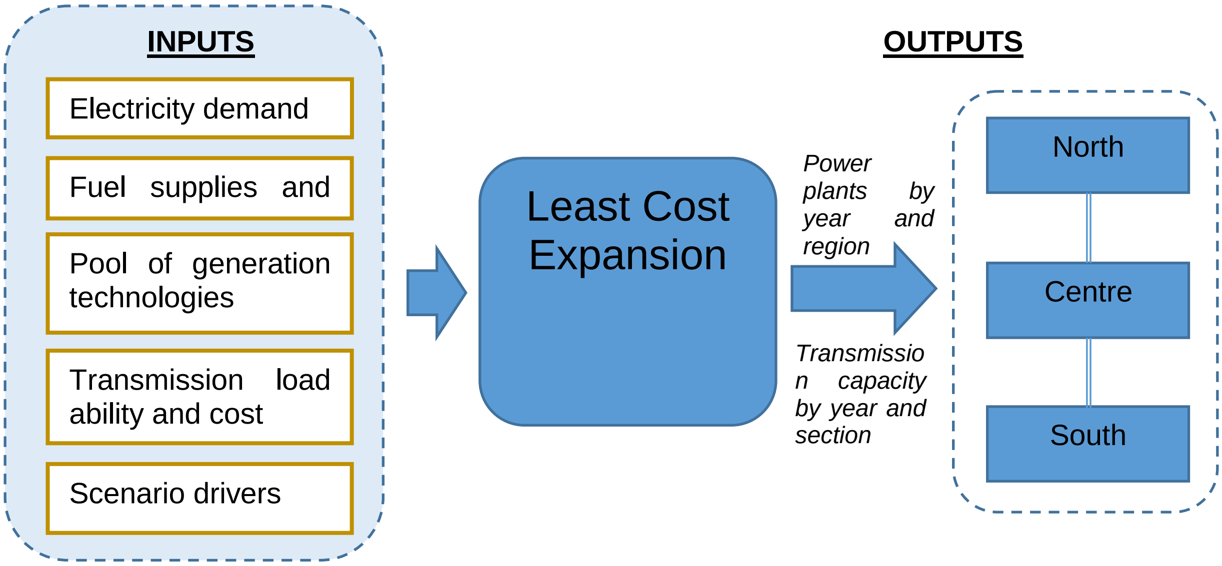


Figure 6: Modeling approach for the power generation of Vietnam

4. Key input data and assumptions

4.1 Power demand forecast

This study adopts the forecast by the PDP VII rev so as to be able to analyze the modeling results versus the PDP VII rev.
By this forecast, energy demand is expected to increase 3.54 folds from 143.4 billion kWh in 2015 to 507 billion kWh in 2030, equivalent to an annual average growth rate of 8.8% per year.

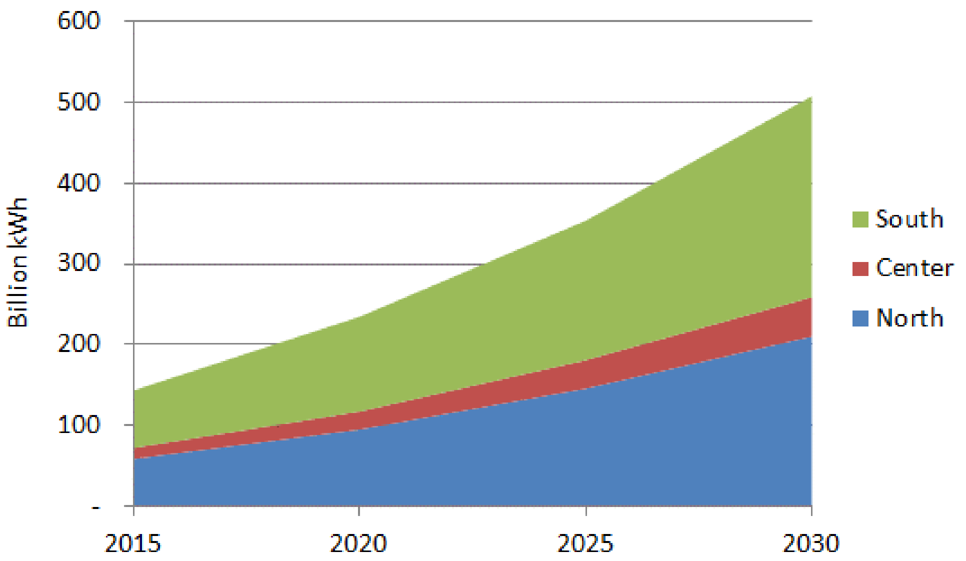


Figure 7: Electricity demand forecast

In addition to the above demand forecast, the study also uses the demand forecast made by Vietnam Sustainable Energy Alliance led by GreenID in 2015[4], in particular the demand scenario which promotes energy efficiency to reflect the impact of implementing energy efficiency measures to the generation capacity requirement and to analyze the scenario where both energy efficiency and renewable energy are considered. By this EE demand scenario, energy demand is expected to increase 2.84 folds from 143.4 billion kWh in 2015 to 407 billion kWh in 2030, equivalent to an annual average growth rate of 7.2% per year.

For the modelling of the generation sources, the above demands will be added with the station use and Distribution and Transmission (T&D) losses which are taken over from the PDP VII rev.

4.2 Fuel supplies

According to the revised master plan on coal development to 2020 with perspective to 2030 approved by the Prime Minister under Decision 403/QD-TTg dated March 14th 2016, coal productions are scheduled as follows:

- 2016: 41 - 44 million tons
- 2020: 47 - 50 million tons
- 2025: 51 - 54 million tons
- 2030: 55 - 57 million tons

Coal supplies to the power sector are presented in Table 6. It should be noted that this coal quantity includes anthracite coal, not brown coal due to the lack of suitable exploitation technologies. In addition, this coal quantity will be available for the North only due to transport issue.

Table 6: Domestic coal supply caps to the power sector (*1000 ton*)

	Unit	2015	2020	2025	2030
Coal supply to the power sector	1000 ton	28,000	34,500	34,700	42,400

[4] GreenID, 2014. Forecast of electricity demand till 2030

As for gas, according to updated plan by PETROVIETNAM, annual gas supplies to the power sector is planned at 10.35 billion m^3/year in 2015, increasing to 13.5 billion m^3/year in 2020, peaked at 19.35 billion m^3/year in 2025 and then decreasing to 14.85 m^3/year in 2030. These supplies are higher than those used in the PDP VII because of the recent discovery of blue whale gas field in the centre coast.

Table 7: Gas supply caps by region

Gas supply by region	Unit	2015	2020	2025	2030
North	Bill CBM	0	0	0	0
Centre	Bill CBM	0	0	6.08	6.08
South	Bill CBM	10.35	13.48	13.27	8.77

For imported fuels - coal, natural gas, LNG and oil (DO and FO) no restrictions are set on the import levels. For coal, the potential sources for import are Indonesia and Australia due to their rich resources and close distances. However, the import possibility is a concern because of the competition with other importing countries and besides exporting countries, in particular Indonesia are having a policy to reduce coal export. Regarding coal import issue, *GreenID* has conducted a separate study which is a part of a big study on sustainable energy development of which this current study is also a part.

As for gas, the import of natural gas via gas pipeline is infeasible due to huge investment cost and the risk of regional political instability. Therefore, if imported, LNG instead of natural gas will be chosen. Already, several ports for LNG handling and storage have been planned[5].

4.3 Fuel costs

Fuel costs play an important role in the modelling – they determine the priority order of thermal power plants to be built and loading order of existing plant. The most important aspect is to ensure that thermal plants are loaded in the correct order from cheapest to most expensive.

Fuel costs presented in Table 8 are taken from the Institute of Energy in its revised report of the PDP VII.

Table 8: Fuel costs

	Unit	2015	2020	2025	2030
Domestic coal[a]	USD/ton	60.3	63.6	67.2	70.9
Import coal[b]	USD/ton	88.1	93.1	98.5	104.1
FO	USD/ton	548.6	690.5	948.1	1,121.7
DO	USD/ton	878.3	1,122.7	1,554.7	1,567.7
Natural gas	USD/Mill BTU	6.1	8.1	10.9	10.9
LNG	USD/Mill BTU	12.6	14.8	14.8	14.8

Notes: [a]: Dust coal 5a is used as the representative coal. It has a net calorific value of 5500 kcal/kg
[b]: Net calorific value of 6700 kcal/kg

4.4 Power generation technologies to be considered

[5] Site planning for LNG import is part of the master plan for the gas industry for the period till 2020 with perspective to 2030

Table 9 lists the technologies that are included in the modeling. A total of 28 technologies are identified which are assumed comprehensive during the modeling period. Coal power is represented by 4 technologies, ranging from the conventional coal (sub-critical, pulverized) to Ultra supercritical and with option of CCS system. Renewable energies are represented by 20 technologies.

Table 9: Candidate power generation technologies for the modeling

Fuel	Technology
Coal	Subcritical coal
	Subcritical coal with CCS
	Supercritical coal
	Ultra supercritical coal
Gas	Gas turbine
	CCGT
Diesel	Gas turbine
FO	Steam turbine
Hydro	Small
	Large
	Pump-storage
Solar PV	Commercial rooftop (3 grades)
	Ground mounted (3 grades)
Wind	High wind
	Medium wind
	Low wind
Biomass	Steam turbine (4 fuel inputs)
Waste to energy	Land fill
	Incineration (internal combustion)
Biogas	Steam turbine
Geothermal	Binary

Economic and technical parameters for these technologies were gathered from the best public available sources, including the followings:

- The PDP VII
- The Vietnam Calculator 2050
- World energy outlook 2015 by the International Energy Agency
- Other sources

Technical parameters are efficiency, lifetime and plant availability. Economic parameters include investment cost per unit of production capacity, fixed O&M cost, variable O&M cost, fuel cost. All these are presented in the annex.

For the renewable energies (wind, solar), availabilities of the exploitation technologies are set at the levels representing the typical resources of the country for example wind are represented by three grades of turbine (to be discussed in detailed in the next section).

4.5 Renewable energy resources and their capacity development caps

This is a key part of the study and very likely influence how the generation mix will look like, so efforts have been made to update resource data and present investment costs and their tendencies for the exploitation technologies.

In this regard, for each resource, first resource potential will be discussed then technology data are described. For variable resources such as wind and solar, there is an additional section that discusses modelling approach for the technologies that capture those resources.

4.5.1 Hydro

4.5.1.1 Resource data

Technical potential was estimated at 18,000-20,000 MW (75-80 billion kWh/year). Small hydro potential (capacities less than 30 MW) represents about 7,000 MW. At the end of 2015, 16,569 MW hydro was installed; representing 43% of the system installed capacity of which large hydro was 14,585 MW and small hydro was 1,984 MW. Hydro produced 35% generation output in 2015[6].
The supply curve for small hydro for the period of 2015-2030 is presented in Figure 8.

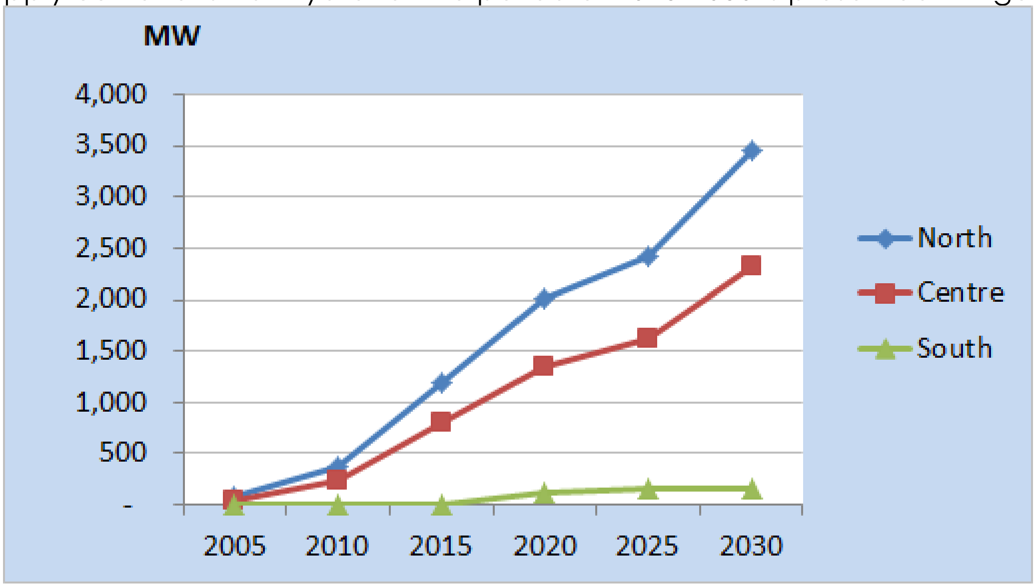


Figure 8: Small hydro power supply curve

4.5.1.2 Technology data

- Plant life time: 30 years
- Capacity factor: 45%
- Investment cost per unit of production capacity: 1700 USD/kW. No cost improvement expected within the modeling period
- O&M cost: 2.5 USD/MWh

4.5.2 Wind

4.5.2.1 Resource data

In 2001, the World Bank sponsored the preparation of a wind energy resource atlas for four countries – Cambodia, Laos, Thailand and Viet Nam – to support wind power development for the region (TWS 2000). According to this, Vietnam was assessed as

[6] National Dispatch Center, EVN, 2016. Annual report on power system performance and operation for 2015 (NDC, 2016).

having the highest wind energy potential amongst the 4 countries. However, many think the World Bank's wind atlas is overly optimistic, and may have a significant margin of error since the potential is based on simulation modelling. In view of this, in 2007, MOIT and the World Bank carried out wind measurement at three points and used these data and other available data to verify wind resource map. The revised wind potential is presented in Figure 9 and tabulated in Table 10.

Table 10: Wind energy potential of Viet Nam at 80 m above ground level according to the new wind resource atlas

Average wind speed	< 4 m/s	4-5 m/s	5-6 m/s	6-7 m/s	7-8 m/s	8-9 m/s	> 9 m/s
Area (km²)	95,916	70,868	40,473	2,435	220	20	1
Area (%)	45.7	33.8	19.3	1.2	0.1	0.01	0
Potential (MW)	956,161	708,678	404,732	24,351	2,202	200	10

Source: AWS Truepower, 2011

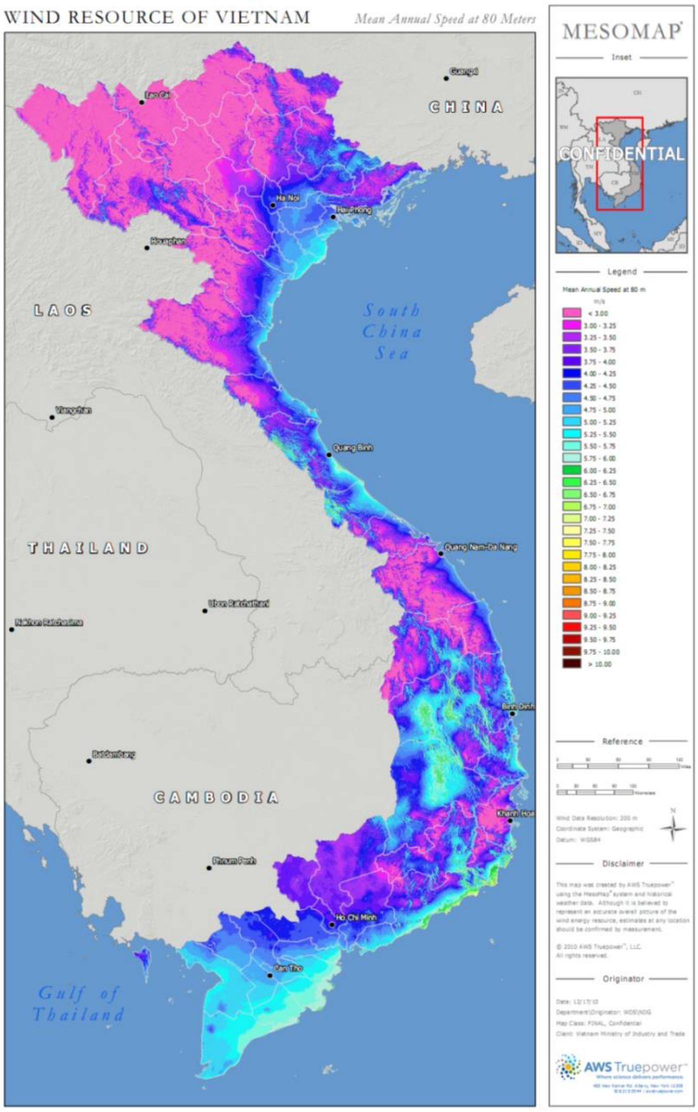


Figure 9: Wind resource map of Viet Nam at the height of 80 m

Aiming at providing support to local governments to conduct wind power planning in their provinces and at the same time support private developers in their wind project developments, the GIZ, under the project **"Establishment of legal framework and technical assistance to gird connected wind power development in Viet Nam"** conducted wind measurement for 10 sites since 2012.

In light of the new data source, in 2015, the MOIT asked ESMAP of the World Bank to help produce a revised wind resource map for Vietnam. The draft resource map has been produced and already estimate of grid connected wind potential has been made[7]. Total onshore wind potential is estimated at 27 GW which is presented by region and respectively by wind grades in Table 11[8].

Table 11: Wind potential by region and wind grade

Region		GW by wind grade		
		Low	Medium	High
North		3.7	0.7	0.1
Centre		6.9	8.9	3.5
South		2.6	0.7	0.1
	Total	**13.2**	**10.3**	**3.7**

4.5.2.2 Modelling wind power in MARKAL

MARKAL has several parameters that can handle wind power. Parameter CF(Z)(Y) specifies the availability of a certain technology during a defined season and time of day that are classified into six periods:

- Summer daytime
- Summer nighttime
- Intermediate season daytime
- Intermediate season nighttime
- Winter daytime and
- Winter nighttime

Table PEAK describes the portion of capacity of the technology that can be mobilized to meet the peak load.
In the present study, those parameters are determined based on wind profile representative for the three regions as shown in Figure 10 and the observations that wind speeds during day time are 20% stronger compared to night time for all three regions (Table 12). In relation to this, methodology for energy yield estimate and therefore capacity factor is presented in Box 1.

[7] The estimated was made by GIZ by taking into account technical constraint and infrastructure proximity (road and transmission grid)
[8] This study focuses on onshore wind as it is cheaper and therefore is prioritized. For a longer term study, near shore and off-shore wind will be studied.

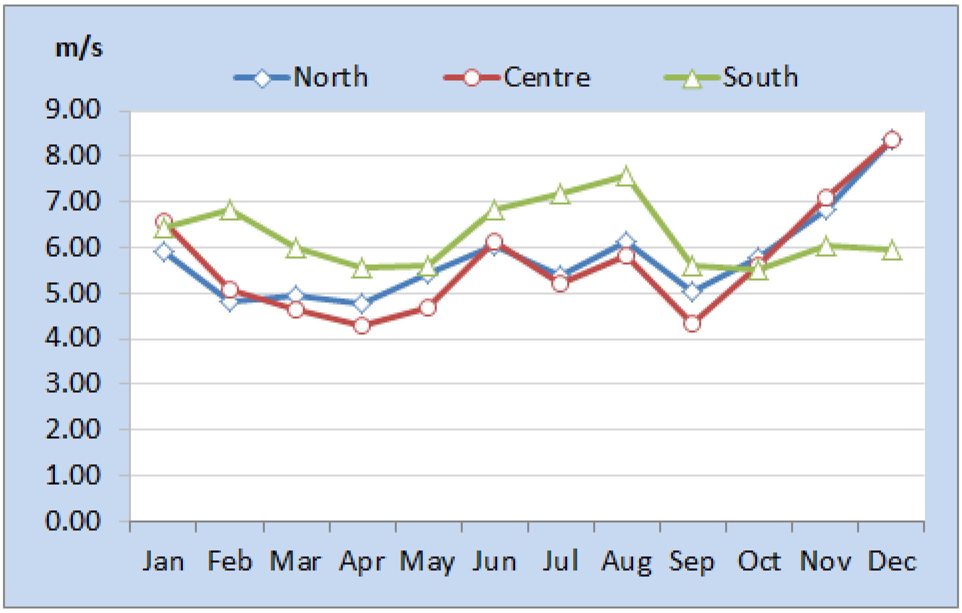


Figure 10: Representative wind profile for the three regions

Table 12: Main parameters for modeling wind turbines in MARKAL

Parameter	Wind grade		
	Low	Medium	High
North			
Seasonal Capacity Utilization Factor			
• Summer daytime	0.35	0.42	0.49
• Summer nighttime	0.17	0.2	0.23
• Intermediate season daytime	0.33	0.39	0.46
• Intermediate season nighttime	0.16	0.19	0.22
• Winter daytime	0.44	0.52	0.61
• Winter nighttime	0.21	0.25	0.29
PEAK	*0.23*	*0.28*	*0.30*
Centre			
Seasonal Capacity Utilization Factor			
• Summer daytime	0.34	0.41	0.48
• Summer nighttime	0.16	0.19	0.23
• Intermediate season daytime	0.32	0.38	0.44
• Intermediate season nighttime	0.15	0.18	0.21
• Winter daytime	0.47	0.56	0.65
• Winter nighttime	0.22	0.27	0.31
PEAK	*0.23*	*0.28*	*0.30*
South			
Seasonal Capacity Utilization Factor			
• Summer daytime	0.38	0.45	0.53
• Summer nighttime	0.18	0.22	0.25
• Intermediate season daytime	0.35	0.43	0.50
• Intermediate season nighttime	0.17	0.20	0.24
• Winter daytime	0.35	0.42	0.49
• Winter nighttime	0.17	0.20	0.24
PEAK	*0.23*	*0.28*	*0.30*

The parameters in Table 12 will be applied to the technical potential defined in Table 11 which in turn is accepted in the present study as the upper bounds in 2030. The other constraint to the development of wind power is the built rate – the MW that can be built per year which is determined largely by the technical capacity of the local constructors and availability of other resources including financial resource. For this exercise, the built rate of 250 MW per year is assumed for the first 5 years which will increase to 500 MW per year in the next 5 years and to 1000 MW per year afterwards.

As of mid-2017, 159.2 MW of wind power capacity has been installed. The existing wind farms are:

- Tuy Phong: 30 MW, in operation in late 2009
- Bac Lieu: Its first phase of 16 MW was put into operation in 2013. It full capacity was realized in 2016 with 99.2 MW
- Phu Lac: 24 MW in operation in late 2016
- Phu Quy: 6 MW, in operation in early 2013

According the Cuong N.D. and Dersch, D., (2014), as of April 2014, the total number of projects having applied for registration was 52 with a total capacity of about 4500 MW distributed over 14 provinces. Amongst 52 projects, 14 are in the stage of pre-feasibility studies, 21 completed the feasibility studies, and three in operation. The remaining projects are at the stage of applying for survey, conducting wind measurements and preparing the pre-feasibility studies.

4.5.2.3 Technology cost

The study by Cuong N.D. and Dersch, D., (2014) gathered data from 23 projects for the purpose of making a proposal of an appropriate support mechanism for wind energy in Vietnam which is presented in Table 13.

Table 13: Dataset used by the GIZ project

Nr.	Project name	Province	Cap. In [MW]	Capex in [Mill. $/MW]	Opex [$/MW/year]	Capacity factor [%]
1	AP	Ninh Thuan	70.0	2.060	37,637	27.40
2	PH	Ninh Thuan	97.5	1.840	24,473	39.00
3	VC	Soc Trang	28.8	2.388	32,907	38.10
4	PL	Binh Thuan	24.0	1.818	51,764	28.00
5	PM	Binh Dinh	21.0	1.927	45,400	36.64
6	BB	Binh Thuan	69.0.	1.782	23,497	25.20
7	HT	Binh Thuan	98.7	1.923	27,121	22.83
8	MD	Binh Thuan	42.0	1.731	8,160	21.20
9	PT	Binh Thuan	30.0	1.952	38,628	29.40
10	QT	Quang Tri	28.9	1.999	39.486	29.70
11	SG	Binh Thuan	199.5	1.852	36,530	28.20
12	TT	Binh Thuan	51.0	1.773	35,114	24.20
13	TD	Soc Trang	29.9	2.125	45,785	29.69
14	TN	Ninh Thuan	35.0	1.911	28.417	29.80
15	TP	Binh Thuan	43.5	1.296	25.936	35.70
16	VT	Binh Thuan	40.5	1.747	24,055	24.80
17	BL	Bac Lieu	83.2	2.503	78,840	37.55
18	TP*	Binh Thuan	30.0	2.635	40.647	25.00
19	NH	Binh Dinh	30.5	1.900	38,000	31.00
20	PH	Ninh Thuan	50.0	2.197	51,500	24.60
21	DH	Ninh Thuan	19.8	1.911	33,397	30.30
22	MD	Ninh Thuan	30.0	2.327	46,000	38.10
23	CL*	Bac Lieu	16.0	2.390	24,987	28.00
		Total	**1,169.0**	**1.980**	**33.190**	**29.76**

Note: *: actual data

According to Table 13, the average unit investment cost for wind in Vietnam is currently around 1980 USD/kW and the O&M cost is 35 USD/kW/year on average. A projection of the future costs has been made based on the international cost trend and the learning curve (BP, 2017; IRENA, 2015). The results are presented in Table 14. This cost information will be applied universally to all wind turbines regardless of wind grades and locations.

Table 14: Cost data for wind power project

Technology	Period of investment	Capex [$ 1000/MW]	Opex [$1000/MW/yr]
Wind turbine	2017-2020	1980	35
	2021-2025	1900	35
	2026-2030	1800	35

Box 1: Methodology for energy yield estimate

Power output of a given wind farm is estimated in two steps. First, the theoretical power output of a reference wind turbine is estimated. This output is then replicated to the whole wind farm by introducing loss coefficients.

Power output of a reference wind turbine: Wind speed is not constant with time. Power from the wind, in turn, varies with the cube of the wind speed. Thus, for the determination of energy output and consequently, theoretical potential, in addition to average wind speed it is of importance to know the wind speed distribution. To determine the wind speed distribution for a given wind *Vm* the Reyleigh function, which is a special case of Weibull function, is used. This function expresses the possibility *f(v)* to have a wind speed v during a year according to

$$f(v) = \frac{\pi v}{2(V_m)^2} * \exp\left(\frac{-\pi}{4}\right)\left(\frac{v}{V_m}\right)^2$$

where V_m is the average wind speed. It has been concluded from experience that this special function represents well enough the real wind speed distribution. The delivered yearly energy output then can be calculated by integrating the power curve:

$$E_U = \sum_{v=1}^{v=25} f(v) * P(v) * 8760$$

where v_m is the average wind speed; *P(v)* is the turbine power at wind speed *v*; *f(v)* is Reyleigh probability density function for wind speed *v*, calculated for average wind speed v_m, and 8,760 is the number of hours per year.

The power output of a single wind turbine is then replicated to the whole wind farm with proper adjustments.

$$E_{TP} = nE_U C_P C_T C_R C_A C_O$$

where n is the number of wind turbines in the wind farm; C_P and C_T are the pressure adjustment coefficients. C_R is wind farm efficiency whose value is dependent on the size of the farm and the geometry of individual wind turbines; C_A is wind farm availability which is equal to 98% as committed by most turbine manufacturers and C_0 represents other losses including cable losses, transformer losses and other miscellaneous losses. C_P and C_T are given by:

$$C_P = \frac{P}{P_0} \qquad C_T = \frac{T_0}{T}$$

where P is the annual average atmospheric pressure at the site, P0 is the standard atmospheric pressure of 101.3 kPa, T is the annual average absolute temperature at the site, and T_0 is the standard absolute temperature of 288.1 K.

4.5.3 Solar

4.5.3.1 Resource data

Figure 11 shows that Vietnam has quite good solar resource, in particular in the southern region (AECID-MOIT. 2014). Daily average solar irradiation is between 5-5.5 kWh/m²/day, comparable to Thailand where solar applications have grown strongly in the last years. According to the Thailand Solar PV Policy Update 05/2016, total installed capacity in Thailand is 2,021 MW. Out of the total there are 1,932 MW of free-field installations/solar farms, while solar rooftops account for 89 MW (BMWi, 2016).

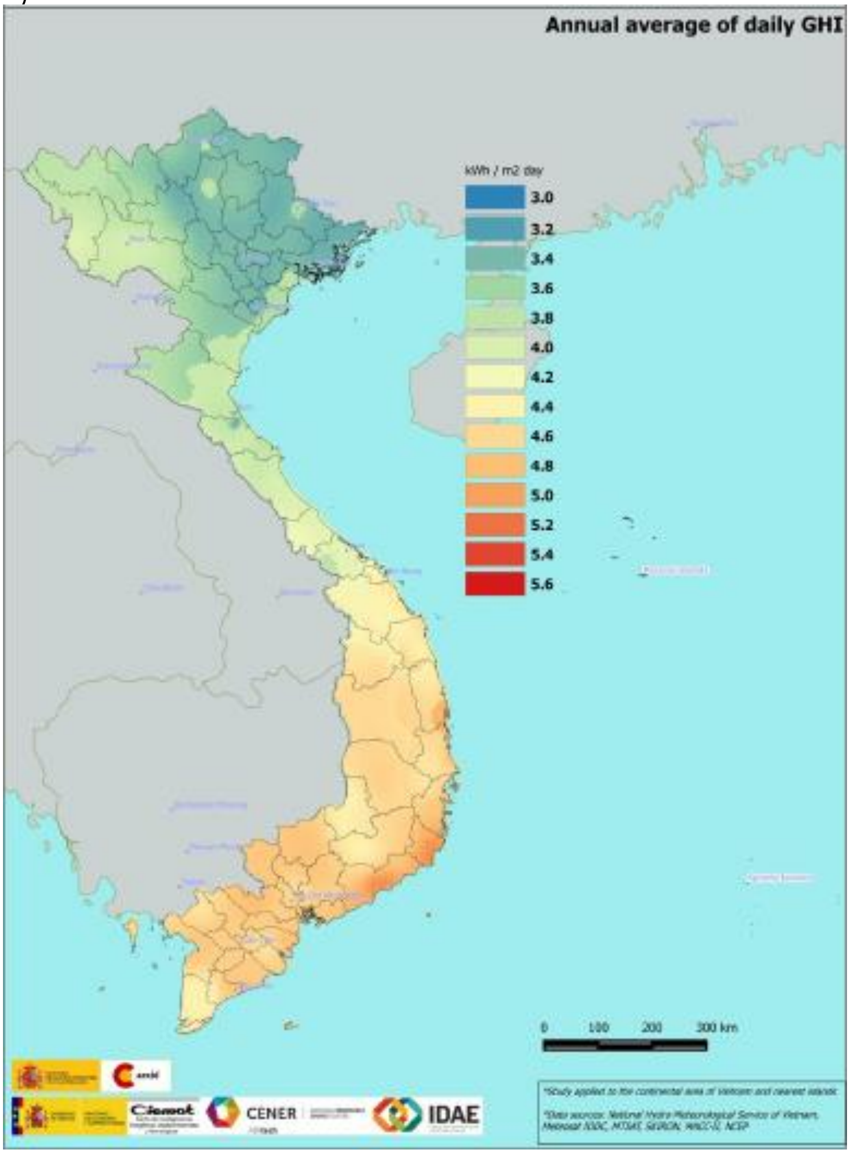


Figure 11: Daily average global solar Irradiation of Vietnam

However, solar resources in Vietnam are not equally distributed. It is better in the center and the best in the south, relatively to its position to the equator. Furthermore, it varies by months and in the course of day. Figure 12 shows the average solar radiation by month for three locations Ha Noi, Da Nang and Ho Chi Minh city which represent solar resources in the North, Centre and South, respectively. According to the figure, solar radiation in Ho Chi Minh is the highest, at 5.09 kWh/m²/day and does not vary strongly between months. It is stronger during January-May. It peaks in March and is quite stable in other months. Solar radiation in Da Nang is also high, however the variation is bigger. It is stronger from March to September, in particular from May to July. Yearly solar radiation in Ha Noi has a similar pattern to that of Da Nang, although at a lower magnitude.

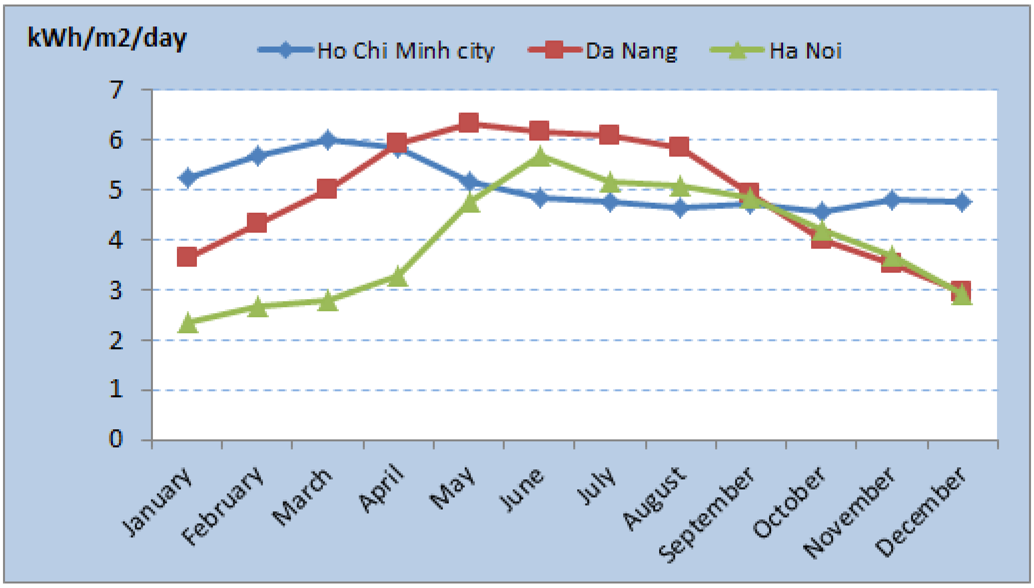


Figure 12: Daily average solar radiation in the Ha Noi, Da Nang and Ho Chi Minh city

From these observations, it is attractive to implement solar PV projects in the centre and in the south. But the north border region poses potential even not as high as in the south.

Two applications of solar energy are considered: (i) free-standing installations or solar farms *and* (ii) solar rooftop. Concentrated Solar Power Plant (CSP) is not considered because the climatic and solar radiation conditions in Vietnam are not suitable. CSP works better at solar radiation of 6 kWh/m²/day and above and in dry climate. Deserts are actually ideal locations for CSP. Move over, it is more costly, and requires more land than solar PV technology. Investment cost for the Parabolic trough technology is around 4600 US/kWp resulting in the LCOE of between 0.14-0.36 $/kWh and for the solar tower 6300-7500 USD/kWp and the corresponding LCOE is 0.17-0.29 $/kWh[9]. In fact, neighboring countries such as Thailand, Malaysia and the Philippines have not got a plan for CSP development.

In the following, the potential for those applications are analyzed.

a. Potential for solar farm

A GIS based approach[10] was used to estimate the potential for solar farm which consists of two sequential steps:

Step 1: Preliminary identification of potential area for solar development: this step identifies the areas that have adequate solar radiation.

Step 2: Identification of specific sites suitable for solar PV farm in the above identified areas by removing areas not suitable in terms of land use and infrastructure (e.g., topography, agricultural and other productive land use value, conservation value of land, access to national grid, access and transportation, site scale).

[9] https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-CSP.pdf

[10] The study uses GsT, a GIS based tool promoted by NREL (National Renewable Energy Laboratory of the US). GsT is provided as a free software with built-in data and it offers the ability to model and assess renewable energy potential visually.

Translating these into specific criteria, these steps would mean the following selection criteria for solar farms are adopted.

Figure 13: Selection criteria for solar resource assessment

- Solar radiation: ≥ 4 kWh/m²/day
- Suitable areas:
  - *Waste land with flat topography with road and grid access and close to load centers*
  - *Distance from road: ≤ 2 km*
  - *Distance from electrical grids: ≤ 5 km*
  - *Land slope: ≤ 5°*

By applying this approach, a suitable land area for ground mounted solar PV of 672 km² has been identified, which is sufficient to accommodate as many as 56,027 MWp at the land take of 1.2 ha/MWp[11]. The suitable area concentrates mainly in the southern region.

This estimate is higher than those given in other studies for example the study by ADB estimated the technical potential for grid connected solar PV in Vietnam at 22,000 MWp. The main reason for this difference is the present study applies a low threshold for solar irradiation at 4 kWh/m²/day versus 5 kWh/m²/day adopted by the former study. This is to respond to the strong focus of the REDS on solar PV development and consequently, areas with lower solar resource are also considered. Lower land-take assumed in this study is another reason. Anyway, this is just a rough estimate which needs further research before a final, realistic number could be derived.

Table 15, 16 and 17 provide summaries of the potential by province, region and by resource.

Table 15: Technical potential of solar PV farm by province

Province	Suitable area (km²)	Capacity (MWp)
Ba Ria Vung	22.31	1,859.2
Bac Giang	5.73	477.5
Bac Ninh	1.34	111.7
Binh Dinh	12.16	1,013.3
Binh Duong	31.90	2,658.3
Binh Phuoc	5.07	422.5
Binh Thuan	7.17	597.5
Dak Lak	89.42	7,451.7
Dong Nai	10.08	840.0
Dong Thap	5.55	462.5
Gia Lai	10.23	852.5
Ha Tay	4.21	350.8
Hai Duong	7.03	585.8
Hoa Binh	4.58	381.7
Khanh Hoa	47.06	3,921.7
Kon Tum	11.12	926.7
Lai Chau	4.08	340.0
Lam Dong	27.60	2,300.0
Long An	48.45	4,037.5
Nam Dinh	11.04	920.0
Ninh Binh	0.93	77.5

[11] Land area required per MWp is site specific. The approximate area in Thailand ranges from 0.8-1.2 ha/MWp while in India it is from 1.0-1.5 ha/MWp.

Ninh Thuan	94.23	7,852.5
Phu Tho	3.34	278.3
Phu Yen	20.04	1,670.0
Quang Binh	0.68	56.7
Quang Nam	11.88	990.0
Quang Ngai	42.10	3,508.3
Quang Ninh	5.75	479.2
Quang Tri	2.61	217.5
Son La	25.62	2,135.0
TP. Ha Noi	4.00	333.3
TP. Hai Phong	4.54	378.3
TP. Ho Chi Minh	6.56	546.7
TP.Da Nang	0.11	9.2
Tay Ninh	54.59	4,549.2
Thai Nguyen	2.76	230.0
Thanh Hoa	1.18	98.3
Thua Thien- Hue	13.44	1,120.0
Tien Giang	11.12	926.7
Vinh Phuc	0.47	39.2
Yen Bai	0.24	20.0
Total	**672.32**	**56,027.0**

Table 16: Technical potential of solar PV farm by solar radiation

Solar radiation	Suitable area (km²)	Capacity (MWp)
Low (4.0 to 4.5 kWh/m²/day)	70.7	5,891.0
Medium (4.5 to 5.0 kWh/m²/day)	171.07	14,255.0
High (5.0 to 5.5 kWh/m²/day)	430.56	35,880.0
Total	**672.33**	**56,027.0**

Table 17: Technical potential of solar farm by region and solar radiation

Region/Solar radiation	Suitable area (km²)	Capacity (MWp)
North		
• Low	70.70	5,892
• Medium	0	0
• High	0	0
Centre		
• Low	16.14	1,345
• Medium	153.85	12,821
• High	1.08	90
South		
• Low	0	0
• Medium	134.6	11,217
• High	295.95	24,662

Similar to wind power, consultation with key stakeholders in the RE sector on the maximum built rate for solar PV was made. Accordingly, the adopted built rate for the first 5 years is 500 MW/year which will increase to 1000 MW in the next 5 years and 2000 MW afterwards.

b. Potential for solar rooftop

Neither the PDP VII rev nor the REDS set specific targets for this kind of application. For commercial buildings, Khanh N.Q (2013) found that there is a good match between PV output and load profiles of typical types of buildings (hotel, office building) in Ho Chi Minh city and accordingly estimated the potential of 113 MW. This study was based on load data in 2011 so the potential for solar PV is expected to grow as the commercial sector is growing.

Similar to commercial sectors, there is certainly rational for solar PV to be installed in the roof of some industries.

In this context, the present study adopted the development scenario by **ADB RETA 7764-REG Ensuring the sustainability of the GMS regional power development** (ADB, 2014). Some updates and changes to it were made. The result is shown in Table 18.

Table 18: Penetration scenario for Rooftop solar PV

Region	Capacity (MWp) 2020	2030
North	5	20
Centre	10	30
South	20	100
Total	**35**	**150**

4.5.3.2 Modelling solar PV in MARKAL

The availability of PV technology during the summer would be higher than in the winter and is absent during the nighttime. In the model, the weather dependent performance of PVs can be simulated with the table PEAK and the parameter Seasonal Capacity Utilization Factor (CF(Z)(Y)) – same set of parameter as used for modeling wind power.

The parameter CF(Z)(Y) specifies the availability of PV technology during a defined season and daytime whereas the table PEAK describes the portion of capacity of a certain technology that can be mobilized to meet peak load.

Solar radiation conditions in the Hanoi, Da Nang and Ho Chi Minh were relied on to derive those parameters for the North, the Centre and the South, respectively. The results are shown in Table 19.

Table 19: Main parameters for modeling solar PV

Parameter	Region North	Centre	South
Seasonal Capacity Utilization Factor			
• Summer daytime	0.52	0.62	0.49
• Summer nighttime	0	0	0
• Intermediate season daytime	0.38	0.50	0.52
• Intermediate season nighttime	0	0	0
• Winter daytime and	0.30	0.34	0.49
• Winter nighttime	0	0	0
PEAK	0.4	0.49	0.50
Lifetime (year)	20	20	20

4.5.3.3 Technology cost

Total investment comprises of the following components: module, inverter, cable, mounting structure, engineering and project management, labor and miscellaneous costs.

- Current specific investment cost in Vietnam is estimated at 1000 USD/kWp for solar farm and 1200 USD/kWp for solar rooftop[12].
- Operation and maintenance (O&M) cost: this includes cleaning of PV array to remove soiling and residual deposits; diagnostic testing and preventive maintenance and replacement of components that have a life span less than the analysis period. O&M is estimated at 1.5% of the initial investment cost.

It is expected that technology cost for solar PV keeps improving following the past trend and as a result of learning curve (BP, 2017; Munsell, M., 2017). Table 20 provides the estimates.

Table 20: Economic parameters of solar farm and solar rooftop

Technology	Period of investment	Capex [$ 1000/MW]	Opex [$1000/MW/yr]
Solar farm	2017-2020	1000	18
	2021-2025	900	18
	2026-2030	800	18
Rooftop solar PV	2017-2020	1200	21
	2021-2025	1100	21
	2026-2030	1000	21

4.5.4 Biomass

4.5.4.1 Resource data

4 technologies will be modeled including two co-generation (bagasse and rice husk) and two internal combustion (rice straw and timber waste).
According to an estimate by Loc, N.V (2014), total potential for power generation from existing sugar mills is about 500 MWe. By 2015, installed capacity from this sector reached 375 MW (Khanh, N.Q, 2016). The power and steam generated from these plants are used firstly for their own, i.e., for crushing sugarcane and refining sugar. Some of these plants are selling redundant electricity at 5.8 US cent/kWh according to Decision 24/2014/QD-TTg dated 24/3/2014.
There is no official estimate on the potential for power generation from rice mills, and rice straw and timber waste. The development caps in Table 21 were made based on respective resource estimates from GIZ and our assumptions on collection rate and built rate of the captured technologies.

Table 21: Development caps for biomass power

Bioenergy	Capacity caps by 2030 (MW)
Bagasse	500
Rice hush	500
Rice straw	250
Timber waste	250

[12] Investment cost for free standing was based on interviews with two international solar PV developers and for roof-top based on interviews with local PV developers who are active in the sector.

4.5.4.2 Technology data

The following technology data are also taken from the technical report initiated by the GIZ to propose supporting mechanism for grid connected electricity from biomass projects in Vietnam (GIZ/GDE-MOIT, 2013a).

Table 22: Economic and technical parameters of biomass power technologies

Parameter	Fuel type			
	Bagasse	Rice hush	Rice straw	Timber waste
Plant life time (years)	20	20	20	20
Hours of full power	5000	6500	6500	6500
Specific investment cost ($/kW)	1,100	1,920	2,000	1,900
Fuel consumption (kg/kWh)	2.38	1.2	1.32	0.91
Fuel cost ($/ton)	4	12	25	25
O&M cost (% of initial investment cost)	4	4	4	4
Other income		Sale of ash (20 $/ton)		

4.5.5 *Waste to energy*

4.5.5.1 Resource data

Two *Waste-to-energy* technologies are modelled: (i) burning captured land fill gas to produce electricity, *and* (ii) combustion of solid waste for power generation, to be in line with the existing development policies.

The development caps for these technologies are based on the Vietnam Calculator 2050.[13]

Calculator 2050 is a modeling tool initiated by the UK government in an effort to find out a pathway for the UK to meet its committed GHG emission target of 80% by 2050 against its level in 1990. A number of countries have been inspired by this effort and subsequently have developed their own versions of Calculator 2050. Vietnam through the Industrial Techniques and Environment Agency (ISEA), Ministry of Industry and Trade (MOIT) published its version early 2015. In Calculator 2050, for each lever, one has up to 4 levels to choose from- these relates to the level of effort being used, ranging from doing nothing to putting in the maximum amount of effort or going to the limit of technical feasibility.

In the present study, capacities corresponding to their level 4 are assumed as the development caps for these technologies.

Table 23: Development caps for waste to energy technologies

Technology/region	Capacity caps by 2030 (MW)
Land fill technology	202
Incineration technology	75

By now (May 2017), there is one land fill power plant of 2.4 MW located in Ho Chi Minh City and one incineration plant in Hanoi with 1.92 MW.

[13] http://vietnamcalculator2050.atmt.gov.vn/pathways/11111111111111111111111111111111111111111111/primary_energy_chart/comparator/01111111111101111100110111101111011111111011,

4.5.5.2 Technology data

The technology data are taken from the technical report initiated by the GIZ to propose supporting mechanism for grid connected electricity from waste projects in Vietnam

Table 24: Economic and technical parameters of waste to energy technologies

Parameter	Technology	
	Land fill	Incineration
Plant life time (years)	20	20
Hours of full power	8000	6500
Specific investment cost ($/kW)	2331	4000
Efficiency (%)	40	25
O&M cost (% of initial investment cost)	10.63	8.5

4.6 Electric import

Import from Lao PDR: By the new regulation of Lao government, all power projects that are developed for export shall keep 20% of the capacity to serve Lao. According to the latest update, the capacity that can be expected from Lao until 2020 is now estimated at 850 MW and is all hydro power. No further MW estimate is available afterwards.

- Se Ka Man 3: went into commercial operation in 2013.
- Nam Mo 105MW's COD is expected after 2020.
- Se Kaman 1 (290MW) and Xekaman Sansay (32MW) are expected to be operational in 2016.
- Sekong 3 Upper (105MW) and Lower Sekong 3 (100MW) are under development by the Vietnam-Laos Electricity Joint Stock Company (Song Da Corporation), started construction in 2014 and start generation in 2017.
- Xekaman 4 (80MW) are under development by the Vietnam-Laos Electricity Joint Stock Company (Song Da Corporation), expected to start construction in 2014 and start generating electricity in 2017.

Import from Cambodia: In the PDP VII, it was expected that 4 hydro power plants in the North East of Cambodia will export power to Vietnam. However, it was made recently by the Cambodian Government that these plants will serve Cambodia only, meaning no import of electricity from Cambodia is expected.

Import from China: Vietnam is currently importing electricity from China through the 220 kV and 110 kV grids. The import capacity is about 700-800 MW and will terminate in 2017 by the contract. There is a consideration of importing electricity from China through the 500 kV. However, it has been proven financially unviable as electricity can be imported during the wet season only and China would like to import power from Vietnam during the dry season.

4.7 Other assumptions

Development of pump storage hydroelectricity: In the PDP VII rev, two pump storage hydro power plants have been planned, one in the centre, one in the south. This is a good match as the centre and the south are rich in wind and solar energy which are variable sources of energy and thus having such storage would enhance the reliability of the system and reduce curtailment rate.
Discount rate: A discount rate of 10% is applied for the present study. This rate is recommended by the World Bank for the analysis of technological choices in Vietnam and is also applied in the development of the PDP VII.

5. Definition of scenarios

To achieve the objectives set out in the Introduction section, three generation scenarios are modelled.
The base generation scenario: under this scenario, power generation mix will be determined on the basis of updated assumptions including fuel price forecasts, specific investment cost for technologies and expected cost evolution. For renewable energies updated inputs include the resource potentials and their investment cost with consideration of cost evolution.
The renewable energy scenario: under this scenario, in addition to assumptions in the base scenario, renewable energies are evaluated in fairer manner by considering external costs.
External costs are costs imposed on society and environment due to unpriced pollutants emitted from electricity generation. The major pollutants are sulphur oxides (SOx), nitrogen oxides (NOx), and carbon dioxides (CO_2). In terms of the above pollutants, renewable energies have little impacts, even on a life cycle basis as compared with conventional generation technologies; so, consideration of externalities would be advantageous for renewable energies and therefore could potentially lead to a higher share of renewable energies in the generation capacity mix.
The International Monetary Fund (IMF) estimated the social and environmental cost for Vietnam at 2.26$/GJ for coal, 0.12$/GJ for natural gas and CO_2 is valued at 35$/ton (IMF, 2014). These numbers will be used in this scenario.
The emission cap scenario: This scenario explores the generation mix under the constraint on CO_2 emission reduction, in this case 20% by 2030 as governed by the National Green Growth Strategy.

Box 2: Targets by the National Green Growth Strategy

- Target for 2020: Reduce GHG emissions from energy activities by 10 percent to 20 percent compared to the BAU case. 10% voluntary, an additional 10% reduction with international support
- Target for 2030: 20 percent to 30 percent. 20% voluntary, 10% with

It should be noted that for all scenarios, choices of technologies until 2020 shall follow the PDP VII rev as it is only 3 years to go from now thus it is assumed that they are all by now under construction. This assumption is not applicable to Wind and Solar power as their construction times are much shorter than conventional power. After 2020, the choice will be made by the model.
Therefore, for the scenario on CO_2 cap, CO_2 emission reduction shall begin in 2021 and be gradually increased towards the target set for 2030. For scenario on carbon tax, the tax will be applicable from 2021 onwards.

So with the 3 generation scenarios and two demand scenarios, 6 cases will be studied. However, for the EE demand scenario, only two generation scenarios will be studied. The emission cap generation scenario is not studied because this demand scenario has already brought about CO_2 emission reduction due to EE promotion. In this regard, a more meaningful approach would be to take an integrated approach where both EE and RE measures will be analyzed on a cost basis.

Table 25: Summary of scenarios and cases

Demand scenarios	Generation scenarios		
	Base scenario	RE scenario	Emission cap scenario
Base scenario	B&B	B&RE	B&CO2CAP
EE scenario	EE&B	EE&RE	

6. Results and discussions

6.1 Evaluate the competiveness of candidate generation technologies

At first we would like to evaluate the competiveness of different power generation technologies. As technologies differ with respect to initial costs and operating costs (*A gas turbine with low investment cost, high annual fuel cost versus PV system with high investment cost + no fuel cost*) and some are using fossil fuels whose costs are expected to increase on a yearly basis over their life time, it is proposed to use Life-Cycle Cost Analysis (LCCA) for assessing the total cost of electricity production. Accordingly, costs incurred over the lifetime of selected technology are estimated. Discounted costs streams, combined with energy values, are used to calculate levelized cost (LCOE) in order to compare various energy technologies. Methodology on LCOE calculation is provided in annex 2.

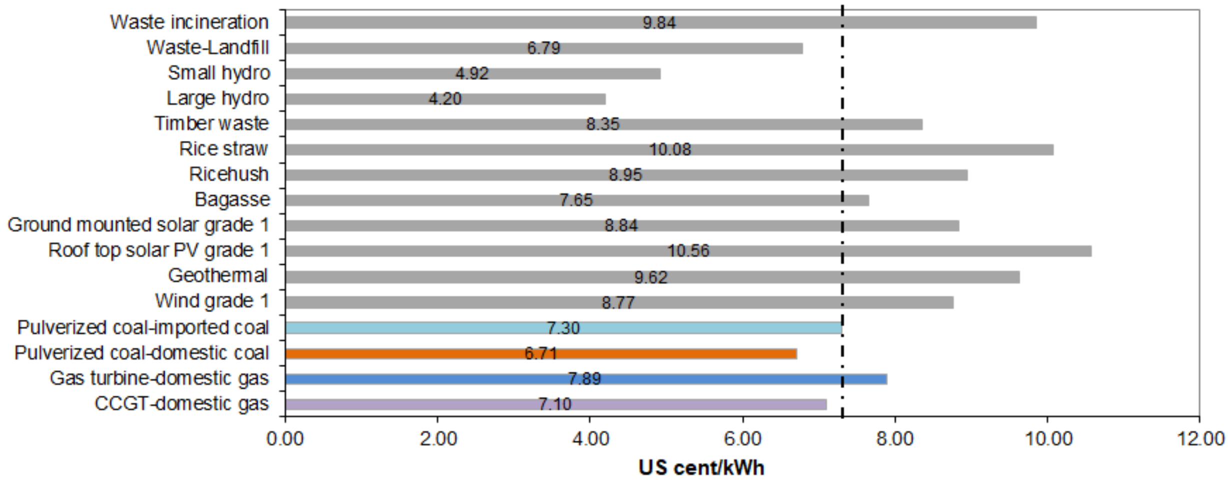


Figure 14: LCOE of key technologies invested in 2017

Figure 14 gives a comparison of the levelized costs of electricity production from selected key technologies calculated using the economic and technical parameters documented in the annex 1. Capacity factor for coal is assumed at 70% and for gas turbine at 75%, which are in agreement with the assumptions by the PDP VII. Without considering the performance characteristics of the technologies, the large hydro has the lowest levelized cost of 4.2 US cent/kWh, followed by small hydro at 4.92 US cent/kWh. The highest cost is that of roof top solar photovoltaic 10.56 US cent/kWh, due to its low availability, short lifetime although its unit investment cost has decreased significantly over the last years. Amongst three fossil fuel based power plants, coal has the lowest cost, followed by CCGT.

Looking into the details of renewable energy technologies taking coal fired power plant as the reference technology as typically the case in Vietnam for setting supportive tariff for renewable energy technologies, only small hydro and waste to energy (land fill technology) amongst selected renewable energy technologies are competitive to coal fired power plants.

However, looking in to the future, the competiveness indexes of renewable energy technologies could change as their investment costs keep improving while fossil fuel cost tends to continue to increase.

The results for 2020 are shown in Figure 15. Supercritical technology is now used as the reference technology instead of Pulverized technology. This assumption is made in the context that OECD countries - the major coal power financiers as the result of the Paris Agreement have reduced their finance for coal fired power projects and will finance certain projects that use supercritical technologies. Between these two opposite directions, ground mounted solar PV grade 1 and bagasse now becomes more cost-effective than supercritical coal.

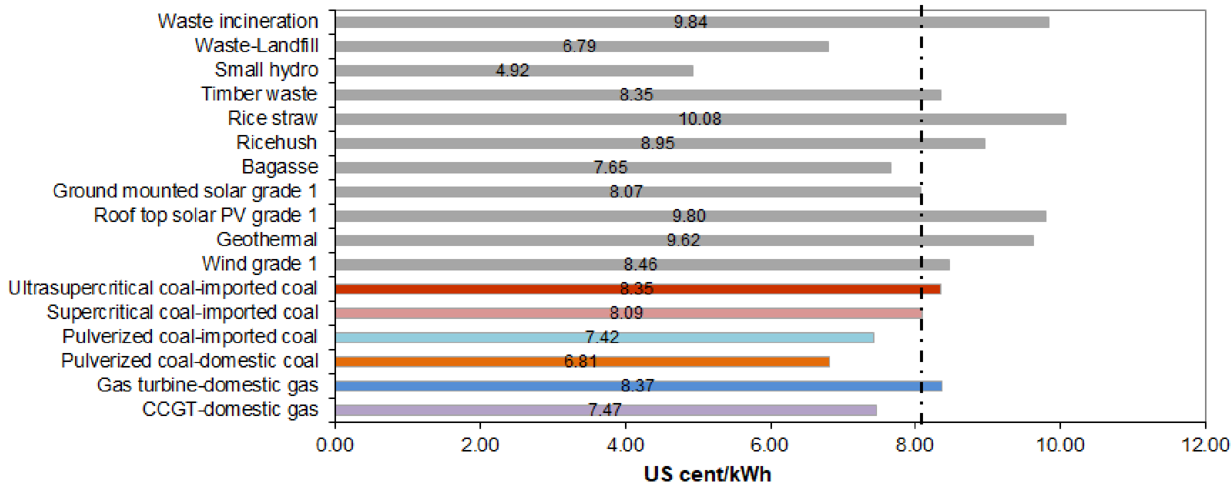


Figure 15: LCOE of key technologies invested in 2020

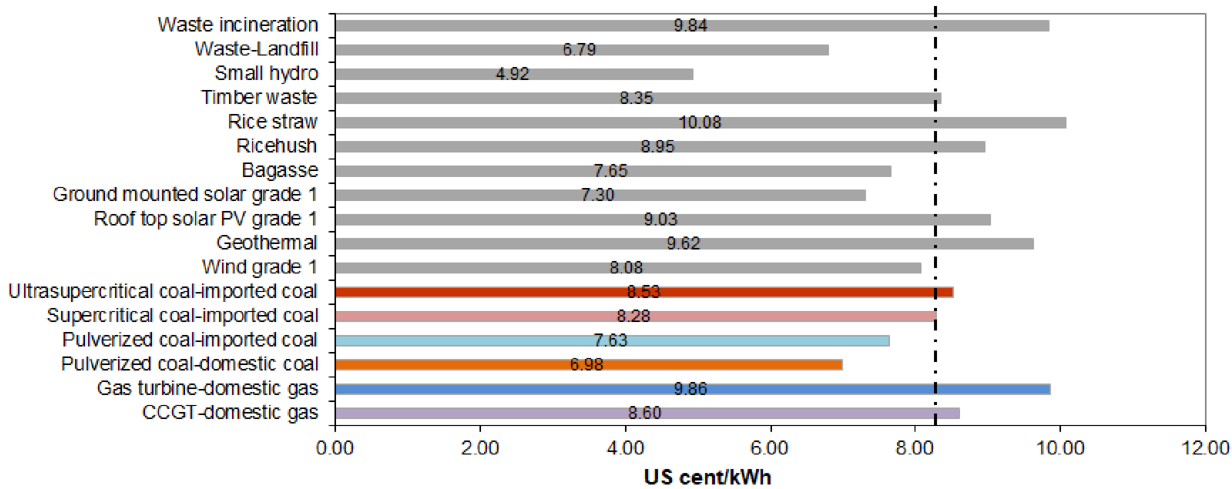


Figure 16: LCOE of key technologies invested in 2025

By 2025, wind grade 1 could compete with supercritical coal. In total, by then small hydro, ground mounted solar PV grade 1 and grade 2, bagasse and wind grade 1 are more cost-effective than coal. The following RE technologies: Waste to energy (incineration technology), biomass, solar PV (roof-top and ground mounted grade 3), and wind grade 2 and grade 3 are still not yet competitive with coal despite of significant cost improvements, even by 2030. There is still a significant cost gap.

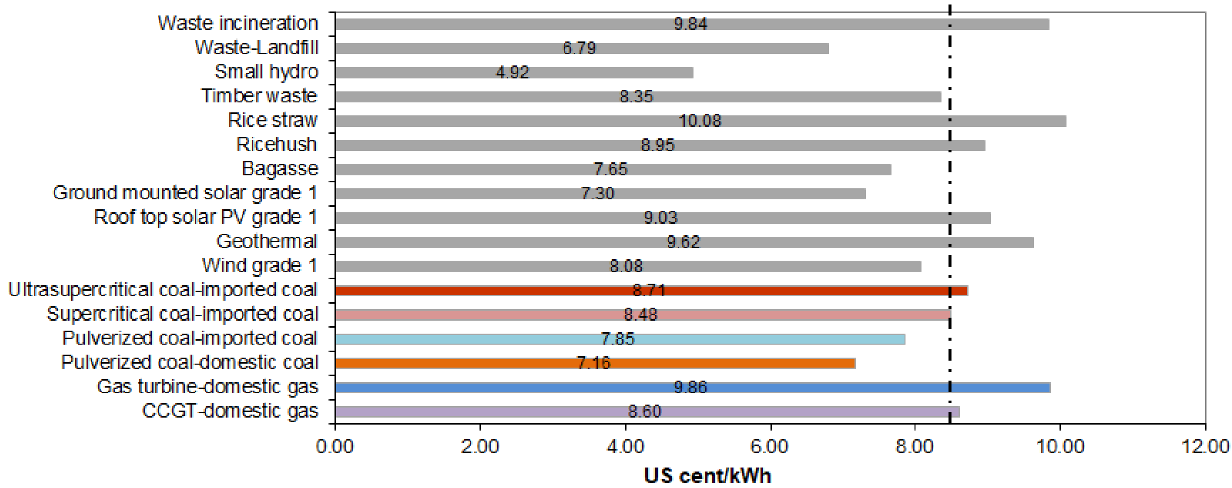


Figure 17: LCOE of key technologies invested in 2030

When externalities are considered, the picture on economic level of technologies changes, even at the present cost levels. All renewable energy technologies become more competitive than coal power, even rooftop solar and low grade wind. Coal has an external cost of 5.2 US cent/kWh for domestic coal, 5.08 US cent/kWh for imported coal, gas turbine (open cycle) 1.66 US cent/kWh and CCGT is 1.24 US cent/kWh.

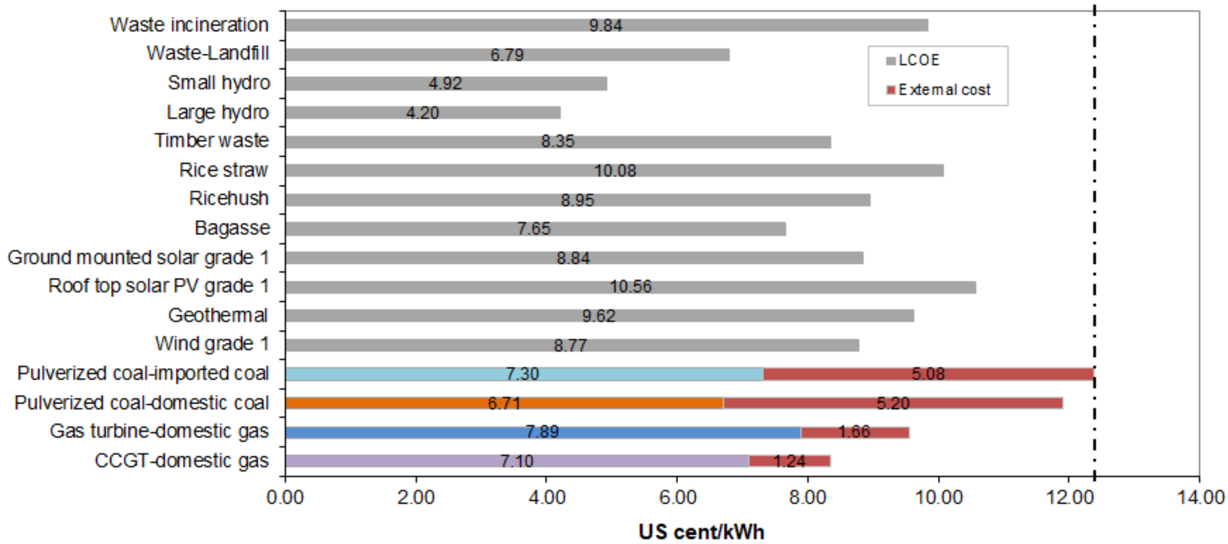


Figure 18: LCOE with consideration of external costs of generation technologies invested in 2017

6.2 The base demand scenario

6.2.1 The base generation scenario (B&B)

Under this scenario, generation capacity is expected to grow from 38.9 GW in 2015 to 100.2 GW in 2030, *i.e.*, equivalent to an annual increase of 3065 MW per year (Table 26 and Figure 19).

Coal power is expected to increase from 13.07 GW in 2015 to 66.25 GW by 2030, hydro from 14.59 GW in 2015 to 22.14 GW in 2030 whereas gas based power is expected to decrease from 7.45 GW to 3.56 GW in the same period, mainly due to retirement of existing gas power plants. These differences in capacity growth lead to changes in generation capacity structure. Shares of coal, gas and hydro change from 33.6%, 19.2% and 37.5%, respectively in 2015 to 66.1%, 3.6%, 22.1% in 2030. Share of renewable energy (not counting large hydro) is expected to grow from 6.3% in 2015 to 7.8% in 2030, by capacity from 2.45 GW to 7.82 GW, mainly as a result of increased capacity by small hydro. Large scale solar PV (ground mounted solar PV) is not selected because of transmission and distribution cost associated with it even though it is proved in section 6.1 that it has competitive generation cost to coal. Therefore, in this scenario, only roof top solar as distributed generation is selected, and therefore with limited capacity. It should be also noted that the model does not put a growth constraint on the choice of coal technologies, other than economic and technical parameters documented in Annex 1.

This dominant share of conventional energy, in particular coal in the generation mix indicates that conventional energy is still cheaper than renewable energies (if externalities are ignored). This is in agreement with the conclusion in section 6.1.

In comparison with the PDP VII rev, the required installed capacity under this scenario is about 30 GW lower (100 GW versus 129.5 GW). Amongst the reasons are (i) share of renewable energy in the in the PDP VII rev is higher – renewable energy technologies generally have lower capacity factors as compared to conventional power (solar PV has a capacity of around 15%, wind around 30% while that of coal and natural gas is around 75%), hence to ensure an equal amount of supply, renewable energy requires higher installed capacity, (ii) some power plants in the PDP VII rev are planned as back up capacity, *i.e,* they will be built if renewable energy is not built as planned.

Table 26: future capacity development under the base scenario

Fuels	Installed capacity (GW)					
	2005	2010	2015	2020	2025	2030
Biomass	-	0.15	0.38	0.38	0.95	1.45
Coal	1.51	4.01	13.07	25.97	39.16	66.25
Natural gas	4.63	6.71	7.45	7.69	6.59	3.56
Hydro	4.32	8.75	16.57	21.84	24.19	28.07
Solar	-	-	-	0.01	0.09	0.13
Wind	-	0.03	0.09	0.15	0.15	0.15
Oil	0.79	1.01	1.34	0.77	0.62	0.40
Others	-	-	-	-	0.15	0.20
Total	**11.25**	**20.66**	**38.90**	**56.81**	**71.90**	**100.21**

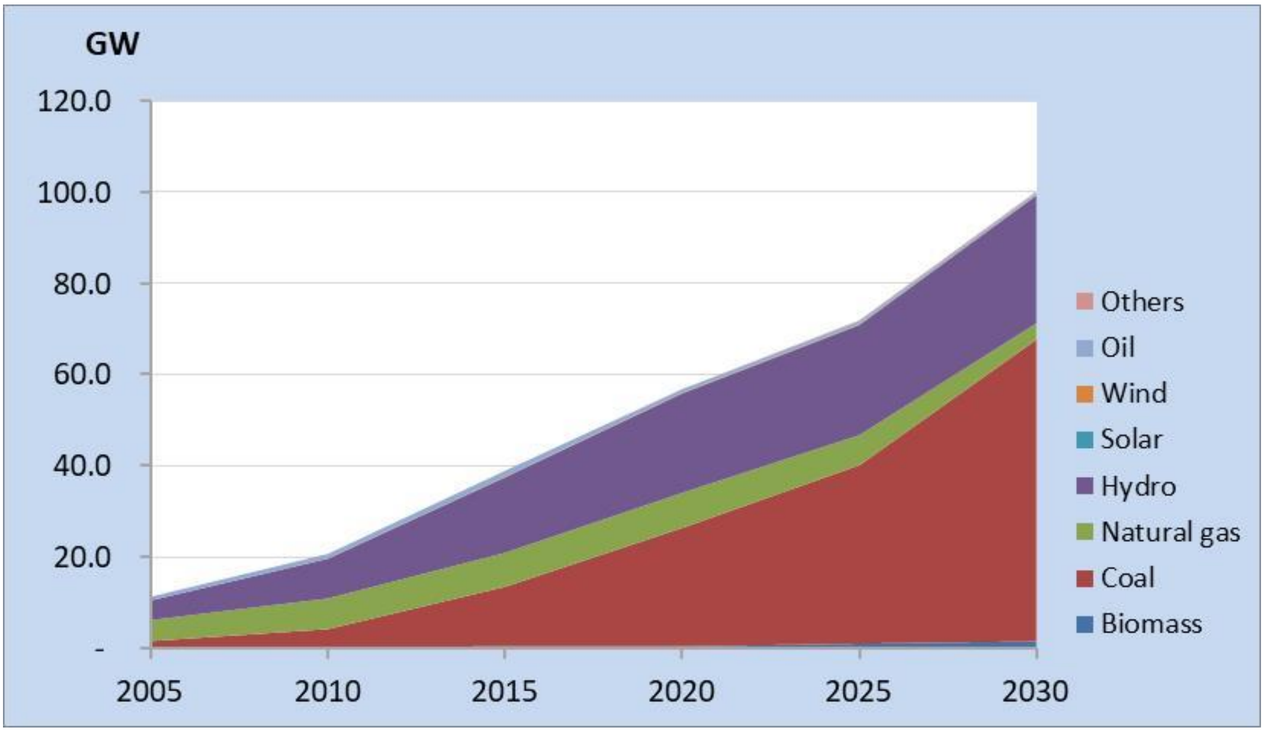


Figure 19: Future capacity development under the base scenario

Nevertheless, the switch from hydro to coal-based power plants still drives 7.1%/year growth in fossil fuel consumption, from 1058.27 PJ in 2015 to 4159.87 PJ in 2030. In order to meet this rapidly growing demand, Vietnam would need to import energy, such as coal, after 2015. The proportion of imported coal in total fuel consumption is expected to increase strongly reaching 46.4% (688 PJ) in 2020 and to 75.7% (3041 PJ) in 2030. This high dependency on imported fuel raises the issue of energy security.

Table 27: Coal requirement & supply for the power sector in the base scenario

	2005	2010	2015	2020	2025	2030
Coal requirement (PJ)	95.8	194.11	644.8	1482.49	2374.86	4017.70
Domestic	*95.8*	*194.11*	*644.8*	*794.48*	*799.09*	*976.41*
Import	*0*	*0*	*0*	*688.01*	*1,575.77*	*3,041.29*

As external cost is ignored, no advanced and/or clean fossil fuel technologies are chosen. For example, for coal, only the pulverized coal technology is selected. Therefore, CO_2 emissions in this period are projected to grow at 8.7%/year, from 73.32 million tons in 2015 to 390.28 million tons by 2030 (Table 28). Per capita, the increase would be from 0.8 million tons in 2015 to 3.78 million tons in 2030, equivalent to a growth rate of 8.1% per year. Emissions of SO_2 are much lower, but they are expected to increase at a significant rate, 10.4% per year. Emissions of NO_x are also small in quantity; however, they are also expected to increase at a considerable rate of 9.2% per year, from 208 thousand tons in 2015 to 1209 thousand tons in 2030.

These emissions could impose huge costs on the society and the environment. The total damage from the pollutants in 2015 is assessed at about 4,071 million USD; equivalent to 4.2% of the real GDP. Damages are projected to grow to 22,754 million USD by 2030. This is equivalent to 8.5% of the projected GDP[14], *i.e.* a bigger percentage of a larger GDP. Representing these in terms of US cent per electricity consumed, the increase would be from 2.8 US cents per kWh in 2015 to 3.1 US cents

[14] GDP is projected to grow at an annual average rate of 6.9% from 2016-2030 and 7% afterwards

per kWh in 2020 and 4.5 US cents per kWh by 2030, primarily driven by the increasing share of coal.

Table 28: Emissions in the base scenario

Emission ('000t)	2005	2010	2015	2020	2025	2030
CO_2	21,156	38,002	73,325	149,397	243,120	390,278
NOx	55	99	208	457	740	1209
PM10	3	6	13	34	55	94
SO_2	110	196	518	1,372	2,197	3,715

6.2.2 The renewable energy scenario (B&RE)

Including external costs in the total production cost of electricity changes capacity requirement. The capacity is expected to grow from 38.9 GW in 2015 to 123.48 GW in 2030, i.e., an increase of 84.58 GW over 20 years, equivalent to an annual increase of 4,229 MW per year (Table 29). This capacity increase is higher than the base case because more wind and solar are selected which have lower capacity factors than that of conventional energy (coal, natural gas…) and because of larger capacity of variable renewable energy (wind, solar) requires larger back-up capacity from gas turbine.

Table 29: future capacity development under the renewable energy scenario

Fuels	Installed capacity (GW)					
	2005	2010	2015	2020	2025	2030
Biomass	-	0.15	0.38	0.63	1.22	1.95
Coal	1.51	4.01	13.07	25.97	25.64	42.21
Natural gas	4.63	6.71	7.45	7.69	18.59	24.40
Hydro	4.32	8.75	16.57	21.84	24.88	28.07
Solar	-	-	-	0.10	6.97	17.75
Wind	-	0.03	0.09	0.15	2.35	8.50
Oil	0.79	1.01	1.34	0.77	0.62	0.40
Others	-	-	-	0.05	0.15	0.20
Total	**11.25**	**20.66**	**38.90**	**57.20**	**80.42**	**123.48**

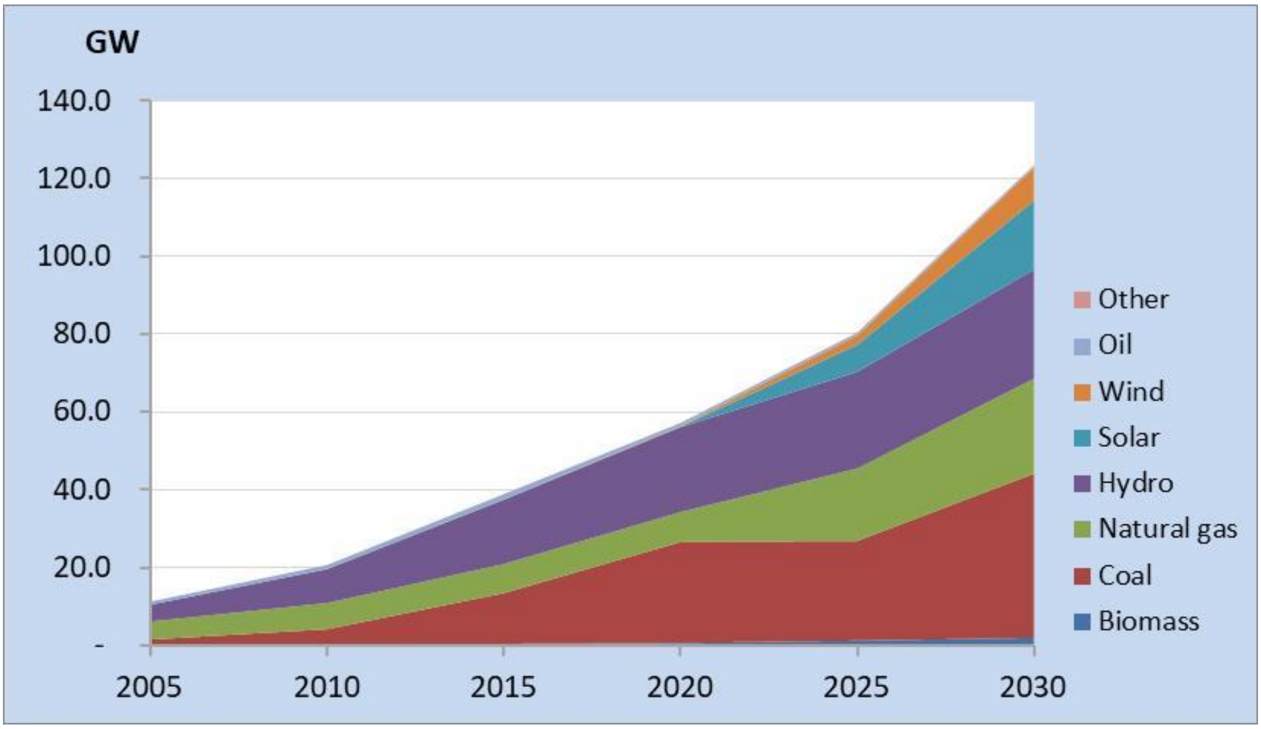


Figure 20: future capacity development under the renewable energy scenario

As a result, the generation mix changes significantly (Table 29 and Figure 20). Share of coal now is reduced to 34.2% in 2030 versus 66.1% in the base scenario, or a reduction of 24 GW in 2030. This reduction in coal capacity is replaced by 16.95 GW of gas turbine and 25.97 GW of renewable energy technologies including 8.5 GW of wind and 17.75 GW of solar PV. Moreover, selected coal technology after 2020 by the model is Ultra supercritical coal which has high efficiency and low emission. This change in generation mix indicates that investments in low emitting technologies such as renewable energy technologies (wind, solar) and low emission coal based technologies are more economic than paying taxes. Relative to the base case, this change in generation mix reduces CO_2, NO_x, SO_2 and PM emissions. Specifically, emissions are reduced by 122.2 million ton of CO_2, 1.49 million tons of SO_2, 413 thousand ton of NO_x and 39 thousand ton of PM by 2030, relative to the base case. As a result, this change in generation mix leads to a reduction of 1,623 PJ of imported coal or 53.4% in 2030 even thought, more gas is required and part of it is expected to be imported. Overall, 1,180 PJ of fossil fuel as fuel requirement is reduced. Thus, energy security of the country under this scenario is much improved.

The reduction in emissions reduces the external costs imposed on society and the environment. By 2030, the external costs are 14,862 million USD or 5.6% of the projected GDP compared to 22,754 million USD or 8.5% of projected GDP in the base scenario. Representing in US cent/kWh, the avoided external costs would be equivalent to 1.56 US cent/kWh.

As there is a high percentage of variable RE energies, a stress test was conducted to test the uncertainty of the system. By this mix, the system can still be able to meet the projected demand even in the day without power from both wind and solar. This chance is very low, even impossible, in particular in this case as wind are solar are distributed by regions and as such, the smoothing effect would lead to a certain contribution from wind at any moment both daytime and night time and for solar during day time.

6.2.3 The emission cap scenario (B&CO2CAP)

With CO_2 emission caps, installed capacity is expected to grow from 38.9 GW in 2015 to 119 GW, i.e., an increase of 80 GW which is higher than that of the base scenario but lower than that of the Renewable energy scenario.

There is also a structural change compared with the base scenario. Coal capacity is reduced by 16.4 GW which is compensated by 10.5 GW of gas and 20.3 GW of renewable energies (16.60 GW of solar and 3.7 GW of wind). By 2030, share of coal is expected to make up 41.9% whereas that of renewable energies (excluding large hydro) is 24.1% (Table 30).

Table 30: future capacity development under the CO_2 emission cap scenario

Fuels	Installed capacity (GW)					
	2005	2010	2015	2020	2025	2030
Biomass	-	0.15	0.38	0.50	1.22	1.95
Coal	1.51	4.01	13.07	25.97	35.69	49.85
Natural gas	4.63	6.71	7.45	7.69	8.54	17.93
Hydro	4.32	8.75	16.57	21.84	24.88	28.07
Solar	-	-	-	0.03	6.70	16.75
Wind	-	0.03	0.09	0.15	2.35	3.85
Oil	0.79	1.01	1.34	0.77	0.62	0.40
Others	-	-	-	-	0.15	0.20
Total	**11.25**	**20.66**	**38.90**	**56.95**	**80.15**	**119.00**

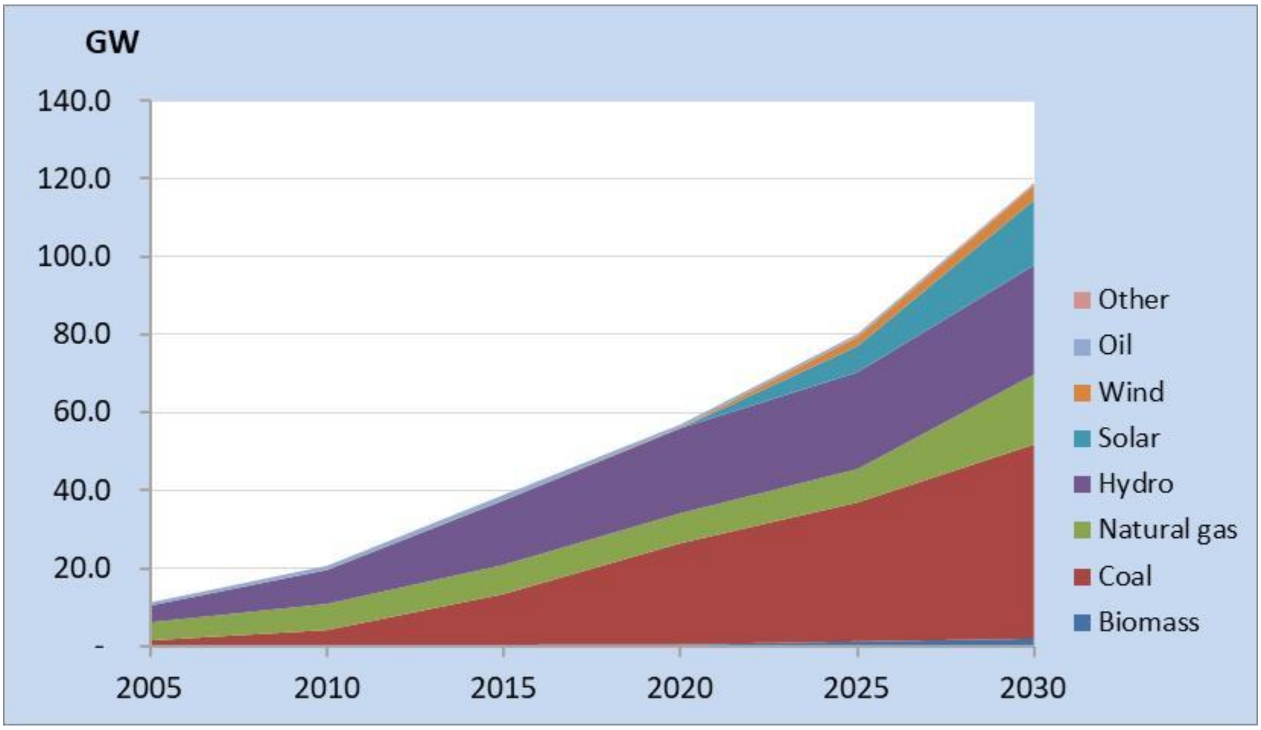


Figure 21: future capacity development under the CO_2 emission cap scenario

This structural change indicates that investing in renewable energy, in particular wind and solar energy and gas power is a cost-effective way to attain CO_2 emission reduction in the generation section while ensuring the reliability of supply. However, this change does not come for free. Discounted total system cost is expected to increase by more than 2.9 billion USD (from 177.9 billion USD in the base scenario to 180.8 billion USD in this scenario).

6.3 The EE demand scenario

6.3.1 *The base generation scenario (EE&B)*

With a lower energy demand, capacity requirement would be lower (Table 30 and Figure 20). As shown in table 30, capacity requirement by 2030 would be 83 GW, about 17.1 GW lower than the base case under this study and as high as 46.4 GW if compared with the PDP VII rev. This reduction comes from coal, resulting in 25.2% CO_2 emission reduction and 34.1% coal import quantity compared with the base case. From these perspectives, promotion of EE measures is an attractive way to reduce CO_2 emission and improve energy security of the country.

Table 31: future capacity development under the base generation scenario

Fuels	Installed capacity (GW)					
	2005	2010	2015	2020	2025	2030
Biomass	-	0.15	0.38	0.38	0.95	1.45
Coal	1.51	4.01	13.07	25.97	31.16	49.17
Natural gas	4.63	6.71	7.45	7.69	6.59	3.56
Hydro	4.32	8.75	16.57	21.84	24.19	28.07
Solar	-	-	-	0.01	0.09	0.13
Wind	-	0.03	0.09	0.15	0.15	0.15
Oil	0.79	1.01	1.34	0.77	0.62	0.40
Others	-	-	-	-	0.15	0.20
Total	**11.25**	**20.66**	**38.90**	**56.81**	**63.90**	**83.13**

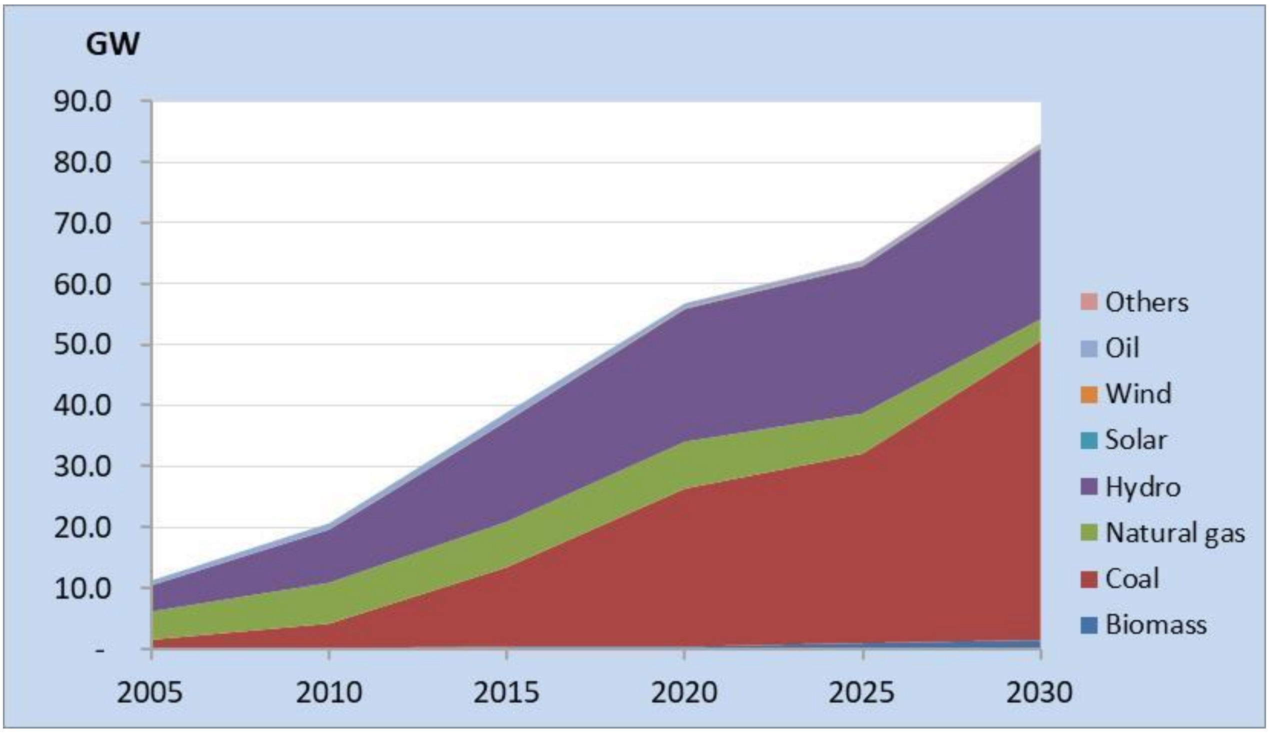


Figure 22: future capacity development under the base generation scenario

6.3.2 *The renewable energy scenario (EE&RE)*

When EE is considered, in addition to external cost, the generation capacity requirement reduces by 18.75 GW compared with the B&RE and the reduction is taken mainly from coal (16.6 GW) and 1 GW solar (Table 32 and Figure 22). This leads to a CO2 emission reduction of 31% by 2030, and as high as 52% if compared with the B&B case. From this result, there appears substantial potential for CO_2 emission by promoting renewable energy and energy efficiency (Table 33).

Table 32: future capacity development under the renewable energy scenario

Fuels	Installed capacity (GW)					
	2005	2010	2015	2020	2025	2030
Biomass	-	0.15	0.38	0.63	1.22	1.95
Coal	1.51	4.01	13.07	25.97	25.64	25.64
Natural gas	4.63	6.71	7.45	7.69	10.60	23.98

Hydro		4.32	8.75	16.57	21.84	24.88	28.07
Solar		-	-	-	0.03	6.70	16.75
Wind		-	0.03	0.09	0.15	2.35	8.14
Oil		0.79	1.01	1.34	0.77	0.62	0.40
Others		-	-	-	0.05	0.15	0.20
	Total	**11.25**	**20.66**	**38.90**	**57.13**	**72.16**	**105.13**

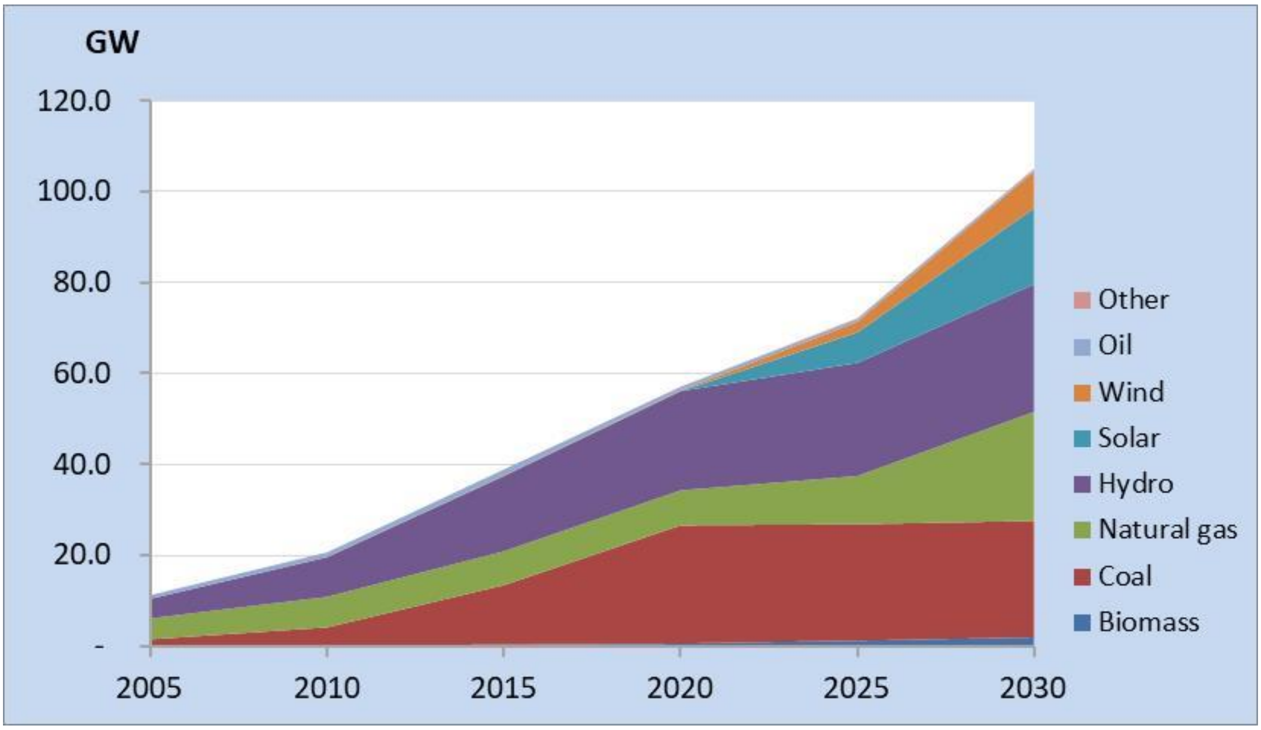


Figure 23: future capacity development under the renewable energy scenario

Table 33: Emissions in the RE&EE case

Emission ('000t)	2005	2010	2015	2020	2025	2030
CO_2	21,156	38,002	68,962	114,725	166,363	186,046
NOx	55	99	194	336	499	539
PM10	3	6	12	23	36	36
SO_2	110	196	476	911	1,436	1,428

6.4 Summary of generation scenarios

Figure 24, 25, 26 and 27 provide summaries of studied cases, respectively in terms of installed capacity, CO_2 emission, import dependency by 2030 and discounted total system costs.

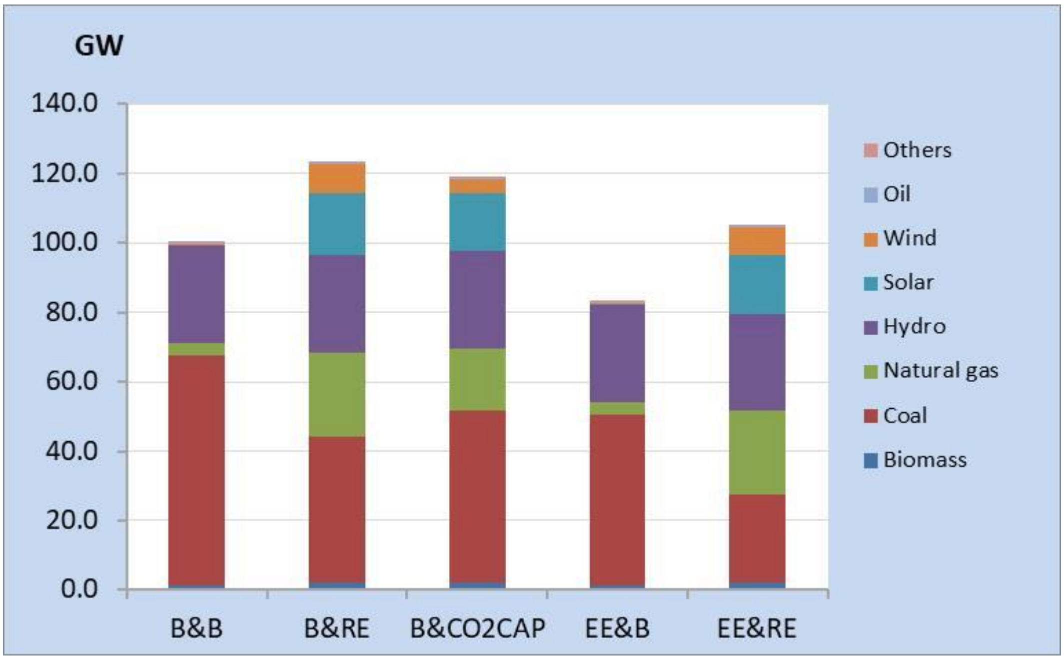


Figure 24: Capacity requirement of studied cases by 2030

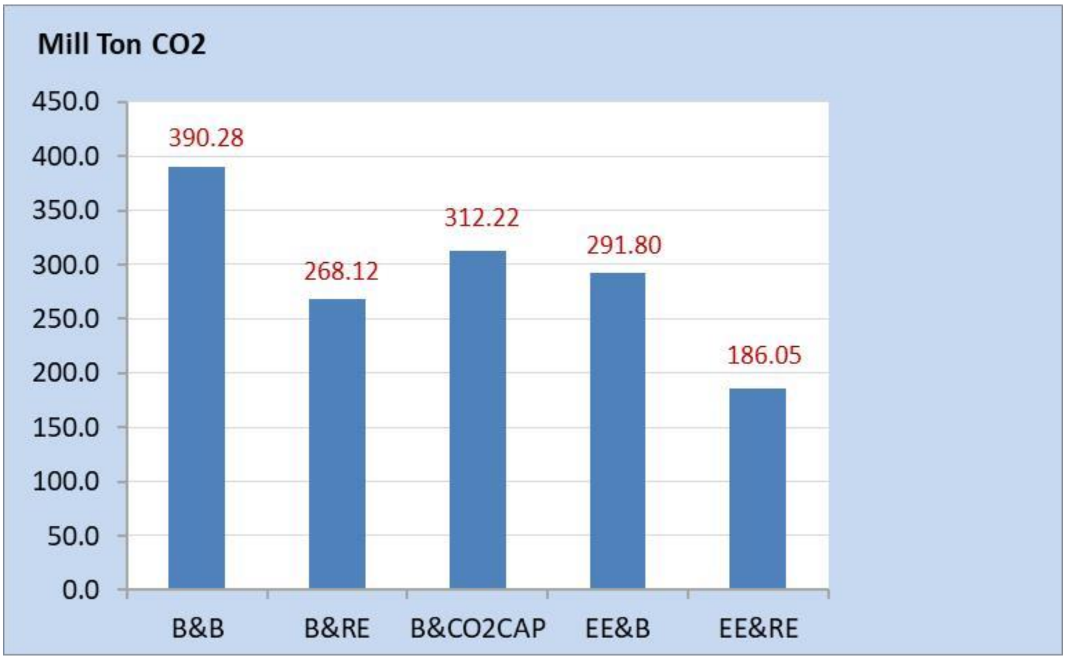


Figure 25: CO_2 emission by studied cases by 2030

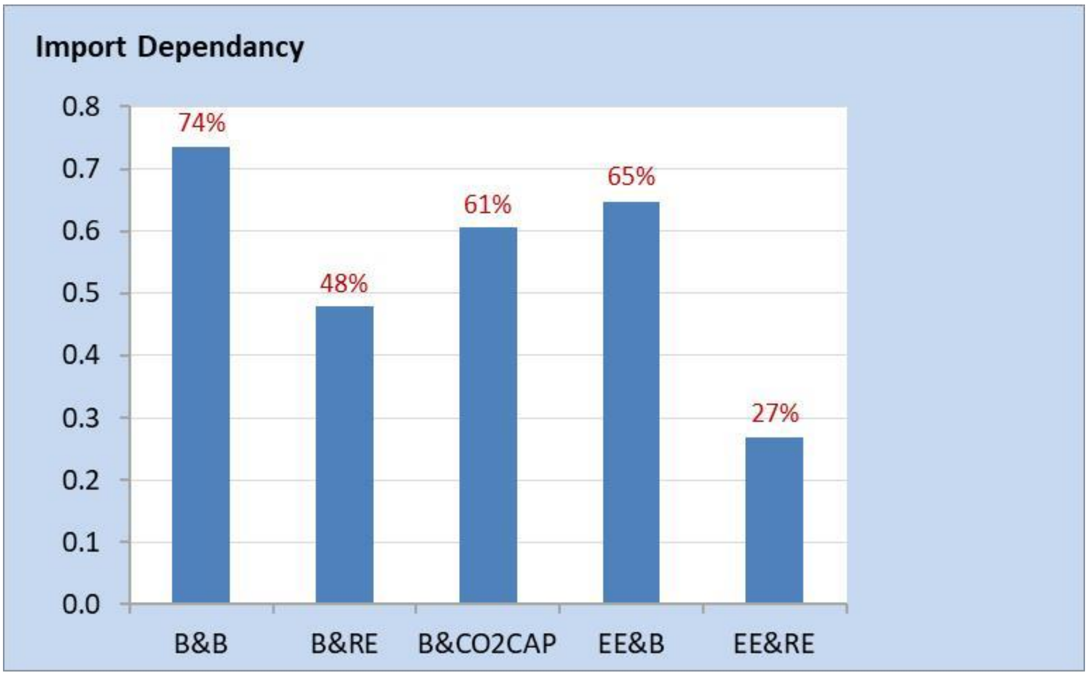


Figure 26: Import fuel dependency by studied cases by 2030

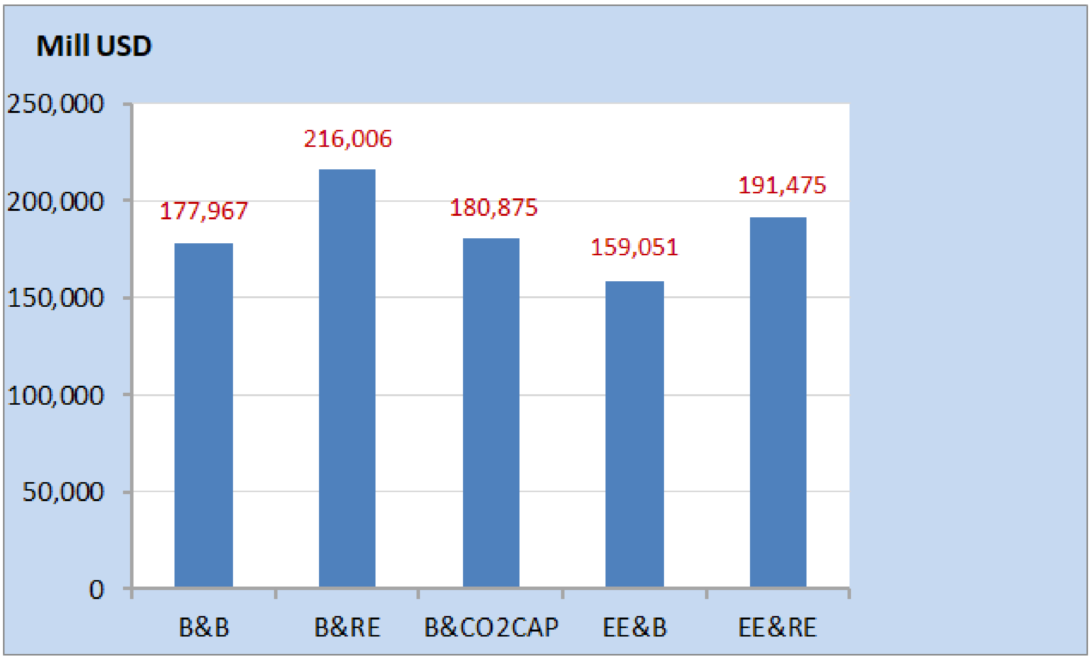


Figure 27: Discounted total system cost by studied cases

7. Conclusions and recommendations

7.1 Conclusions

From the modelling and analysis, the following broad conclusions could be drawn:

- Without consideration of external costs, coal power is amongst the cheapest, thus the generation mix is expected to be dominated by coal. This is in agreement with the PDP VII rev. In this case, coal requirement by 2030 would increase by 6.23 folds (as compared to the 2015 level) and 76% of which would be imported which thus jeopardizes the energy security of the country and at the same time would cause huge external cost to the environment and the society.

- Renewable energies are getting cheaper and cheaper. Solar PV as of 2020 and wind power as of 2025 could compete directly with fossil fuel based power.
- Development of renewable energy brings many benefits including cost, environment, and energy security….. Including just the environmental and social benefits would make many renewable energy technologies, those even with poorer resources become cost-competitive to fossil fuel based technologies.
- Results from the modelling shows that share of renewable energy capacity could reach 27.8% in 2030 which is higher than the PDP VII rev at 21%. Higher share could be expected if a longer time horizon is studied as then a higher built rate for renewable energy technologies could be assumed.
- Implementing EE could lessen significantly the burden on capacity addition. It is estimated that as much as 17 GW could be reduced - equivalent to 14 coal fired power plants. This, if combined with additional RE development would result in CO_2 emission reduction of up to 52%.

7.2 Recommendations

- The power development plan considers energy efficiency properly. There is large capacity within Vietnam to implement greater energy efficiency, due to its high intensity of energy consumption. EE options can be modeled as generation technologies. In this case, these technologies avoid demand, rather than provide additional supply.
- It is recommended to use cost curve to present EE options. The cost curve shows the relations ship between cost of saving and the amount of saving that can be implemented.
- The "profile" of saving should be captured as this means greatly different for the system, to the cost that the system could avoid. If the savings are at peak times when the demand on the grid is highest and the most expensive generation has to be brought on-line, the avoided cost to the system could be many folds more than the similar at off-peak times.
- In the long-run, it might be worthwhile to evaluate the performance of the sectors in terms of their contribution to the economy and the resources, in particular energy resources. From the perspectives, restructuring of the economy might be proposed to improve the efficiency of the economy.
- Further on EE, attention should be paid to roof-top solar PV as it can reduce peak demand due to a high correlation of its power output profile and the system load curve, in particular in the southern provinces.
- In terms of power planning, the choice of power generation technologies/sources should be made from the view point of the economy. Ignorance of external cost would eliminate the possible contribution of renewable energy sources.
- It is recommended that the existing power development plan be updated in the direction of reducing coal power and replaced it by renewable energy and gas power to ensure supply reliability.

- The present study has tried to capture the seasonal and spatial (regional) characteristics of wind and solar energy as the key renewable energy technologies and in fact, stress tests were conducted. However, solar and wind vary at higher temporal and spatial level, therefore, there is still an issue of supply reliability associated with the chosen power generation mix with a high share of variable renewable energies. Therefore, it is important that a high resolution modeling of the power system is initiated. For that purpose, typical hourly solar and wind data should be collected and so the load profile so that the modeling could be conducted on an hourly basis.

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Annex 1: Technical and economic assumptions for the candidate power generation technologies

- All costs are expressed in 2015 US dollar
- Capital costs presented represent all in plants costs, inclusive of all engineering, procurement, and construction (EPC), owner's costs; and interest during construction (IDC).

Fuel	Technology	Start year	Availability	Lifetime (Year)	Efficiency (%)	Capital cost ($/kW)			Fixed O&M cost ($/kW.yr)			Variable O&M cost ($/MWh)		
						2015	2020	2030	2015	2020	2030	2015	2020	2030
Coal	Subcritical coal	2015	70	30	39	1700	1700	1700	33.6	33.6	33.6	0.15	0.15	0.15
	Subcritical coal with CCS	2020	70	30	30	2950	2950	2950	85	85	85			
	Supercritical coal	2020	70	30	43	2000	2000	2000	60	60	60			
	Ultra critical coal	2020	70	30	46	2200	2200	2200	66	66	66			
Gas	Gas turbine	2015	75	25	45	620	620	620	20	20	20			
	CCGT	2015	75	25	60	1000	1000	1000	25	25	25			
Diesel	Gas turbine	2015	75	25	44	650	650	650	25	25	25			
FO	Steam turbine	2015	75	25	35	1100	1100	1100				2.7	2.7	2.7
Hydro	Small	2015	45	30	100	1700	1700	1700				2.5	2.5	2.5
	Large	2015	45	40	100	2500	2500	2500				2.5	2.5	2.5
	Pump-storage	2020	21	40	75	3000	3000	3000	60	60	60			
Rooftop solar PV	Rooftop-High Irradiation	2015	17.5	20	100	1200	1100	1000	21	21	21			
	Rooftop-Medium Irradiation	2015	15.8	20	100	1200	1100	1000	21	21	21			
	Rooftop-Low Irradiation	2015	14.2	20	100	1200	1100	1000	21	21	21			
Solar farm	Ground mounted-High Irradiation	2015	17.5	20	100	1000	900	800	18	18	18			
	Ground mounted-Medium Irradiation	2015	15.8	20	100	1000	900	800	18	18	18			
	Ground mounted-Low Irradiation	2015	14.2	20	100	1000	900	800	18	18	18			
Wind	High wind	2015	35	25	100	1980	1900	1800	35	35	35			
	Medium wind	2015	30	25	100	1980	1900	1800	35	35	35			
	Low wind	2015	25	25	100	1980	1900	1800	35	35	35			
Biomass	Bagasse	2015	57	20	20.7	1100	1100	1100	44	44	44			
	Rice Hush	2015	74	20	23.1	1920	1920	1920	77	77	77			
	Rice Straw	2015	74	20	26.7	2000	2000	2000	80	80	80			
	Timber waste	2015	74	20	47.4	1900	1900	1900	76	76	76			
Waste to energy	Land fill	2015	91	20	40	2331	2331	2331	93	93	93			
	Incineration	2015	74	20	25	4000	4000	4000	340	340	340			
Biogas	Steam turbine	2015	50	25	25	1800	1800	1800				4	4	4
Geothermal	Binary	2020	70	25	15	4000	4000	4000	120	120	120			

Annex 2: Method to calculate Levelized Cost of Energy

Levelized cost of energy is a cost of generating energy for a particular system. It is an economic assessment of the cost of the energy generating system including all the costs over its lifetime: initial investment cost, operation and maintenance and fuel cost, therefore it is a matric to compare the competitiveness of generation technologies with each other. Discounted costs streams, combined with energy values, are used to calculate levelized cost (LCOE) in order to compare various energy technologies

LCOE of electricity from a given power generation technology is calculated as:

$$LC = \frac{C_{pw} + M_{pw} + F_{pw}}{E_{pw}} \tag{1}$$

where pw is a subscript and indicates the present worth of each factor.

Capital cost (*C*) represents initial costs for purchasing equipment and installation including interest during construction that should be spent before the system operation starts (year 0).

Maintenance cost (*M*) represents recurring costs spent every year for maintenance and operation of the system. These are discounted at rate *d*. The levelized maintenance and operation cost for a lifetime:

$$M_{pw} = \text{Annual Maintenance cost} * \left[\frac{1-(1+d)^{-N}}{d}\right] \tag{2}$$

where N is the evaluation period in year.

Fuel cost (*F*), commonly expressed as the annual fuel expenditure which is defined from the equation:

$$F_{pw} = \text{Annual Fuel cost} * \left(\frac{(1+e_f)}{(d-e_f)}\right) * \left[1-\left(\frac{(1+e_f)}{(1+d)}\right)^{N}\right] \tag{3}$$

where e_f is fuel cost escalation.

Energy output (*E*) represents the present worth of an annual energy output (*A*) received over a time period (N years) at the discount rate *d*

$$E_{pw} = A * \left[\frac{1-(1+d)^{-N}}{d}\right] \tag{4}$$

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