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Acronyms

AD	Anaerobic Digestion
ADB	Asian Development Bank
AGL	Above Ground Level
ASEAN	Association of Southeast Asian Nations
ASES	Advanced Sustainable Energy Sector
BAU	Business As Usual
BCM / Bcm	Billion Cubic Metres
BNEF	Bloomberg New Energy Finance
BOT	Build-Own-Transfer
BP	British Petroleum
BST	Bulk Supply Tariff
BTU / Btu	British Thermal Unit
CAA	Commercial Arrangement Area
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CENER	National Renewable Energy Centre
CHP	Combined Heat and Power
CIEMOT	Centro de Investigaciones Energeticas Medioambientales y Tecnológicas
COD	Commercial Operations Date
CSP	Concentrated Solar Power
DNI	Direct Normal Irradiation
DR	Demand Response
DSM	Demand Side Management
DTU	Technical University of Denmark
EE	Energy Efficiency

EIA	Energy Information Administration
EPTC	Electric Power Trading Company
ERAV	Electricity Regulatory Authority of Viet Nam
EVN	Electricity of Viet Nam
FOB	Free on Board
FOM	Fixed Operating and Maintenance
GDE	General Directorate for Energy
GDP	Gross Domestic Product
GHI	Global Horizontal Irradiance
GMS	Greater Mekong Subregion
GT	Gas Turbine
HV	High Voltage
ICT	Information and Communication Technology
IDAE	Instituto para la Diversificación y Ahorro de la Energía
IEA	International Energy Agency
IES	Intelligent Energy Systems Pty Ltd
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
LCOE	Overall Levelised Cost of Electricity
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MKE	Mekong Economics
MMCM	Million Cubic Metres
MOIT	Ministry of Industry and Trade
MOU	Memorandum of Understanding
MTPA	Million Tonnes Per Annum
MV	Medium Voltage
NASA	National Aeronautics and Space Administration (the United States)
NLDC	National Load Dispatch Centre

NPT	National Power Transmission Corporation
NPV	Net Present Value
NREL	National Renewable Energy Laboratory (the United States)
OECD	Organisation for Economic Co-operation and Development
OPEC	Organisation of the Petroleum Exporting Countries
OPEX	Operational Expenditure
PC	Power Corporation
PDP	Power Development Plan
PDR	People's Democratic Republic (of Laos)
PPA	Power Purchase Agreements
PRC	People's Republic of China
PV	Photovoltaic
PV Gas	Gas Trading Corporation under PVN
PV Power	Power Corporation under PVN
PVN	PetroVietnam - Viet Nam National Oil and Gas Group
RE	Renewable Energy
REVN	Renewable Energy of Viet Nam Joint Stock Company
ROR	Run of River
RPR	Reserves to Production Ratio
SB	Single Buyer
SCADA/EMS	Supervisory Control and Data Acquisition/Energy Management System
SES	Sustainable Energy Sector
SMO	System and Market Operator
ST	Steam Turbine
SWERA	Solar and Wind Energy Resource Assessment
SWH	Solar Water Heating
TCF / Tcf	Trillion Cubic Feet
TKV	Viet Nam National Coal and Mineral Industry Group
TNO	Transmission Network Operator

TOE	Tonne of Oil Equivalent
UN	United Nations
US	United States
USAID	United States Agency for International Development
USD	United States Dollar
VCGM	Viet Nam Competitive Generation Market
VINACOMIN	Viet Nam National Coal and Mineral Industry Group
VOM	Variable Operating and Maintenance
VWEM	Viet Nam Wholesale Electricity Market
WBG	World Bank Group
WEO	World Energy Outlook
WWF	World Wide Fund for Nature
WWF-GMPO	WWF – Greater Mekong Programme Office

Table of Contents

1 Introduction

Intelligent Energy Systems Pty Ltd ("IES") and Mekong Economics ("MKE") were retained by WWF – Greater Mekong Programme Office ("WWF-GMPO") to undertake a project called "Produce a comprehensive report outlining alternatives for power generation in the Greater Mekong Sub-region". This was to develop scenarios for the countries of the Greater Mekong Sub-region (GMS) that are as consistent as possible with the WWF's Global Energy Vision to the Power Sectors of all Greater Mekong Subregion countries. The objectives of WWF's vision are: (i) contribute to reduction of global greenhouse emissions (cut by >80% of 1990 levels by 2050); (ii) reduce dependency on unsustainable hydro and nuclear; (iii) enhance energy access; (iv) take advantage of new technologies and solutions; (v) enhance power sector planning frameworks for the region: multi-stakeholder participatory process; and (vi) develop enhancements for energy policy frameworks.

The purpose of this report is to provide detailed country-level descriptions of three scenarios for the power sector of the Socialist Republic of Viet Nam (Viet Nam):

- Business as Usual (BAU) power generation development path which is based on current power planning practices, current policy objectives;
- Sustainable Energy Sector (SES) scenario, where measures are taken to maximally deploy renewable energy[1] and energy efficiency measures to achieve a near-100% renewable energy power sector; and
- Advanced Sustainable Energy Sector (ASES) scenario, which assumes a more rapid advancement and deployment of new and renewable technologies as compared to the SES.

The scenarios were based on public data, independent assessments of resource potentials, information obtained from published reports and power system modelling of the GMS region for the period 2015 to 2050.

1.1 Report Structure

This report has been organised in the following way:

- Section 2 sets out recent outcomes for Viet Nam's electricity industry;
- Section 3 summarises the main development options covering both renewable energy and fossil fuels;
- Section 4 provides a brief summary of the scenarios that were modelled and a summary of the assumptions in common;
- Section 5 sets out the key results for the business as usual scenario;

[1] Proposed but not committed fossil fuel based projects are not developed. Committed and existing fossil fuel based projects are retired at the end of their lifetime and not replaced with other fossil fuel projects. A least cost combination of renewable energy generation is developed to meet demand.

- Section 6 sets out the key results for the sustainable energy sector scenario;
- Section 7 sets out the key results for an advanced sustainable energy sector scenario;
- Section 8 provides comparative analysis of the three scenarios based on the computation of a number of simple metrics that facilitate comparison;
- Section 9 provides analysis of the economic implications of the scenarios; and
- Section 10 provides the main conclusions from the modelling.

The following appendices provide some additional information for the scenarios:

- Appendix A contains the technology cost assumptions that were used;
- Appendix B provides the fuel price projections that were used;
- Appendix C sets out information used to estimate jobs creation potential for each scenario.
- Appendix D sets out a number of wind resource maps; and
- Appendix E sets out several solar resource maps.

Note that unless otherwise noted, all currency in the report is Real 2014 United States Dollars (USD). All projections presented in this report commence in the year 2015.

2 Background: Viet Nam's Electricity Sector

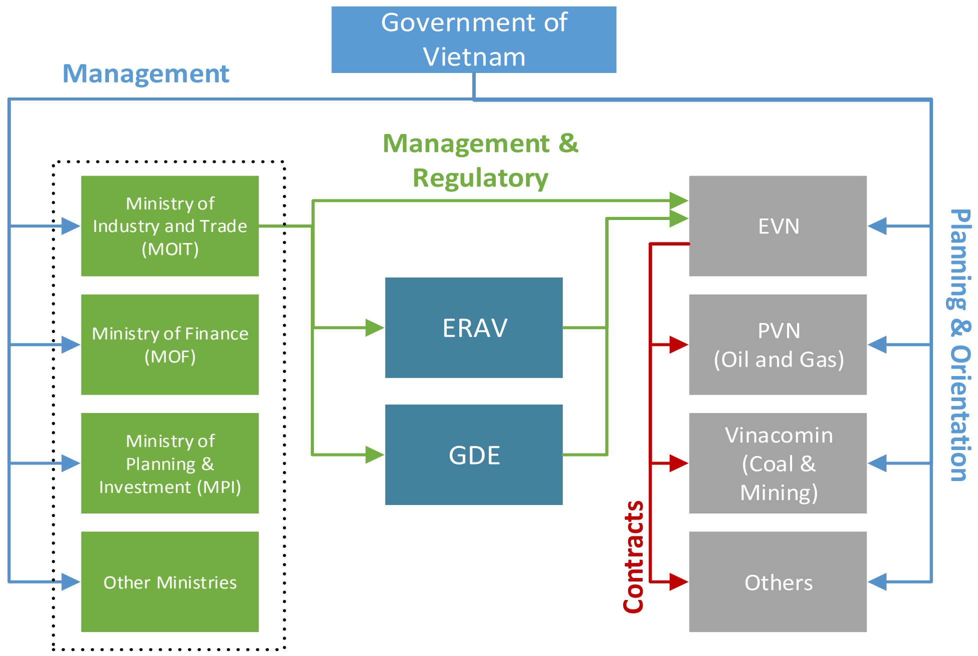
2.1 Industry Structure

Viet Nam's electricity industry has been undergoing restructuring since 2005 and this is a process that is ongoing.

Restructuring Viet Nam's electricity sector started with the establishment of Viet Nam Electricity (EVN) as a holding company in 2006. EVN and its subsidiaries (the PCs) have since played a dominant role in the electricity industry. EVN's activities cover most aspects in Viet Nam's electricity sector: generation, transmission, the role of the single wholesale buyer, distribution, and selling being managed by five PCs. As of 2013, EVN held majority ownership of approximately 61% of the installed generating capacity directly and through its subsidiaries[2].

The governance structure of Viet Nam's electricity industry is illustrated in Figure 1. The key organisations in Viet Nam's power sector under the Government of Viet Nam are the Ministry of Industry and Trade (MOIT), the General Directorate for Energy (GDE), ERAV, and EVN. Other major electricity producers also include Viet Nam National Oil and Gas Group, PetroVietnam (PVN) and Viet Nam National Coal and Mineral Industry Group (Vinacomin).

Figure 1 Governance Structure to Illustrate Ministries

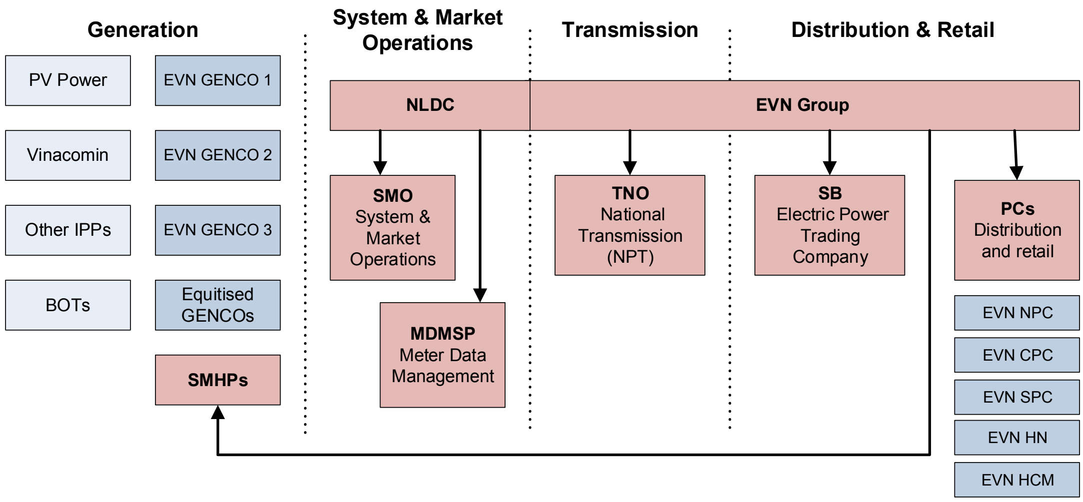


Source: based on EVN presentation: "Vietnam Electricity and Power Development of Vietnam", 2013.

[2] As reported by ERAV in March 2014, EVN has 6,782 MW (22%) of installed capacity attributable to strategic generation assets, 4,774 MW (16%) attributable to EVN GENCO 1, 3,384 MW (11%) attributable to EVN GENCO 2, and 3,729 MW (12%) attributable to EVN GENCO 3.

The operational structure of Viet Nam's electricity industry under the Viet Nam Competitive Generation Market (VCGM) is illustrated in Figure 2.

Figure 2 Structure of Viet Nam's Electricity Industry under the VCGM



Source: Consultant

The VCGM commenced full operation in July 2012 and was a key step in reforming Viet Nam's electricity industry. The goal of the VCGM was to establish the rules and procedures for a single-buyer electricity market, unbundle and restructure EVN, and to develop the systems and infrastructure necessary to support the operation of an electricity market.

In the VCGM the roles have been allocated to different entities within EVN as follows:

- National Load Dispatch Centre (NLDC). NLDC is a division of EVN and is responsible for the planning, operation and management of the national power system, including generation, transmission, and distribution. NLDC is responsible for ensuring the power system is operated in a secure and reliable manner at all times. In the VCMG NLDC performs the role of System and Market Operator (SMO).
- NLDC has an IT division that performs the role of the Metering Data Management Service Provider (MDMSP).
- National Power Transmission Corporation (NPT) performs the role of Transmission Network Operator (TNO), and is responsible for transmission equipment at the 220 kV and 500 kV voltage levels.
- Electric Power Trading Company (EPTC) performs the role of the Single Buyer (SB) in the VCGM. More generally EPTC is responsible for planning, negotiating and executing Power Purchase Agreements (PPAs) in Viet Nam and selling electricity to Power Corporations (PCs) at the Bulk Supply Tariff (BST) rates.

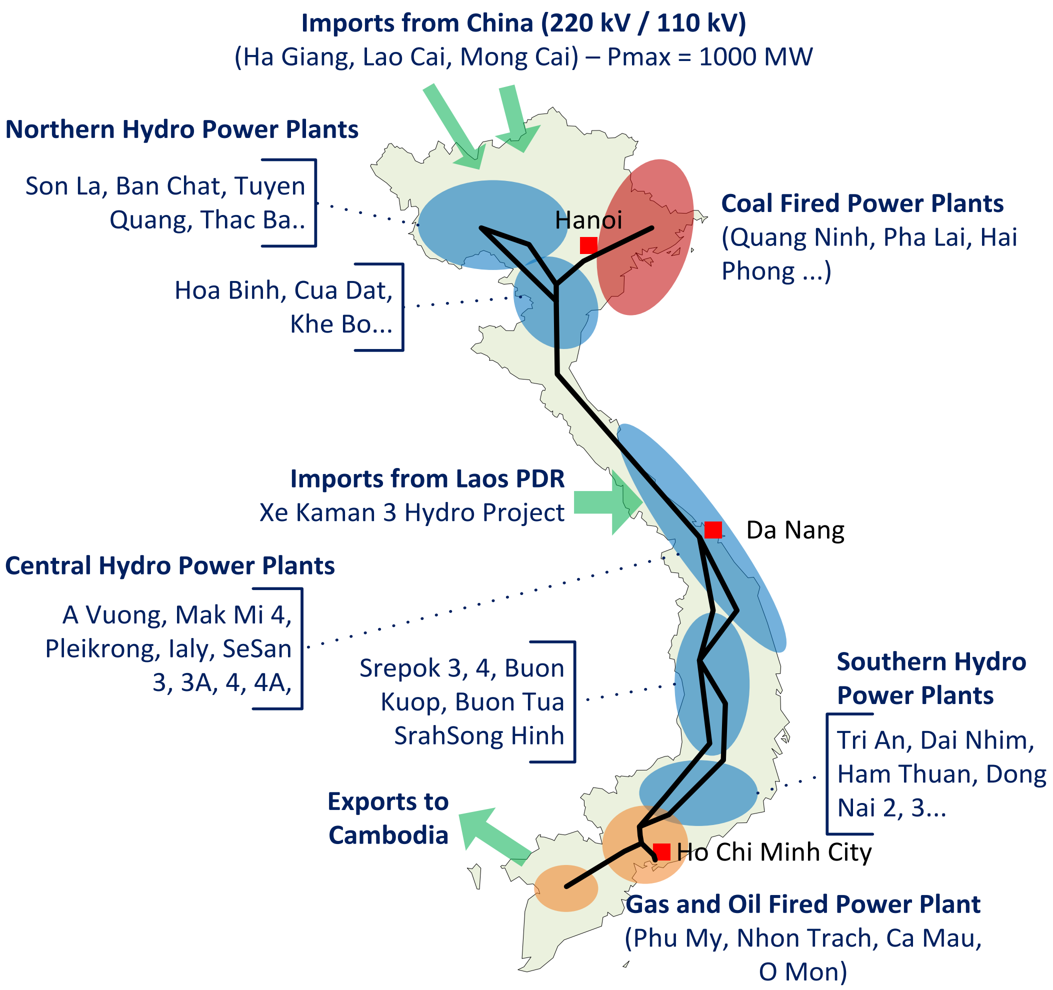
- The five PCs are distribution and retail companies. They purchase power from EPTC at the BST and sell electricity to their customers at regulated uniform tariffs.

There are plans to transition the VCGM towards the Viet Nam Wholesale Electricity Market (VWEM) by 2019, which would involve having PC's being responsible for managing their own power purchases, rather than the SB and taking measures to maximise the direct participation of all generators in the wholesale market.

2.2 Power System

A stylised representation of the Vietnamese power system is illustrated in Figure 3. The diagram highlights the main generation resources and their locations together with the basic topology of the transmission system.

Figure 3 Vietnamese Power System (2014)



Source: Consultant

In the north, electricity generation is dominated by hydro power plants and coal plants that run on indigenous coal sources. Indigenous coal reserves are available mainly in the north east region (Quang Ninh Province) and are being exploited for power generation. Likewise the reservoirs for the hydros generally lie in river basins in the northwest, particularly in the red river system. Apart from electricity generation the large reservoirs within the Red river system are used for flood mitigation in the Red river delta. In the north, there are also power imports from People's Republic of China (PRC), although the national systems of Viet Nam and PRC are electrically isolated.

The central region of Viet Nam is almost entirely dominated by hydro generation. The central region is considered to consist of two main subregions: the east coastland and the south-west highlands. The coastal subregion is a narrow strip of land which consists of a number of separate basins. There is considerable hydro potential due to the gradient of the rivers in mountainous areas that are close to the coastline. The south-west highlands have a number of Mekong tributaries that flow towards the western border of the country.

The southern region is dominated by hydro, Combined Cycle Gas Turbines (CCGT) and Steam Turbines (ST). The CCGTs including Phu My Complex, Nhon Trach, Ba Ria and Ca Mau and run on natural gas that is transported from a number of offshore fields. The main river systems in the south region include the Dong Nai River Basin with significant potential for hydro power generation and to the west of it, the downstream Mekong Delta (only 5% of the entire Mekong basin). This poses challenges for flood mitigation in the delta.

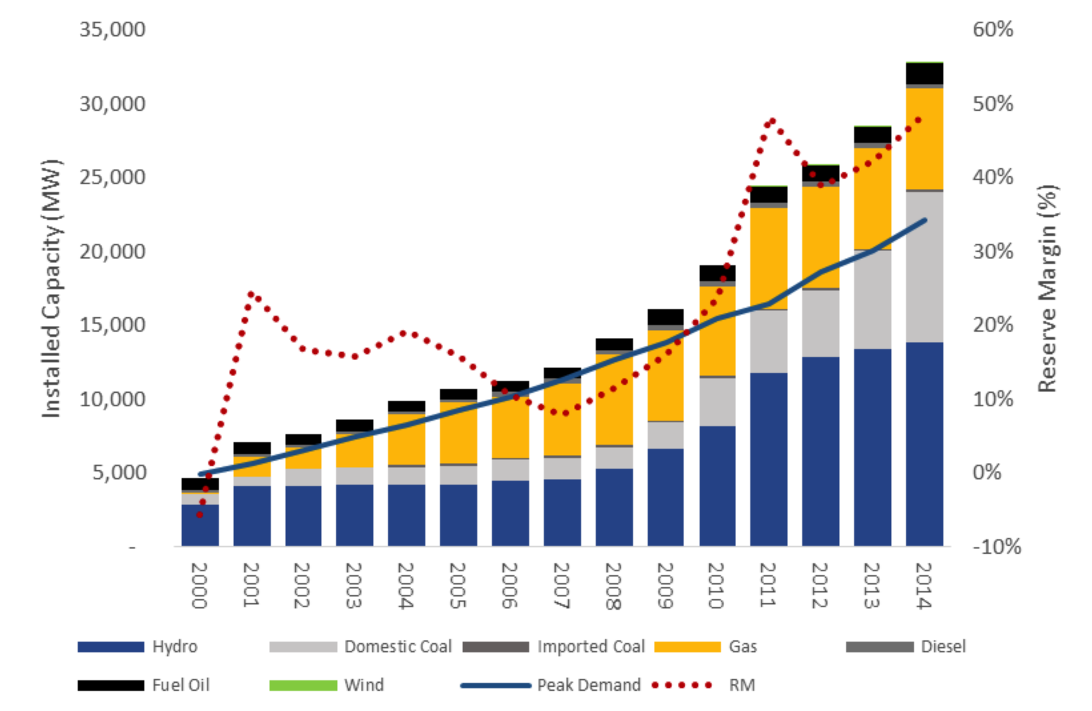
It is noted that, under the government's strategy to diversify different technologies across the regions, coal power plants have been planned and constructed for the central and southern regions, with several generators already commissioned, with recently the Vinh Tan coal thermal complex in Binh Thuan province (South), Duyen Hai coal thermal complex in Tra Vinh province (South) and Vung Ang coal thermal generation complex in Ha Tinh province (Centre). In addition, the first nuclear power plants may be constructed in Ninh Thuan province (Centre).

2.3 Installed Capacity and Reserve Margin

Figure 4 shows the installed capacity and peak demand on a national level by type of generation and region-combined in Figure 5. These are based on estimates undertaken by the consultant in preparation for this project. The reserve margin (based on nameplate capacity) is also shown. This illustrates that system reserve margin has increased notably over the period from 2008 to 2010, through the commissioning of a number of projects. Nevertheless, supply and demand in the country can become quite tight at times due to: (i) seasonality of hydro inflows which for the smaller reservoirs affects availability of hydro generation during the dry season and (ii) transmission limits, particularly between south and central Viet Nam result in tight supply and demand within the south region.

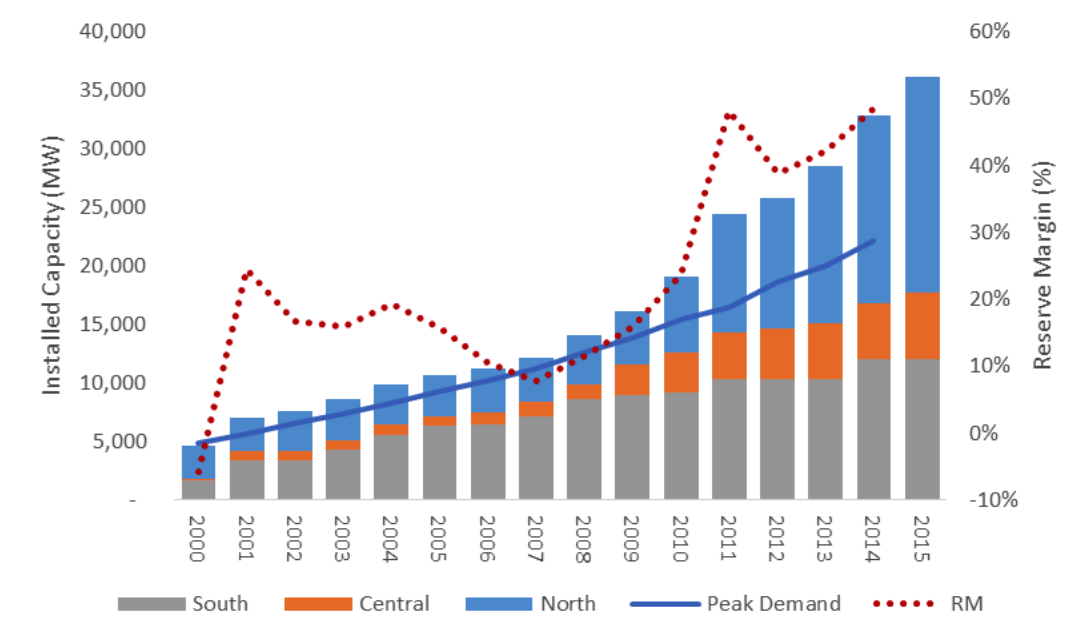
As of the end of 2014, we put the installed generation of Viet Nam at 33,964 MW with the shares in the total installed capacity as shown in Figure 6. Note that of the installed capacity, EVN owns approximately 55% (18,426 MW) either directly or through its 3 power generation companies that were established in 2012 as a step in Viet Nam's electricity industry reforms process. The other main owners of generation capacity in Viet Nam include the state-owned PV Power (15%), TIKV Power (4%) and foreign Build Own Transfer (BOT) projects and Joint Stock Companies. Viet Nam is also dependent on power imports from PRC of up to 1,000 MW (not included in the installed capacity / reserve margin assessment) and imports power from a hydro project in Laos (Xekaman 3) that is dedicated to supplying power to Viet Nam (included in the installed capacity / reserve margin assessment).

Figure 4 Installed Capacity and System-wide Reserve Margin (2000-14)



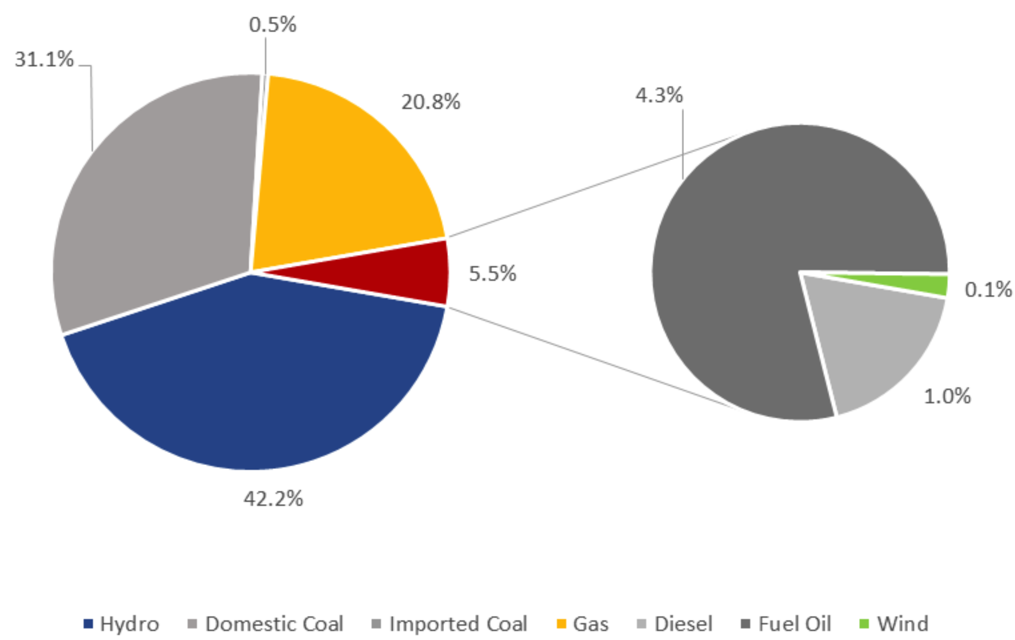
Source: Consultant's estimate

Figure 5 Installed Capacity (by Region) and System-wide Reserve Margin



Source: Consultant's estimate

Figure 6 Capacity Breakdown by Type (2014)



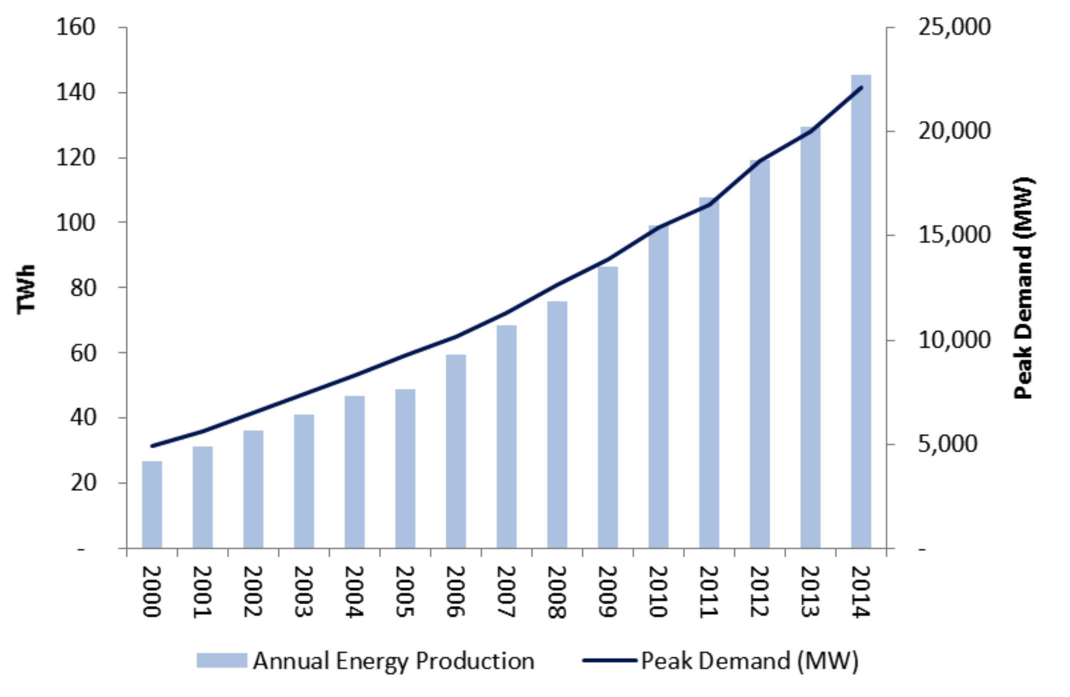
Source: Consultant's estimate

2.4 Electricity Demand

2.4.1 System-Wide and Regional Demand Trends

Figure 7 shows maximum (peak) demand on a national level and total electricity demand. Over the past 10 years national energy demand has had a compound annual growth rate (CAGR) of 12.7% and for peak demand CAGR of 10.2%. Regionally, demand in the south of Viet Nam has grown the most rapidly in the recent past, although when CAGRs are considered for the period 2004 to 2013, the "long-term" regional growth rates are: North region at 14.0%, south region at 13.5%, and central region at 12.0%. These are very high rates of demand growth. Peak demand in each region has exhibited a similar trend.

Figure 7 Peak Demand and Energy Production (2000-14)



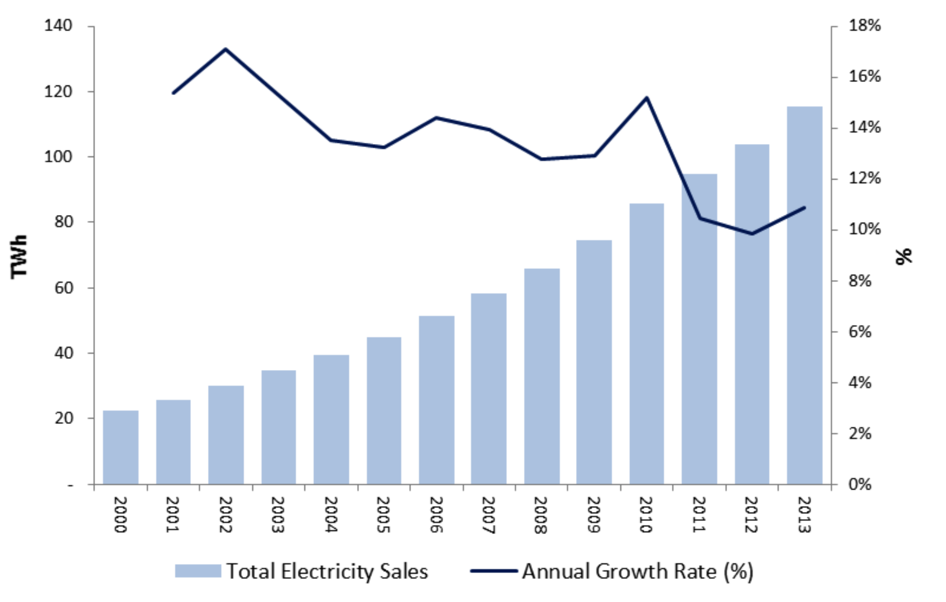
Source: ERAV

2.4.2 Electricity Sales (Grid Connected)

Economic development in Viet Nam has driven strong growth in electricity demand, which reflects rapid industrialisation, an expansion of business and services and also rising household consumption in line with rising living standards; for example, from 1995 to 2010 the per capita consumption rose during the same period from some 156 kWh to about 900 kWh. Figure 8 shows the national electricity sales for the period 2000 to 2013 and the associated year-on-year growth rates, which have averaged around 12% over the period 2009-13.

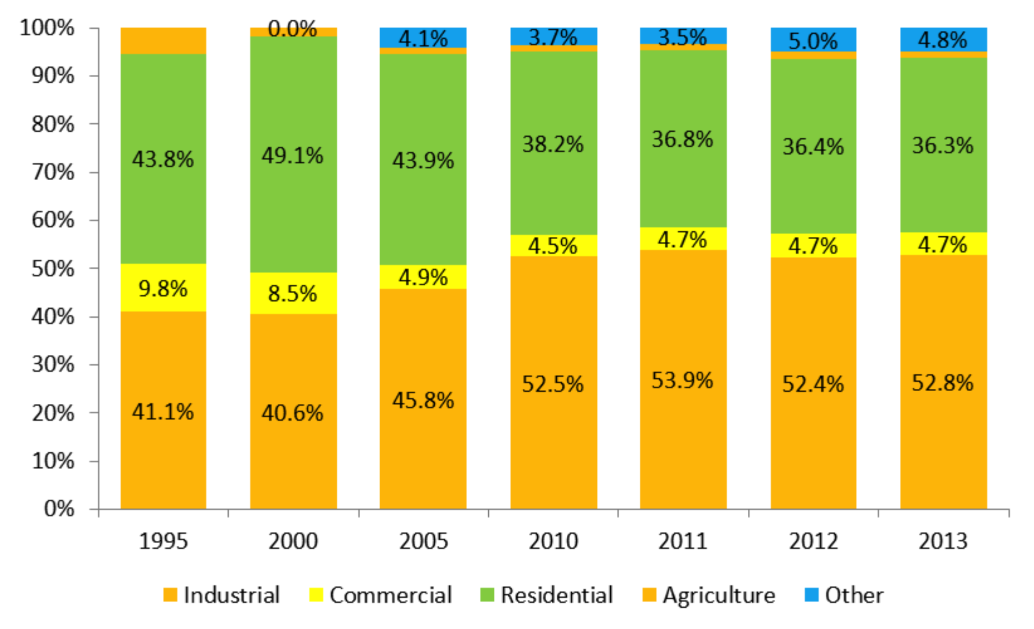
The composition of electricity sales is illustrated for selected years in Figure 9 to facilitate comparison and for the period 2010-13 in Figure 10. These show that industrial and residential customers in aggregate make up the most dominant consumers of electricity in Viet Nam and that in the last 3 years the breakdown between industrial, residential, and the other categories has remained almost unchanged.

Figure 8 Viet Nam Electricity Consumption and Annual Growth Rate (2000-13)



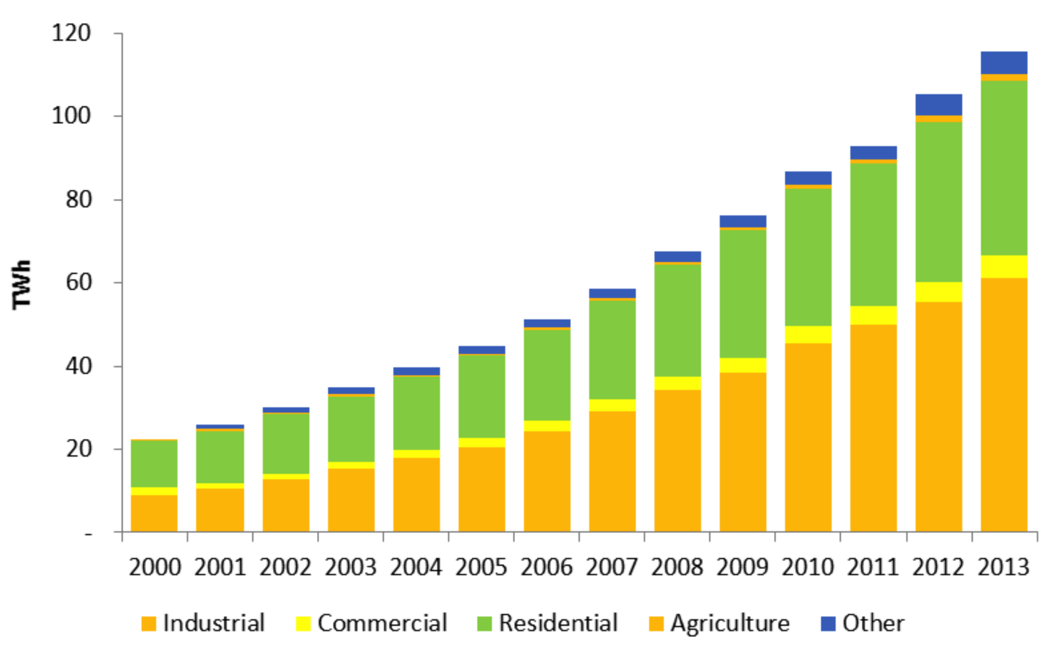
Source: ERAV

Figure 9 Electricity Sales Composition for Selected Years (1995, 2000, 2005, 2010-13)



Source: ERAV

Figure 10 Electricity Sales Breakdown by Customer Category (2000-13)

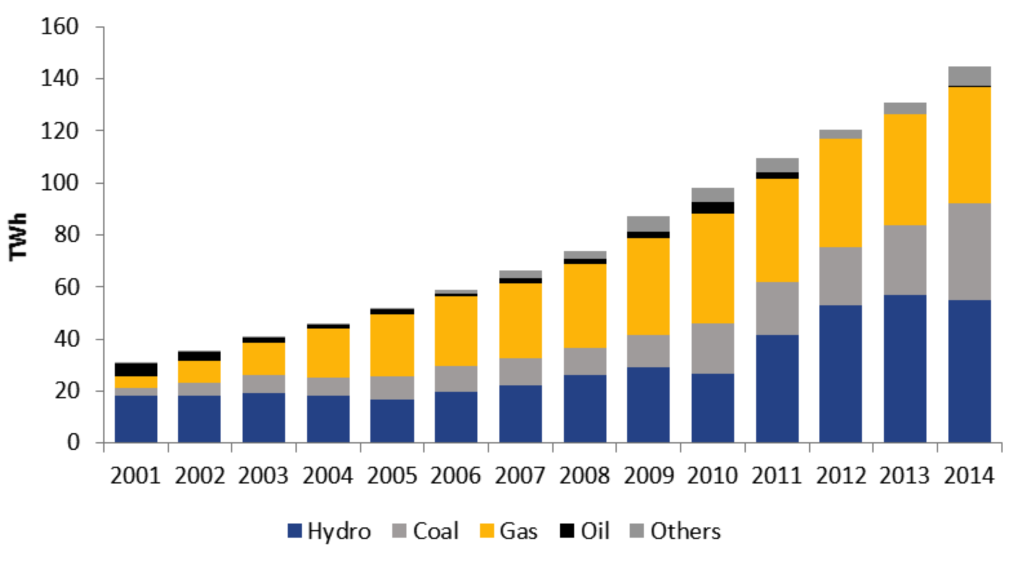


Source: ERAV

2.5 Generation Supply

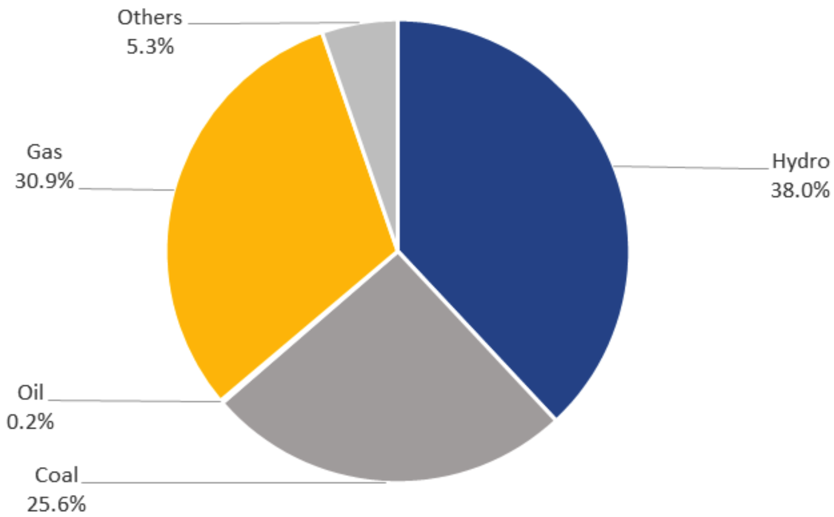
Figure 11 shows generation by fuel type over the last 14 years in Viet Nam illustrating that gas, hydro and coal make significant contributions to satisfying the demand for electricity.

Figure 11 Generation by Fuel Type (2001-2014)



Source: ERAV/ EVN

Figure 12 Generation by Fuel Type (2014)



Source: ERAV/EVN

2.6 Imports and Exports

A number of small load centres in Viet Nam's north are effectively supplied with power imports from PRC. Viet Nam also receives power imports from a recently commissioned hydro project in Laos (Xekaman 3) and Viet Nam's grid is connected to Cambodia to provide exports to the country. A summary of the current situation as of 2013 is:

- Imports of around 3.61 TWh[3] on average from PRC in the North;
- Imports from Xe Kaman 3 hydro project from Laos PDR in the central region: and
- Exports of around 1.22 TWh on average to Cambodia, in the South.

2.6.1 Imports from PRC

Power imports from PRC commenced in 2004 via two 110 KV lines and later two 220 kV lines. The combined maximum capacity of these interconnections is 1,000 MW. The annual imported amount is around 3.6 TWh on average but has been generally declining from 5.6 TWh in 2010 to 1.8 TWh in 2015 (estimated). The existing purchase agreements (for ten year duration) are expected to end after 2015. Note that the Chinese grid and Vietnamese grids are not electrically connected; loads in the north are switched from being connected to the Vietnamese national system to the Chinese grid.

At present the following transmission lines import power from PRC to Viet Nam:

- 220 kV transmission line from Ha Giang;
- 220 kV transmission line from Lao Cai;
- 110 kV transmission line from Ha Giang; and
- 110 kV transmission line from Mong Cai.

2.6.2 Imports from Lao PDR

Xe Kaman 3 Hydropower project is located in Laos PDR and is dedicated to exporting power to Viet Nam's transmission system. The 250 MW project was mostly financed by the Government of Viet Nam. The project started commercial operation in 2013. It has a power purchase agreement in place with EVN and is operated by NLDC according to fixed generation schedules.

2.6.3 Exports to Cambodia

Viet Nam exports power to Cambodia via a 220 kV Chau Do – Takeo transmission line. In 2013, Viet Nam exported some 1.34 TWh to the country.

[3] Reported to be 2.46 TWh in 2014.

3 Development Options for Viet Nam's Electricity Sector

3.1 Overview

As with a number of other countries in the region Viet Nam's economy has experienced significant growth which has been accompanied by very high rates of electricity demand growth. Even with a slight softening in the economic outlook for the country in the last year, basic analysis shows that electricity demand growth rates in the country will be relatively high into the near term future. This is more so the case given long-term strategic plans by the Government to focus on transitioning the economy towards one where the industrial sector plays a larger role than at present. Accompanying economic growth has been an increase in the living standards, which has translated into increasing levels of household electricity consumption, particularly in urban areas. These trends have put pressure on the existing infrastructure including distribution networks, transmission networks and generation facilities to ensure a stable and reliable flow of electrical energy is provided to end users.

Viet Nam is endowed with a diverse set of primary energy resources, including domestic coal, offshore natural gas reserves, biomass, biogas, solar, large and small-scale hydro, onshore and offshore wind, geothermal, and marine-based technologies such as tidal and wave. While each of these resources has its own set of challenges, they provide the basis for developing a range of possible development paths for the country's electricity industry. A summary of the main resource development options available to Viet Nam is as follows:

- **Domestic coal**. There are reserves of lignite and sub-bituminous grades of coal with reserves located mainly around the red river basin around Quang Ninh province in the northeast of the country. The majority of the coal-fired power stations in Viet Nam exploit these reserves. Estimates of reserve sizes suggest that further exploitation is possible, although apart from the externalities such as greenhouse gas emissions and local pollution, the northeast location of the reserves is not ideally located given the structure of Viet Nam's transmission system, the fact that many coal plant in this area are already in place and the grade of coal being in the lower end of the range of what is typically preferred for coal based generation. Domestic transportation networks (via sea or rail) for domestic coal have been contemplated, but with domestic coal prices for the electricity sector being regulated to come into line with international coal prices, the economics of such infrastructure investments against investment in facilities to import higher quality coal at locations along the coastline, make this unlikely.
- **Imported coal**. Viet Nam has a coastline that spans some 3260 km which provides a number of sites that would allow for the development of coal import and storage facilities to support coal projects at locations that are convenient

given the transmission network structure and location of load centres. A number of such facilities are already under development and there are plans under the last power plan to continue to expand and grow these facilities in support of coal import projects that would likely source high grade coal from coal suppliers in Indonesia and/or Australia.

- **Offshore natural gas reserves**. Viet Nam is estimated to have some 617 Bcm (21.8 Tcf) of proved reserves, or around 52% of the total proved natural gas reserves of the GMS. Gas reserves have been found in five of the seven offshore basins[4]: Song Hong, Phu Khanh, Nam Con Son, Cuu Long and Malay-Tho Chu. The Nam Con Son and Cuu Long basins are exploited to supply gas to the Phu My complex, Ba Ria, and Nhon Trach. Off the south coast, the PM3 field in the Malay-Tho Chu basin is also in production and supplies gas to the Ca Mau complex. Further developments of Viet Nam's offshore gas reserves has been contemplated, with the most prospective being:
  - **Further development of the south-west region**. Offshore Blocks B, 52/97, 48/95, could support significant natural gas power generation projects in the south of Viet Nam, and in particular, top up gas to the Ca Mau complex and allow further development of the O Mon complex. PetroVietnam is currently working with recent joint venture partners Murphy Oil and ExxonMobil to develop these fields; and
  - **North-east region**. Offshore oil and gas fields have been identified off the northeast coastline with extensive surveying and exploration still ongoing. As the investment in the infrastructure to support development of this field is significant, this is considered to be a longer-term option for development.
- **LNG.** The most recent Gas Development Plan and Power Development Plan 7 (PDP7) to have been approved by the government include plans for an LNG regasification terminal sited in the central province of Binh Thuan (near Ho Chi Minh City) with a capacity of 3 MTPA. However, the development of the LNG terminal has been delayed and it appears unlikely that an LNG import terminal would be in operation before 2020.
- **Nuclear Power.** As part of a long-term energy security strategy Viet Nam has been enhancing their nuclear power knowledge and capability. Viet Nam has in place agreements with Russia and Japan to build nuclear power projects of 2400 MW and 2000 MW respectively[5]; both planned to be constructed in the Ninh Thuan province. Nuclear power features in Viet Nam's power development plans, although the dates of first generation from nuclear power remains uncertain with tightening safety requirements and unforeseen delays occurring in advancing the deployment of this technology in Viet Nam.

[4] "BCC Contract Signed for Billion Gas Pipeline Project," PetroVietnam, March 11, 2010, http://english.pvn.vn/?portal=news&page=detail&category_id=11&id=3278.
[5] World Nuclear Association, www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Vietnam, October 2015.

- **Large Hydro.** Around 38% of Viet Nam's electricity is currently generated by a range of large reservoirs and in some cases cascaded hydropower stations that are located throughout the country. The largest reservoirs, Hoa Binh and Son La, are located in the north west of the country, although there are significant storages located in the central and south regions as well. Viet Nam is able to gain the benefits of diversity in hydrological conditions across many separate river systems with notable diversity in inflows across north, central and south regions. However, Viet Nam has largely exploited all of the large scale hydro considered to be economically feasible; further development beyond what has been exploited to date and what is under construction now is not considered an option.
- **Small, mini, and micro hydro**. Viet Nam has untapped small scale hydro potential. In recent years, there has been a lot of small hydropower development in Viet Nam with the number of projects going from about 141 in 2006 (167 MW) to about 156 (622 MW) by 2009, and some 226 projects (1635 MW) by 2014. Some 1943 MW of capacity is now under construction, and some 236 projects (with total capacity of 2019 MW) under study. However, concerns have been raised on small hydro projects in the country based on considerations of the low levels of efficiency achieved from some projects relative to the environmental externalities.
- **Pumped storage hydro**. Viet Nam does not presently have any pumped storage hydro plant in operation. However, feasibility studies have been carried out and show that pumped storage power plants may be feasible with the south and central regions offering the most favourable geographical conditions.
- **Onshore and offshore wind**. Viet Nam is considered to have moderate to good onshore wind energy potential, with the best locations in Viet Nam recording reasonable wind speeds throughout the year except for the months of April, May and September. Most of the onshore wind potential is along the country's south central and central coastal areas, and a number of locations in the mountainous areas in the central region. The greatest onshore wind potential that has been measured is in Binh Thuan province. A limited amount of data is reported in relation to offshore wind potential in Viet Nam, however, it appears that Viet Nam has potential for offshore wind with a little under half the sites having been tested being rated as "good" or better for offshore.
- **Solar Energy**. Viet Nam is considered to have very high potential for the development of solar energy resources. A number of studies have been conducted to assess the potential, the most recent and detailed of which was a study entitled: "Maps of Solar Resource and Potential in Vietnam", published in January 2015. This was undertaken by the MOIT and a Spanish Consortium consisting of Centro de Investigaciones Energeticas Medioambientales y Tecnológicas (CIEMOT), National Renewable Energy Centre (CENER) and

Instituto para la Diversificación y Ahorro de la Energía (IDAE). This broadly shows that based on GHI and DNI measurements there is substantial potential for solar photovoltaic deployment throughout the country, with the greatest potential identified in the southeast, central highlands, Mekong River Delta, all coastal areas and the northeast. The study also concludes that based on DNI measurements, there is substantial potential for concentrated solar power (CSP) based technologies, with the greatest potential in the central regions, highlands and southeast of Viet Nam.

- **Geothermal**. Presently there are no geothermal power plants in Viet Nam. However, based on surveys and studies carried out over the last few decades on geothermal energy resources, the country is recognised to have a limited amount of geothermal potential with some 300 MW to 400 MW having been identified to date.
- **Bio Generation (Biomass and biogas)**. As an agricultural country, Viet Nam has significant potential for power generation from biomass and biogas sources. Typical forms include wood energy, crop waste and residues, animal waste, urban waste and other organic waste. Sustainable exploitation capacity of biomass for energy production in Viet Nam is estimated at about 150 million tons per year[6], with overall power generation potential of around 11-15 GW from biomass and 4-5 GW from biogas.
- **Power Imports**. Viet Nam has been active in pursuing opportunities for power import from neighbouring countries. Since 2004 the country has imported power from PRC and at different times there has been discussion of increasing power imports from PRC, although more recently this option seems unlikely. Viet Nam has been involved in the joint development of hydro projects in Lao PDR which are dedicated under 25 year PPAs to supplying their output to Viet Nam. There has been discussion of similar projects in Cambodia with MOUs in place for a number of hydro projects, although these are longer-term prospects and are not considered to be committed.

3.2 Domestic and Imported Coal Resources

3.2.1 Domestic Coal

Viet Nam is a country with a comparative advantage in the coal sector which comes from the country's relatively abundant coal reserves. By January 2011, the results of investigations indicated that Viet Nam has coal reserves of around 48.7 billion tons, of which, some 39.35 billion tons, lie beneath the Red River basin in an area of size 2000 km^2. The Northeast of Viet Nam possesses the second largest coal deposit with reserves estimated to be around 8.83 billion tons. The Northeast is the largest mining area in the country because it is currently not feasible to exploit coal from

[6] http://ievn.com.vn/tin-tuc/Tong-quan-ve-hien-trang-va-xu-huong-cua-thi-truong-nang-luong-tai-tao-cua-Viet-Nam-5-999.aspx

the Red River basin, as deposits lie some 150-2,500 meters underground necessitating large investment and modern mining technologies that are currently not available in Viet Nam. In addition, the Red River deposit has complicated hydrogeological features and is located in a populous area. As such coal production is mainly carried out in the Northeast of the country.

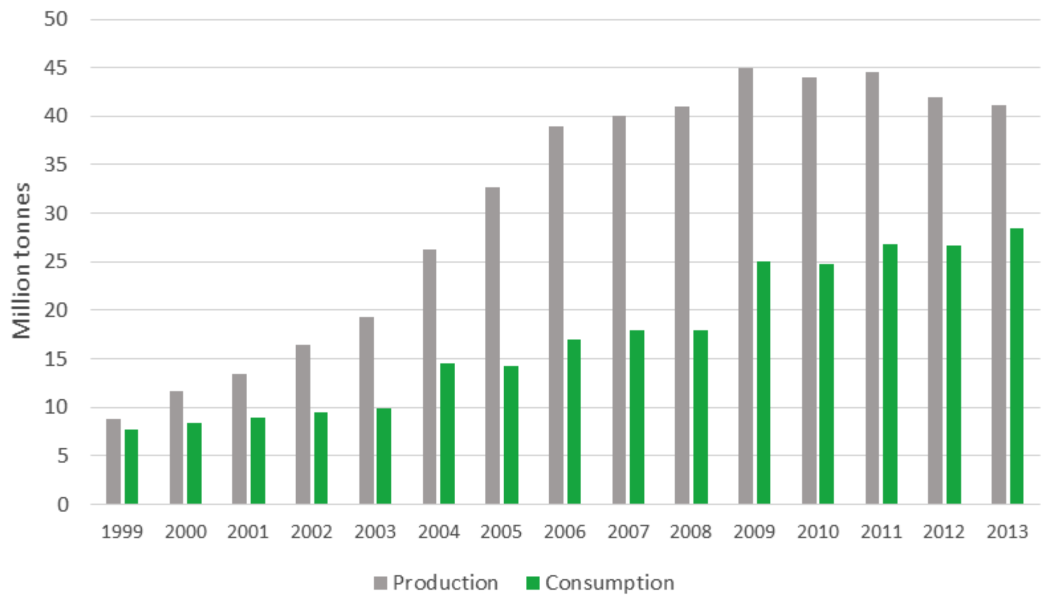
As of 2012, Viet Nam is the 17th coal producer in the world. Figure 13 provides statistics on coal production and coal consumption. It indicates coal production in Viet Nam has increased rapidly from 11.6 Mt/y in 2001 to 44.5 Mt/y in 2011. The large increase in production is due mainly to increases in coal exports, although domestic consumption has also increased significantly from 2009, driven in part by the commissioning of coal plants in the north. Coal reserves from Viet Nam have almost entirely been produced in the form of anthracite, sourced from Vinacomin mines and used in industry, the electricity sector, and sold as exports.

Viet Nam National Coal Mineral Industries Holding Corporation Limited (Vinacomin) is the major coal producer in Viet Nam, accounting for 95% of the nation's total coal production. The corporation has 5 big open-cast mines with the capacity of over 2 million tons/year, 15 other open-cast mines with the capacity of 100-700 thousand tons/year and some with the capacity of less than 100 thousand tons/year.

Coal demand is expected to grow at around 5.3% annually, due mainly to greater anticipated use in the electricity generation sector. It is expected that coal exports will reduce as MOIT introduces policies for utilising Viet Nam's coal production for internal consumption only. A further extension of this policy could occur if MOIT recommends that the country stops exporting coal, in order to secure additional supplies for domestic use in the electricity generation industry. Business as Usual projections for 2030 suggest coal supply reaching some 65 million tons with coal demand being around 110 to 150 million tons. Under Business as Usual projections Viet Nam will need to import coal from 2017 with import volumes needing to rise to make up expected shortfalls in domestic supply.

Domestic coal prices for the electricity sector have been regulated and subsidised but coal pricing has been slowly freed to the point where the domestic coal prices for power generation purposes will in the shorter-term be similar to prices of imported coal.

Figure 13 Viet Nam Coal Production and Consumption (1999-2013)



Source: BP Statistics 2014

3.2.2 Imported Coal

Viet Nam has a coastline that spans some 3,260 km which provides a number of options for the development of facilities to support coal import. A large number of imported coal power projects are planned to commence operation in the near future. These include Duyen Hai 3 (1,200 MW, to be operated in 2016-17), Duyen Hai 3 Extension (600 MW, 2017), Vinh Tan 4 (1,200 MW, 2017-18), Long Phu 1 (1,200 MW, 2017-18), Song Hau 1 (1,200 MW, 2018-19) and Quang Trạch 1 (1,200 MW, 2020).

Indonesia and Australia are the two most feasible countries for Viet Nam to import coal due to their close proximity, coal quality, level of coal reserves and stage of development in terms of transportation and coal handling facilities. Petro Viet Nam has recently signed three contracts that provide frameworks for coal import from Australia and Indonesia, and is reportedly in negotiation for two further supply contracts with Indonesia.

3.3 Natural Gas Resources

3.3.1 Gas Reserves

Viet Nam is estimated to have some 617 Bcm (21.8 Tcf) of proved reserves, or around 52% of the total proved natural gas reserves of the GMS. Table 1 summarises proved natural gas reserves for the GMS countries. The figure also shows the reserves to production ratio (RPR)[7]. For Viet Nam, the number is relatively high because a number of fields with proven reserves have not been put into production. The most commercially viable reserves are those located off Viet Nam's southern coast which are relatively close to the most prospective markets[8].

Table 1 Proved Natural Gas Reserves in GMS Countries

	Proved Reserves		RPR
	Bcm	Tcf	Years
Myanmar	283	10	22
Thailand	285	10	7
Viet Nam	617	22	63

Source: BP Statistics 2014

3.3.2 Gas Infrastructure

The key infrastructure in Viet Nam that supplies gas to onshore facilities includes:

- **Rang Dong-Bach Ho transmission system**. This gas transmission system supplies natural gas via a 160 km pipeline from the Bach Ho field in the Cuu Long basin. It commenced operation in 1995 to transport gas to power stations in Phu My. This pipeline is owned by the Viet Nam Oil and Gas Group (PetroVietnam, or PVN, Viet Nam's state-owned energy consortium) and operated by the subsidiary PVGas. In 2002, an extension to transport gas from Rang Dong (also in the Cuu Long basin) was implemented – this increased production from around 1.5 Bcm/y to 2.0 Bcm/y. Natural gas from the Cuu Long basin is supplied to the Phu My Fertiliser Plant and some other industrial users; the remaining is used for EVN gas fired power stations in the Phu My complex including Phu My 2.1, Phu My 2.1 Extension, Phu My 4 and Ba Ria Power Plant.
- **Phu My-Nhon Trach onshore pipeline**. The Phu My-Nhon Trach pipeline is an (onshore) pipeline system to supply gas to Hiep Phuoc and Nhon Trach power stations and consumers in the Ho Chi Minh City area. It has a capacity of 2 Bcm/y and became operational in August 2009.
- **Nam Con Son Gas Project (NCSGP)**. The NCSGP is is Viet Nam's largest integrated gas-to-power project delivering gas from the offshore natural gas fields of Lan Tay and Lan Do to the Phy My power complex via a 370km subsea pipeline. The power stations supplied with gas are: EVN owned plants Phu My 1, Phu My 2-1, Phu My 2.1 Extension, Phu My 4 and Ba Ria; BOT plants Phu My 2.2 and Phu My 3; and PV Power plants Nhon Trach 1 and Nhon Trach 2. The

[7] The RPR is the proved reserves divided by the amount of reserves produced each year and thus a rough measure of how many years remain until the resource is depleted. Further information: http://en.wikipedia.org/wiki/Reserves-to-production_ratio.
[8] The Brookings Institution Center for Northeast Asian Policy Studies, "Policy Suggestions for the Initial Development of Vietnam's Gas Industry", Hai Tien Le, CNAPS Visiting Fellow, Vietnam, 2010.

Lan Tay / Lan Do fields reportedly hold some 2Tcf of gas reserves with output from the field said to be some 530mmcf/d (193Bcf/y). The project started operation in 2003. The project is operated by a consortium comprising PetroVietnam (51%), BP (32.67%) and ConocoPhilips (16.33%). BP operated the pipeline from its establishment in 2003 until 2008, when it was transferred to PVN. In the future, this pipeline may be used to transport natural gas from other fields within the Nam Con Son basin onshore; and to supply gas to users in Phu My, Dong Nai, and Ho Chi Minh City.

- **PM3-Ca Mau pipeline**[9]. Commissioned in 2007, the PM3-Ca Mau pipeline supplies gas from the PM3 / Block 46 fields to the 1,500 MW Ca Mau power complex. The pipeline was completed under the PM3 Commercial Arrangement Area (CAA) at the southern tip of Viet Nam and national production surpassed Bcm with the transportation of natural gas from Block PM3 CAA and the Cai Nuoc field – an offshore area administered jointly with Malaysia. Gas is transported to the Ca Mau 1 and 2 power stations, which consume around 2 Bcm per year. In the Ca Mau gas distribution station, there is a future tie-in for the Ca Mau fertilizer plant which consumes around 500 MMCM of gas per year, as well as other users in Ca Mau province. The pipeline system is funded completely by PVN; PVGas operates this pipeline system on behalf of PetroVietnam.

3.3.3 Past Production and Consumption

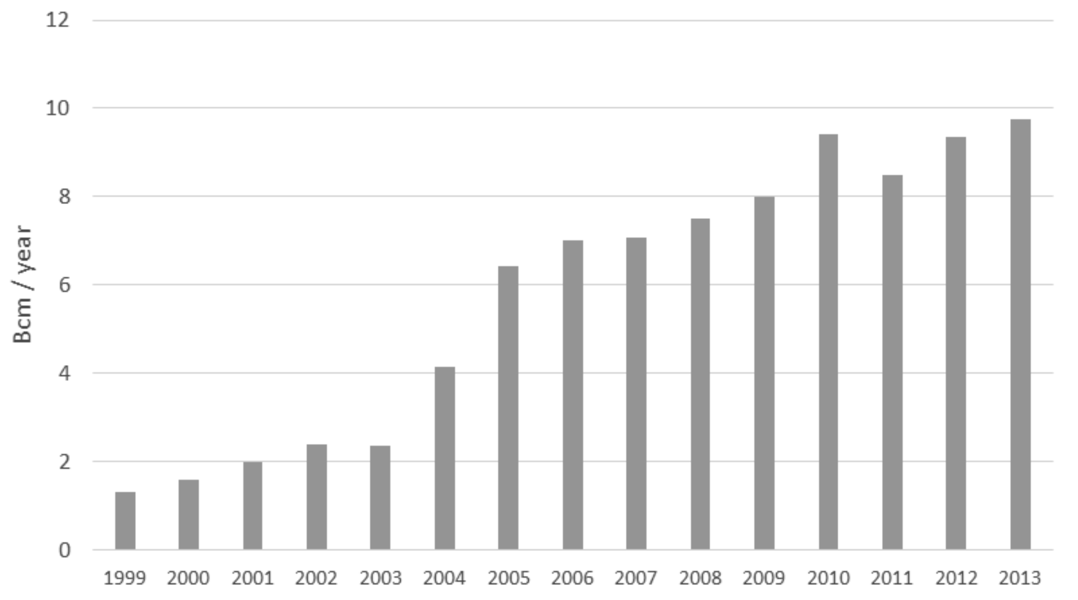
Being a coastal country, Viet Nam has several hundred thousand square kilometres of continental shelf in which seven tertiary basins have been identified. Gas reserves have been found in five of the seven offshore basins: Song Hong, Phu Khanh, Nam Con Son, Cuu Long and Malay-Tho Chu. Figure 14 shows the trend in gas production in Viet Nam (all gas produced is consumed within Viet Nam). Gas production is observed to have ramped up since 2003 and again in 2007 coinciding with the commissioning of the Nam Con Son Gas Project and the Ca Mau pipeline developments.

Figure 15 shows the gas consumption trend for the period 1999 to 2013 as reported by PV Gas in 2014. Around 85% of natural gas consumption is attributable to power generation, 10% for fertilizer production, and the rest provided to low pressure gas networks or as LPG to industrial consumers. Current gas supply is only satisfying 60% of the demand for gas for Viet Nam's power demand, 30% of the demand for fertilizer feed stocks and 60% of the demand for LPG[10].

[9] The Brookings Institution Center for Northeast Asian Policy Studies, "Policy Suggestions for the Initial Development of Vietnam's Gas Industry", Hai Tien Le, CNAPS Visiting Fellow, Vietnam, 2010.

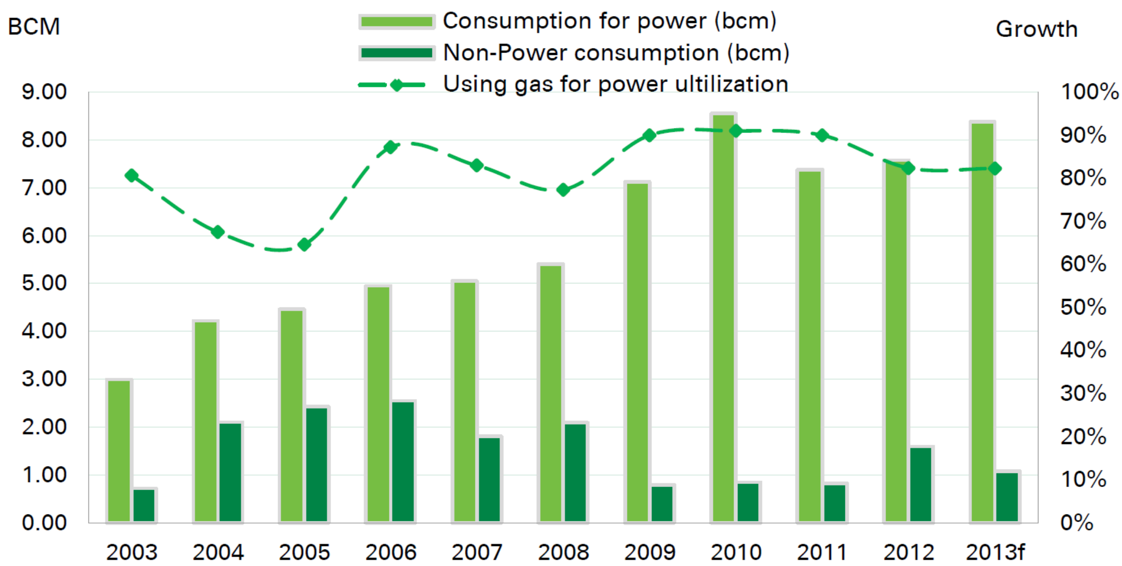
[10] Around half of Vietnam's LPG demand is satisfied by domestic production, with the remainder imported from China, Australia, United Arab Emirates and others.

Figure 14 Gas Production and Consumption in Viet Nam (1999-2013)



Source: BP Statistics 2014

Figure 15 Gas Production and Consumption in Viet Nam (1999-2013)



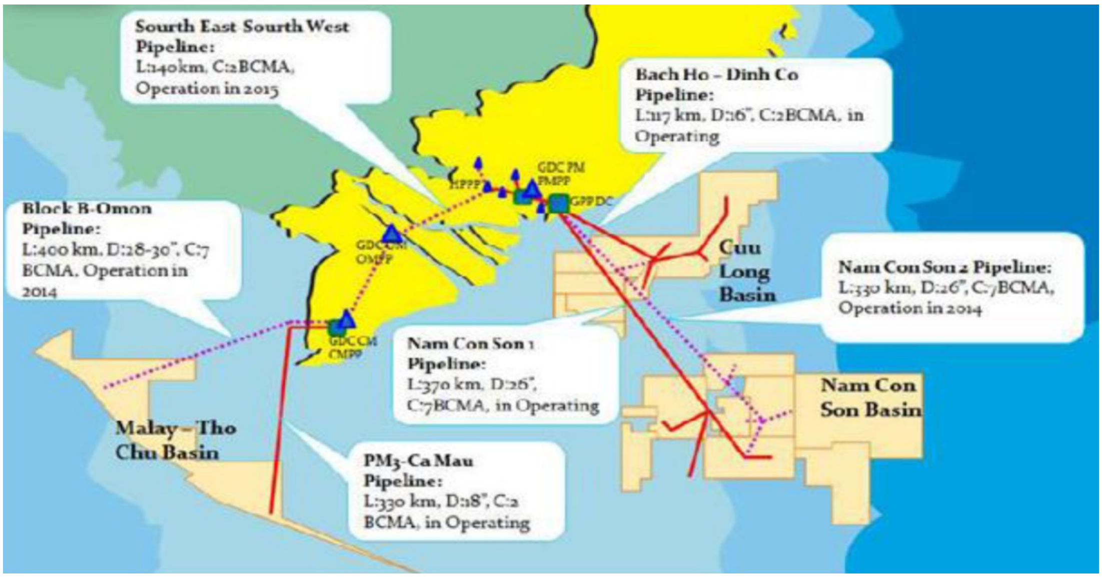
Source: PV Gas, VBPS (2014)

3.3.4 Possible Developments

There are a number of options that could be taken to further exploit Viet Nam's offshore gas reserves. The main options that have been examined and their current status are as follows:

- **Further Development of the South-West Region**. There has been promising exploration of South West offshore Block B, 52/97, 48/95, in the past consideration was given to developing a pipeline to be built from these fields to supply the planned O Mon Complex and backfill the Ca Mau Complex. This would have involved the construction of a 500km pipeline to O Mon in the Can Tho province. However, in 2014 these plans were abandoned by field developer, PetroVietnam and Chevron citing an inability to agree on gas offtake prices and development plans. This ended with PetroVietnam purchasing Chevon's stake in the field and pursuing other joint venture partners.
- **Developments in the North-East Region.** Some offshore oil and gas fields have been identified off the northeast coastline, although extensive surveying and exploration of the region is still ongoing. Investment in the infrastructure necessary to support development of offshore gas pipelines is understood to not presently be viable, but in the future, if energy supplies to Viet Nam remain tight, gas in this region may be developed.
- **Further offshore / onshore pipeline infrastructure.** Figure 16 shows the existing pipeline infrastructure and contemplated pipeline developments. This shows further pipeline development for the Nam Con Son, the development of the Block B52 and the onshore interconnection of the current onshore gas networks to form a larger gas transportation system. While none of the planned developments shown in the diagram have materialised, it provides insight into some options that have been considered and that have been studied in detail for the expansion of gas infrastructure in Viet Nam.

Figure 16 Contemplated Offshore Developments (PVN, Circa 2012)



Source: PVN

3.3.5 LNG Import

The most recent Gas Development Plan and Power Development Plan 7 (PDP7) to have been approved by the government include plans for an LNG regasification terminal sited in Son My in the central province of Binh Thuan (near Ho Chi Minh City) with a capacity of 3 MTPA, with an option to double or triple its capacity as needed. However, the development of the LNG terminal has been delayed and it seems unlikely that Viet Nam would develop an LNG import terminal before 2020. Most likely LNG import sources would be Australia and Qatar given the production capability of these countries.

Apart from an LNG terminal being situation in Binh Thuan province, other locations that have been considered include: Lach Nguyen in Hai Phong, My Giang in Khanh Hoa province, and a terminal in Ca Mau to support backfilling the Ca Mau complex.

3.4 Nuclear Power

In January 2006, the Prime Minister of Viet Nam signed decision No.01-2006-QD-TTg on the approval of the strategy to apply nuclear energy for peaceful purposes by 2020. The intent is to build and develop a nuclear technology industry. The strategy in place envisaged the commencement of the first nuclear power plant project in Viet Nam by 2020.

In 2009, the National Assembly decided the first nuclear power plant of 2,000 MW capacity would be built in the Ninh Thuan province. The investigation and construction work has since then begun but the expected commencement of the plant’s operation was pushed back until 2024 due to additional unforeseen work components and tightened safety requirements as part of the fallout from the Fukushima crisis. The second plant, Ninh Thuan 2, has been scheduled to be constructed in the same location and operating from 2025.

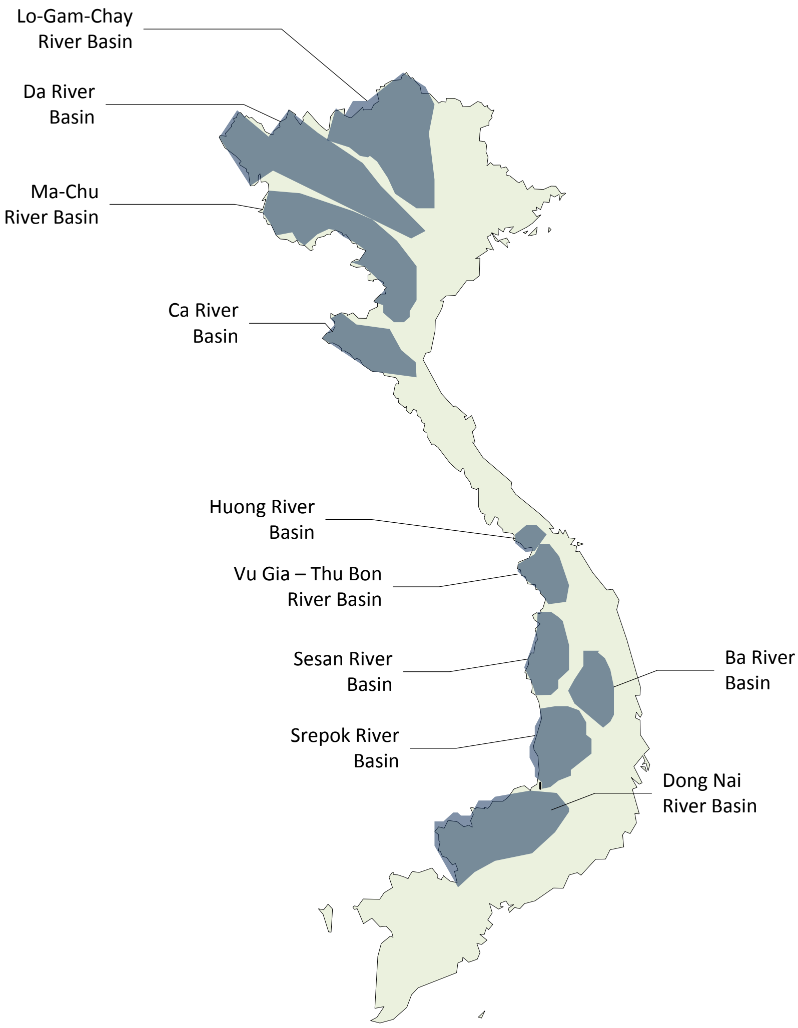
3.5 Hydro Power

Viet Nam has high potential for hydro power. The country has some 2,360 rivers and streams of that exceed 10km. The main river systems are illustrated in Figure 17. The Red River system in the north comprises the Da and Lo-Gam-Chay river basins, the Mekong river delta is in the south. In the central region, there are many river basins, including the Ma River, Ca River in the north central area, Vu Gia – Thu Bon River in the central area, Sesan River and Srepok Rivers are in the central highlands and the Ba River is in the coastal area. The Dong Nai River basin is in the south.

In 2013, hydro power accounted for 47.5% of the country’s total 30,473 MW installed generating capacity. In 2014, hydropower production was 59,479 million kWh, accounting for 41.41% total electricity supply. Currently, the Son La hydropower plant is the largest power plant with 2,400 MW installed capacity.

According to Prime Minister Decision No. 2068/QD-TTg dated 25 November 2015, approving the development strategy of renewable energy of Viet Nam by 2030 with a vision to 2050, electricity production from hydropower sources would increase from approximately 56 billion kWh in 2015 to nearly 90 billion kWh in 2020 and to approximately 96 billion kWh from 2030.

Figure 17 Illustration of the Main River Systems in Viet Nam



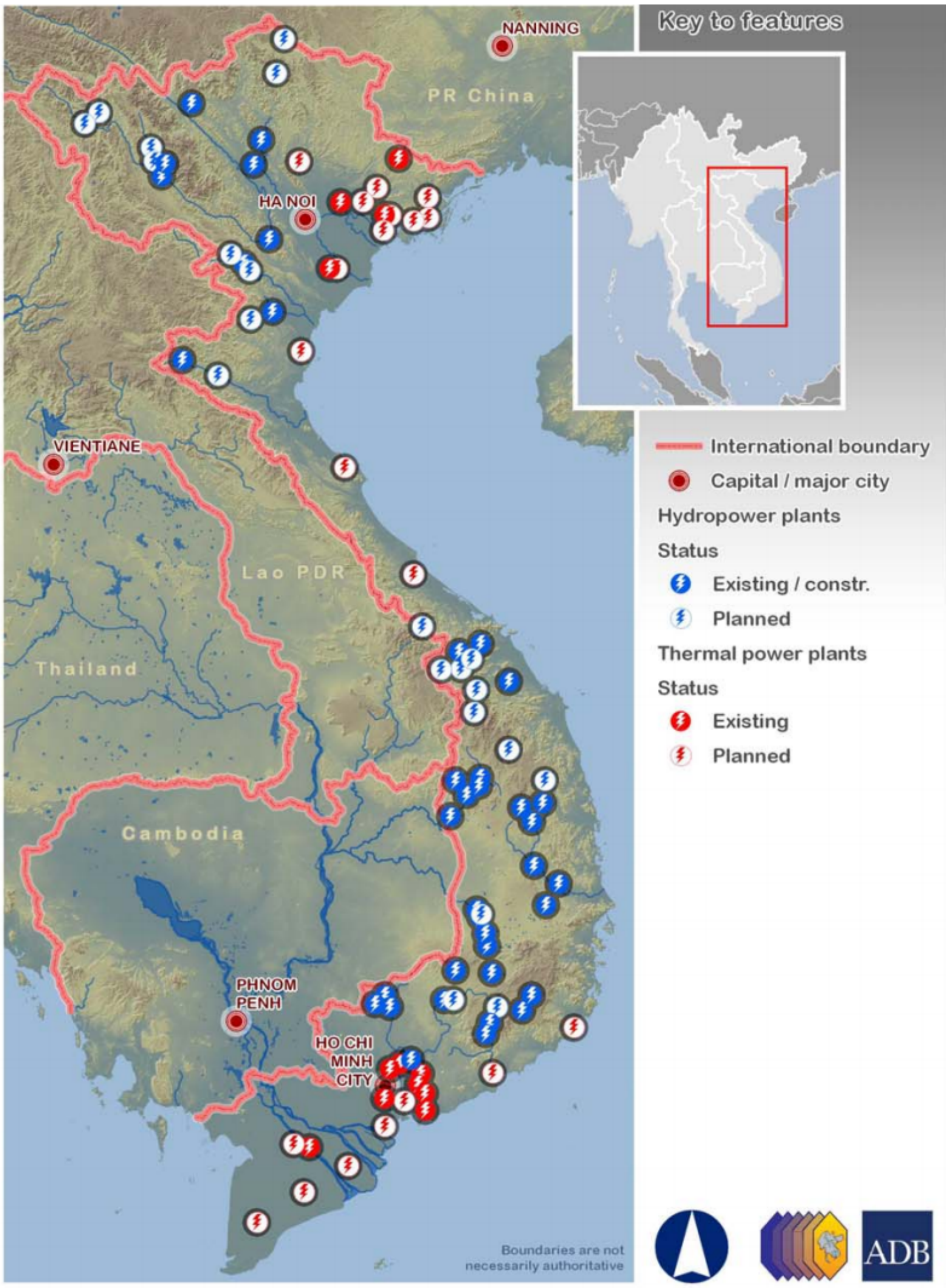
Source: Consultant

Estimates put Viet Nam's gross theoretical hydro potential at some 35 GW, of which around 18 to 20 GW of large scale hydro is considered economically feasible, 1000 to 1500 small hydro, and some 1000 to 3000 of micro hydro.

3.5.1 Large Scale Hydro

Most hydroelectric reserves with capacity in excess of 50 MW have been exploited in Viet Nam or are under development. Figure 18 provides a basic overview of the location of existing and planned hydro developments in Viet Nam. A chart to compare the potentials (for large scale hydro) compared with hydro capacity that has been developed or that is under construction is shown in Figure 19. This illustrates quite clearly that all large scale hydro potential in Viet Nam is essentially exploited and in the case of the central region there has been exploitation of hydro power potential in neighbouring Laos. Thus future hydro development is likely to be driven by two forms: (1) imports from hydro projects developed in neighbouring countries, and (2) small hydroelectric plants developed in the more remote regions.

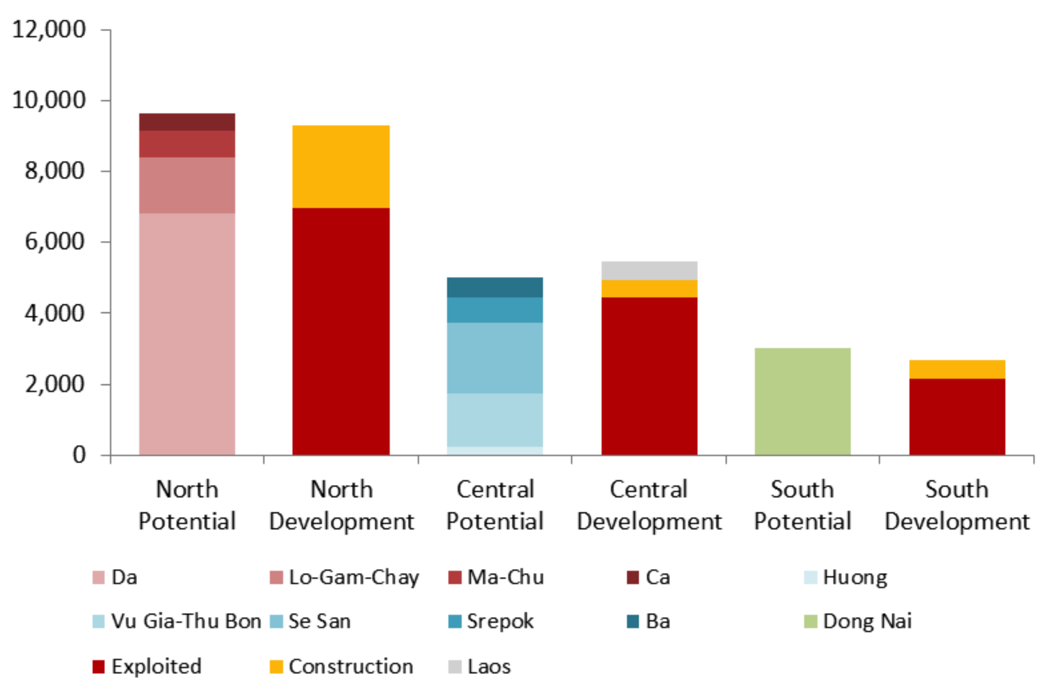
Figure 18 Location of Existing, Under Construction & Planned HPPs and TPPs (2009)[11]



Source: SEI-International (2009)

[11] SEI International, "Strategic Environmental Assessment of the Hydropower Master Plan in the Context of the Power Development Plan VI: Final Report", January 2009, available: http://www.sei-international.org.

Figure 19 Large Hydro Potential, Hydro Exploited and Hydro under Construction (2015)



Source: Consultant analysis

3.5.2 Small and Micro Hydro

In recent years, there has been a lot of small hydropower development in Viet Nam. As of the end of 2006, 141 small hydropower plants with an installed capacity 167 MW had been constructed and by the end of 2009, the number had increased to 156 with a total installed capacity of about 622 MW. As of August 2014 there were:

- 226 small hydro power plants in operation, with total capacity of 1,635 MW;
- 171 small hydro power projects with total installed capacity of 1,943 MW under construction; and
- 236 projects (totalling some 2,019 MW) under study.

Concerns on small and micro hydro in Viet Nam in relation to the low level of efficiency that can be achieved relative to environmental and sustainability externalities. As such, there have been recent revisions to hydroelectric planning with the number of originally planned small and micro hydro projects being removed from plans along with two larger cascaded hydropower projects[12]. Overall, there is a total of 815 hydroelectric projects (24,334 MW) considered to be feasible of which 268 projects are in operation (14,240 MW) and 205 projects under construction (6,198 MW), with commissioning dates from the present to

[12] Dong Nai 6 and 6A.

2017.

3.5.3 Pumped Storage Hydro

Viet Nam does not presently have any pumped storage hydro plant in operation. However, feasibility studies have been carried out and show that pumped storage power plants may be feasible with the south and central regions offering the most favourable geographical conditions. Pumped storage hydro plants do feature in government plans for the electricity industry.

The National Master Plan for power development for the 2011-2020 period with the vision to 2030 has included five pumped storage hydro plants to be constructed between 2019 and 2030. These projects include Bac Ai 1 (4 x 300 MW), Dong Phu Yen (4 x 300 MW), Don Duong (4 x 300 MW), Ninh Son (4 x 300 MW) and a Pumped Storage Hydro plant in the North (3 x 300 MW).

According to the latest Prime Minister's Decision No. 2068/QD-TTg dated 25 November 2015, approving the development strategy of renewable energy of Viet Nam by 2030 with a vision to 2050, pump storage hydro installed capacity should target 2,400 MW by 2030 to 8,000 MW by 2050.

3.6 Wind Power

Viet Nam is considered to have moderate to good wind energy potential. However, like many other developing countries, the potential of wind power in Viet Nam has not yet been quantified in detail. In 2011, the World Bank supported the Ministry of Industry and Trade to reconstruct the Wind Resource Atlas of Viet Nam. Based on this study, they estimated a total of 10,000 MW of onshore wind capacity could be theoretically exploited at surfaces with 80 m height and with wind speeds over 6 m/s.

However, more recent studies have indicated that onshore wind potential in Vietnam is considerably higher, with estimates as high as almost 27 GW MW[13]. According to the latest Prime Minister's Decision No. 2068/QD-TTg dated 25 November 2015, approving the development strategy of renewable energy of Viet Nam by 2030 with a vision to 2050, total electricity production from wind power would increase from 180 million kWh in 2015 to about 2.5 billion kWh in 2020 (1% share), approximately 16 billion kWh in 2030 (2.7%) and about 53 billion kWh in 2050 (5%).

Figure 20 shows monthly wind speed measurements for all regions in Viet Nam as reported by NASA Atmosphere Science Data Centre of each region in Viet Nam with the dashed line representing the average speed of the top 7 square profiles (above 5.2 m/s). This graph shows that many locations in Viet Nam record reasonable wind speeds throughout the year except for April, May and September. When these locations are shaded over the map of Viet Nam, as illustrated in Figure 21, we can

[13] For example: 26,673 MW is suggested by ADB (2015)

see that in the main the locations are along the country's south central and central coastal areas. Figure 22 plots a wind resource map from the AWS TrueEnergy / MOIT and World Bank study conducted in 2011 for heights of 80 metres. This also provides further indication of the locations for the best wind power potential in Viet Nam and highlights the areas of the country (coastal and mountainous parts) where wind speeds are in excess of 6 m/s. The greatest wind potential that has been measured is in Binh Thuan province.

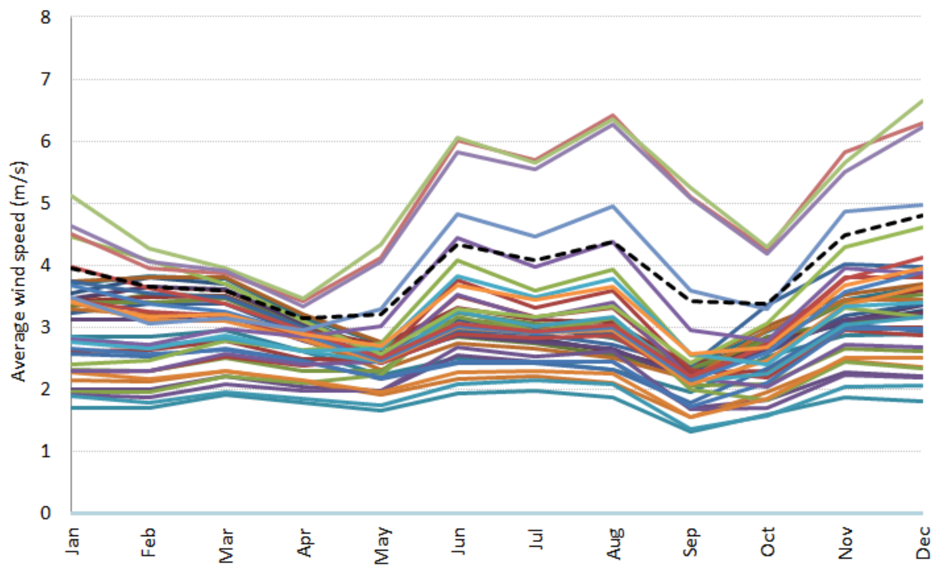
Further insight into geographical dispersion of wind power in Viet Nam can be assessed based on high resolution maps of simulated wind potential as presented in Figure 23 and the corresponding wind power density in Figure 24. The first presents simulated wind speeds based on a set of measurements at 100m above ground level taken over 2003-10 and the second shows the corresponding power density. These were based on information sourced from IRENA's website[14]. Further information and additional plots are provided in Appendix D. The charts are well correlated with the other sources we have plotted and show that there is substantial offshore wind potential along the south coast of the country.

Different reports have indicated that since 2007 Viet Nam has planned up to 50 wind power projects. However, many of these projects have not progressed due to various difficulties and barriers. A majority of the previously registered wind farms have no plan for construction or had the permit revoked due to delay in implementation. According to MOIT data, the country currently has only three projects in operation with combined capacity of 52 MW. The first project generating electricity to the grid from 2012 is Tuy Phong wind farm, developed by Renewable Energy of Viet Nam Joint Stock Company (REVN) in Binh Thuan district. The existing capacity is 30 MW, which will be expanded to 120 MW in the next stage. The other wind farms include a 100 MW (62 turbines @ 1.6 MW each[15]) project located in a Mekong Delta province of Bac Lieu (in operation since 2013 and scaled up over time to 100 MW by 2016), and a 6 MW off-grid project in Phu Quy Island, also of Binh Thuan province.

A limited amount of data is reported by Institute of Energy in relation to offshore wind resources at a height of 10m for 11 islands and at a height of 60m for two islands. The information is limited, but it appears that Viet Nam has potential for offshore wind with a little under half the sites having been tested being rated as "good" or better for offshore.

[14] Refer to: http://irena.masdar.ac.ae/.
[15] Source: http://www.power-technology.com/projects/bac-lieu-offshore-wind-farm/.

Figure 20 Monthly Wind Speeds for Different Locations in Viet Nam



Source: NASA Atmosphere Science Data Centre, obtained via the SWERA Geospatial Toolkit

Figure 21 Locations in Viet Nam with Highest Wind Potential

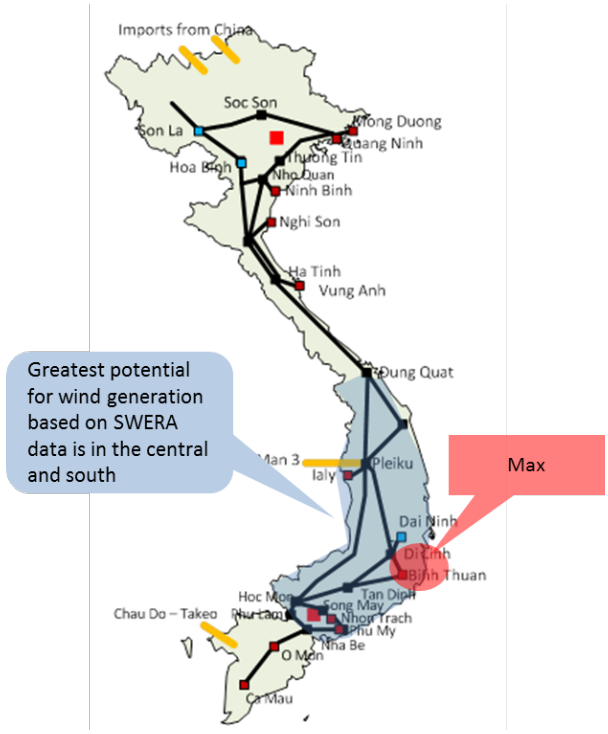
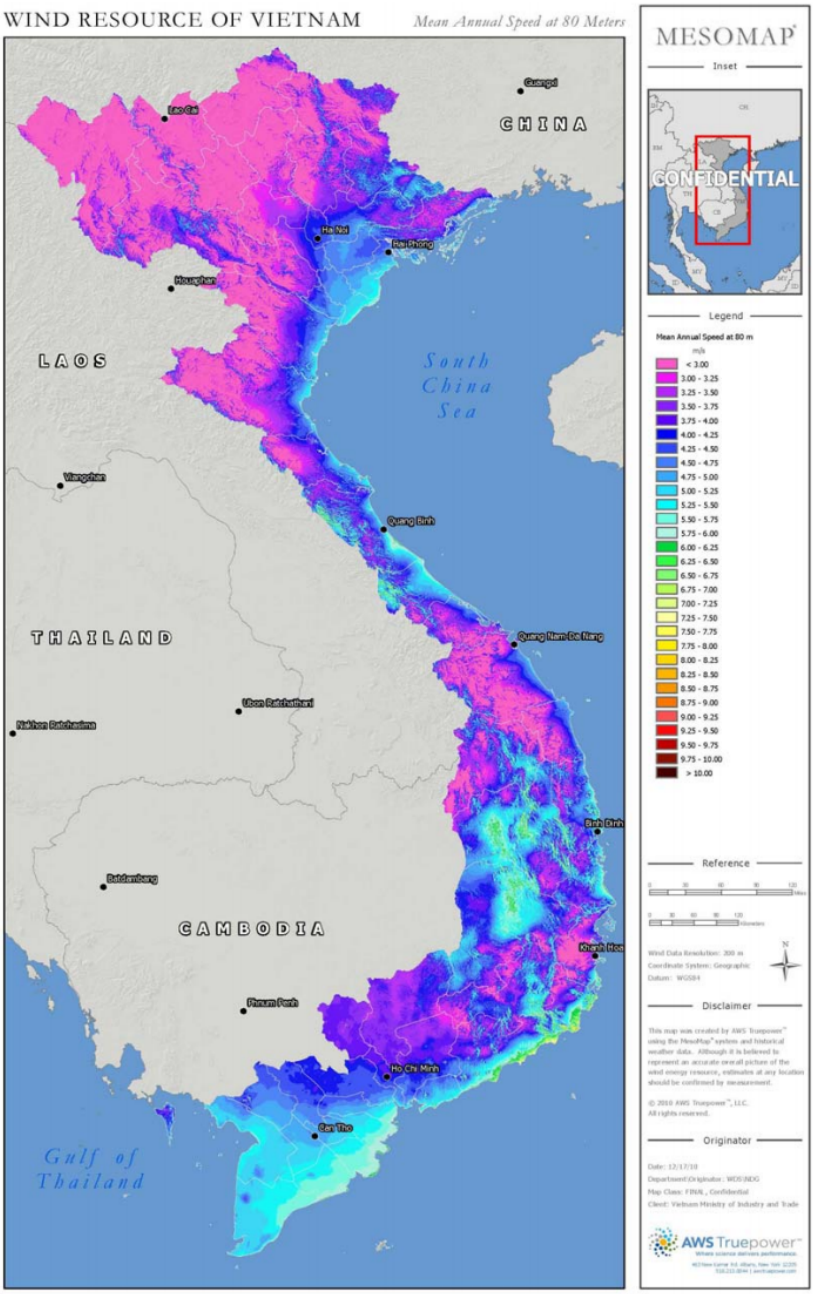
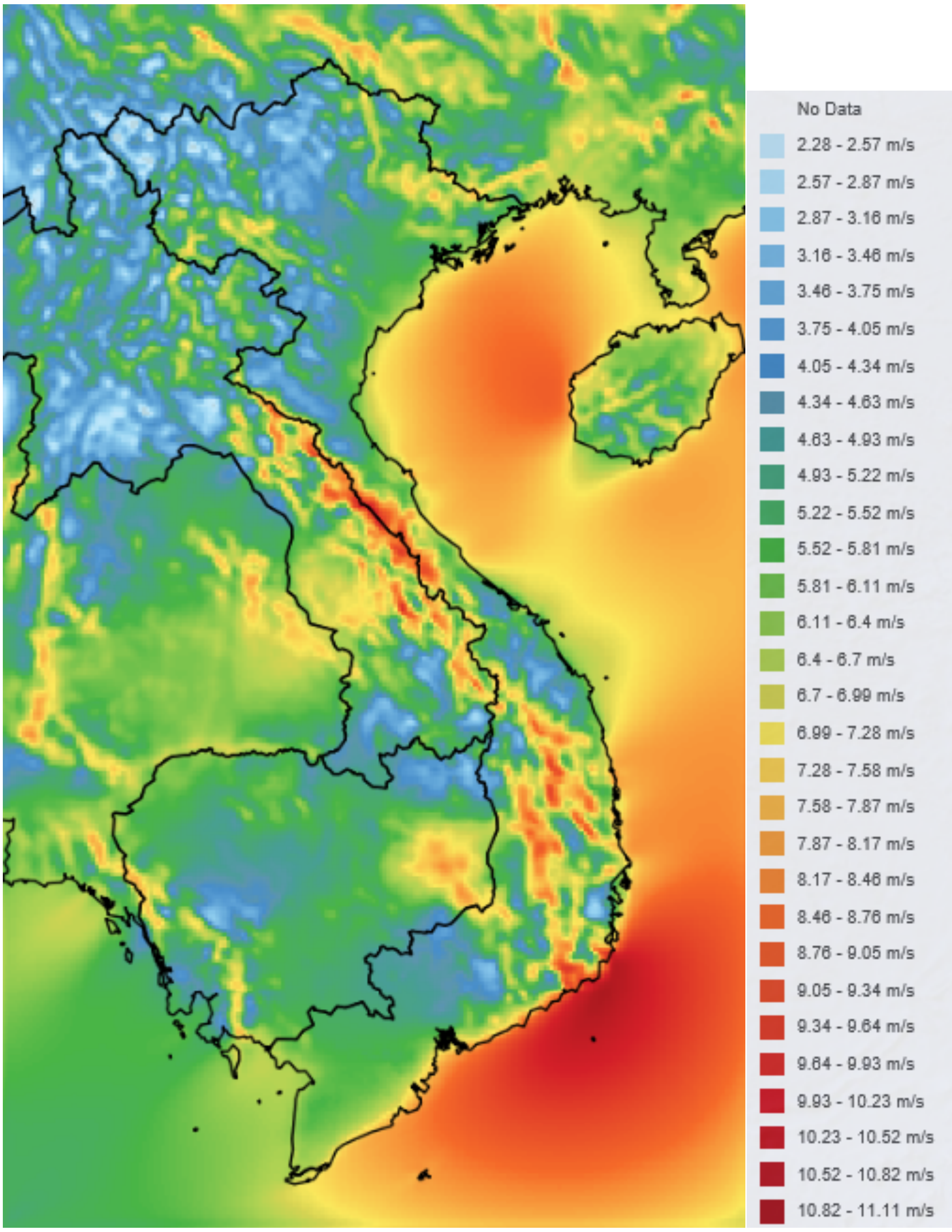


Figure 22 Wind Resource Map of Viet Nam based on Mean Annual Speed and 80 metre AGL



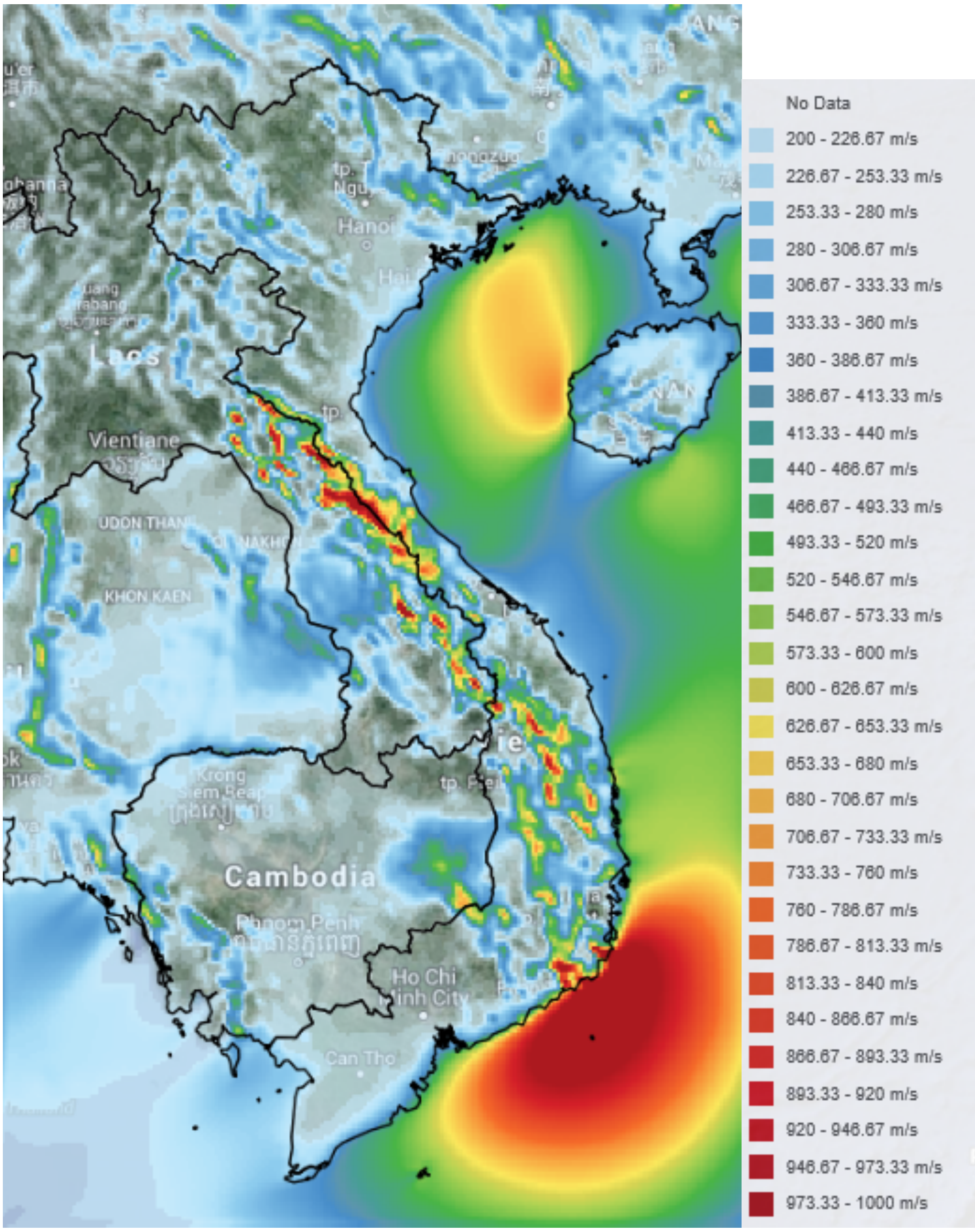
Source: AWS TruePower and MOIT (2011) World Bank report.

Figure 23 Simulated Wind Speed m/s 100m Viet Nam 5km 2003-2010 WBG



Source: World Bank Group, via IRENA

Figure 24 Simulated Wind Power Density 100m 2003-2010 WBG in W/s[16]



Source: World Bank Group, via IRENA

[16] We understand the legend should be "W/s" not "m/s" based on the description of the charts on the IRENA website.

3.7 Solar Power

Viet Nam is considered to have high potential for the development of solar energy. The country has 13 weather stations to measure radiation, and over 170 weather stations distributed over most of the provinces to measure the number of hours of sunshine. The number of hours of sunshine ranges from 1,300 to 2,900 hours per year, depending on the station tends to increase gradually from north to south. The total installed capacity of solar PV in Viet Nam until 2014 was approximately 4MWp.

According to the latest Prime Minister's Decision No. 2068/QD-TTg dated 25 November 2015, approving the development strategy of renewable energy of Viet Nam by 2030 with a vision to 2050, total electricity production from solar power would increase from 10 million kWh in 2015 to 1.4 billion kWh in 2020 (0.5% share), about 35.4 billion kWh in 2030 (6%) and about 210 billion kWh in 2050 (20%).

A number of studies have been conducted on assessing the potential, the most recent and detailed of which was a study entitled: "Maps of Solar Resource and Potential in Viet Nam", published in January 2015. This was undertaken by the MOIT and a Spanish Consortium consisting of Centro de Investigaciones Energeticas Medioambientales y Tecnológicas (CIEMAT), National Renewable Energy Centre (CENER) and Instituto para la Diversificación y Ahorro de la Energía (IDAE).

Figure 25, Figure 26 and Figure 27 show solar resource maps of annual average of daily Global Horizontal Insolation (GHI)[17] and Direct Normal Insolation (DNI)[18]; the first illustrates the solar irradiation map for 2015 data, while the latter are respectively GHI and DNI maps for the based on annual data for the period 2003-12[19]. Table 2 summarises the findings of the Spanish Consortium's study in relation to the daily average Global Horizontal Insolation (GHI) and Direct Normal Insolation (DNI) findings by zone. GHI provides an indication for flat-panel photovoltaic (PV) potential while DNI provides the potential for concentrated solar power (CSP). The theoretical potential for CSP and PV systems is provided in the study and the areas where it could be deployed are set out in Table 3.

[17] GHI is solar radiation measured with an instrument mounted horizontally so that it sees the whole sky (effectively it is the direct insolation plus any diffuse radiation that occurs from the scattering of light).
[18] DNI is solar radiation solar radiation that comes directly from the sun, with minimal attenuation by the Earth's atmosphere or obstacles.
[19] Maps were plotted using IRENA's freeware tool here: http://irena.masdar.ac.ae/ and they are based on World Bank Group (WBG) data.

Table 2 Summary of Annual Daily Average GHI and DNI Findings by Zone

<table>
<tr><th>Area / Zone</th><th>Annual Daily Average GHI kWh/m^2/day</th><th>Annual Daily Average DNI kWh/m^2/day</th></tr>
<tr><td>North</td><td>3.4</td><td rowspan="2">2.5</td></tr>
<tr><td>North Central Coast</td><td>3.8</td></tr>
<tr><td>Central Highlands</td><td rowspan="3">4.8</td><td>4.7</td></tr>
<tr><td>South Central Coast</td><td rowspan="2">4.2</td></tr>
<tr><td>South</td></tr>
</table>

Source: Solar Resource Study (2015)

Table 3 Theoretical Solar Potential Estimated

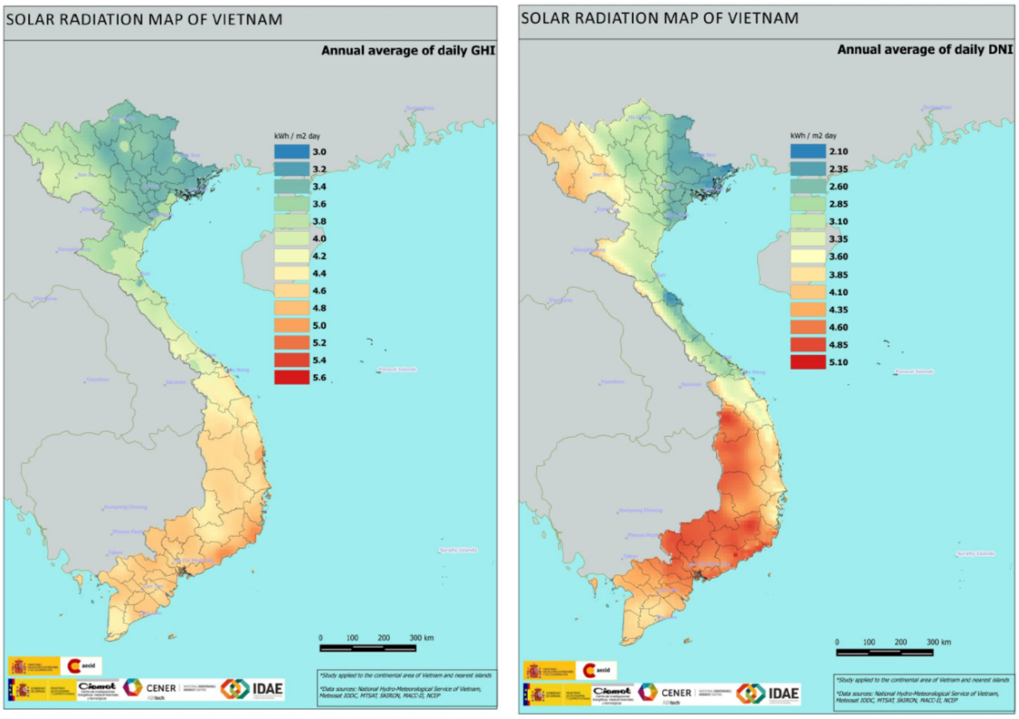
Type of Solar Technology	Theoretical Potential of Reference Technology[20]	Feasible Regions in Viet Nam for Deployment of the Technology
CSP system	60 – 100 GWh/year (per CSP System)	• Central Highlands and Southeast regions
PV system[21]	0.8 – 1.2 GWh/year (per PV System)	• Central Highlands and Southeast • Mekong River Delta • All the coastal areas • Northeast region

Source: Solar Resource Study (2015)

[20] Our understanding of the study conclusions is that it provides the theoretical potential on a per system basis.

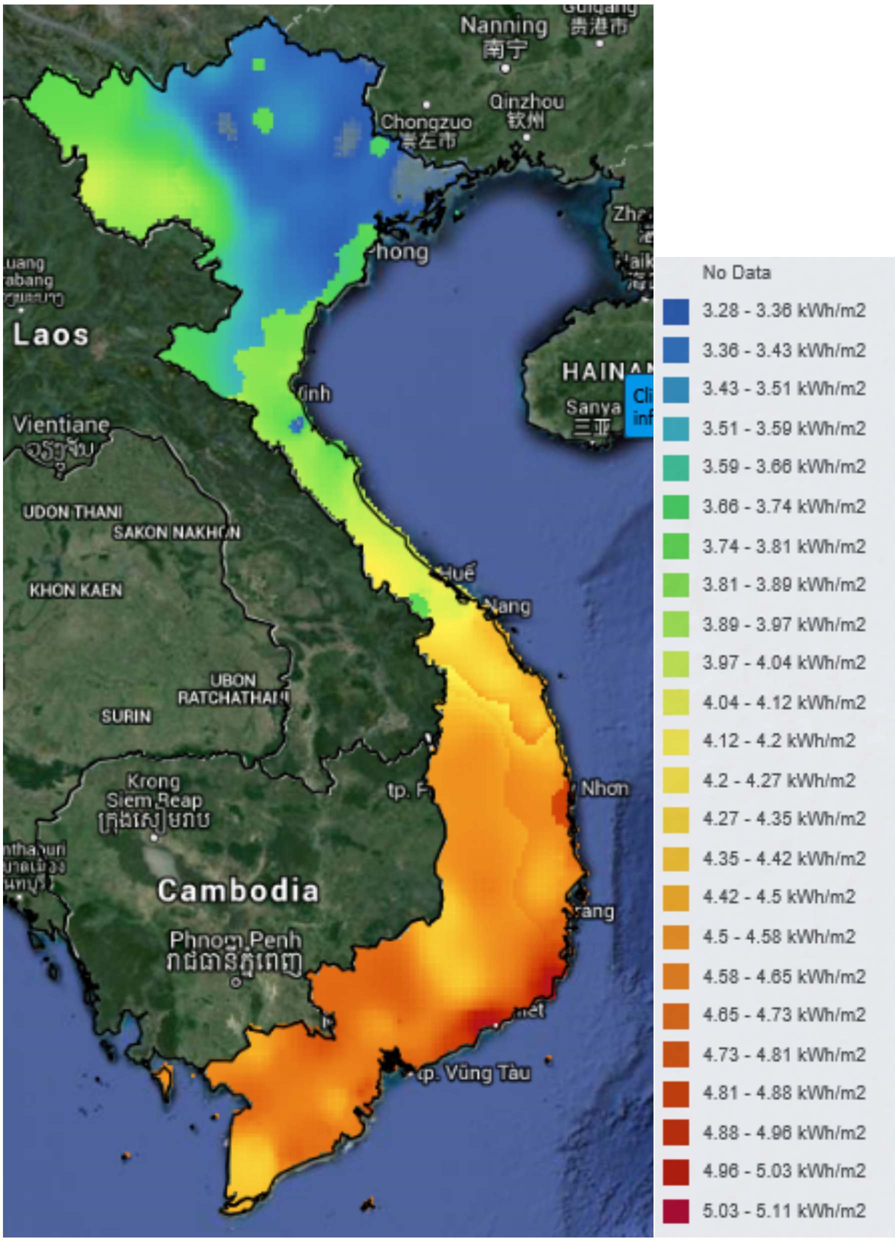
[21] The report defines a PV system as an array of 21 modules of Atersa A-230 P modules and 9 AGILO 100.0-3 Outdoor inverters.

Figure 25 Annual Average Daily GHI and Annual Average Daily DNI Maps (2015)



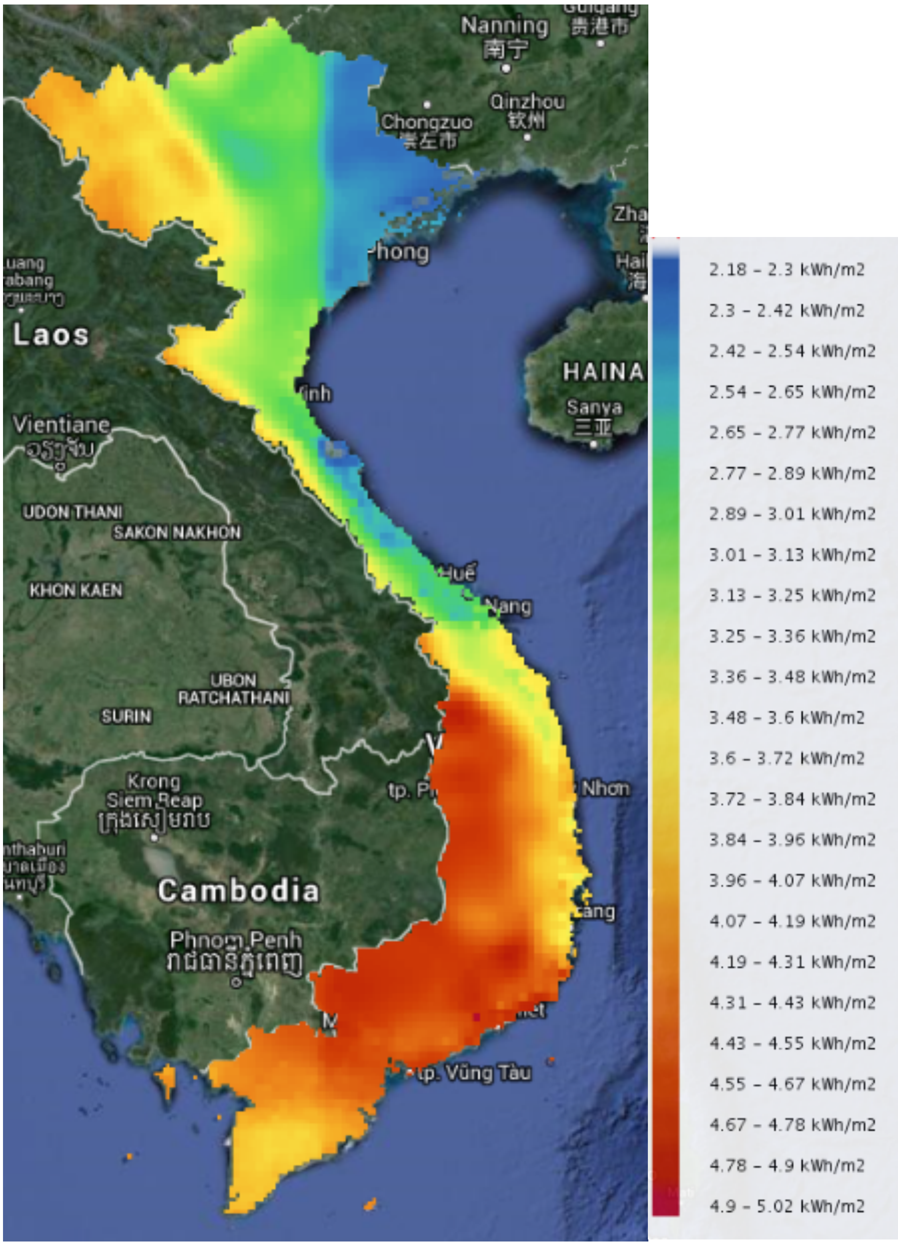
Source: Solar Resource Study (2015)

Figure 26 Global Horizontal Irradiance (GHI) kWh/m2 2003-12 WBG



Source: World Bank Group, via IRENA

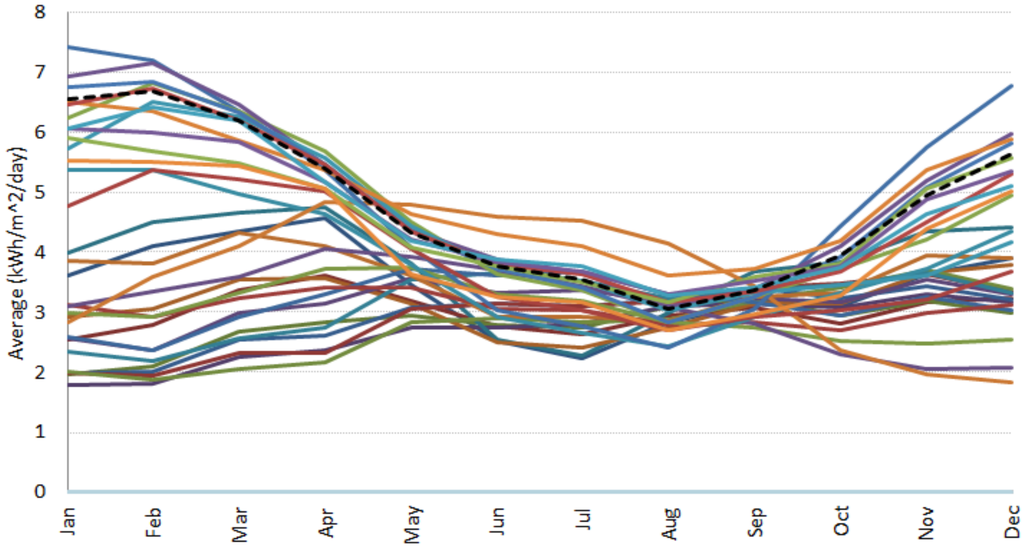
Figure 27 Direct Normal Irradiance (DNI) kWh/m2 2003-12 WBG



Source: World Bank Group, via IRENA

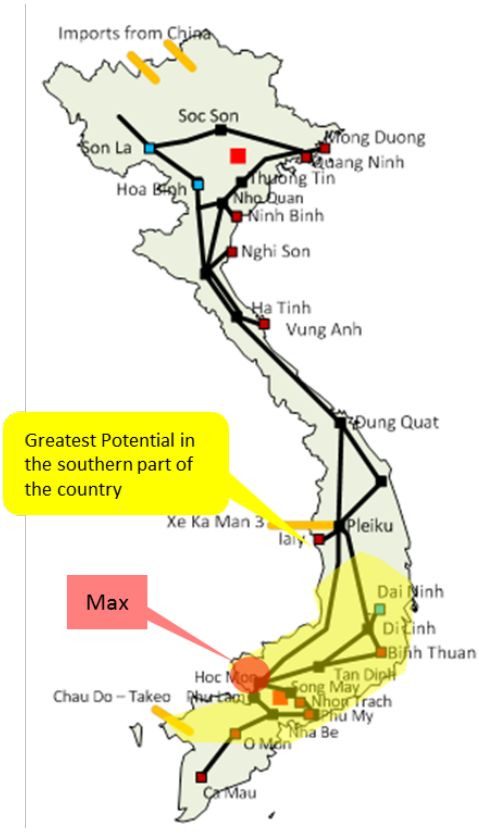
Figure 28 plots the monthly irradiation levels for different locations in Viet Nam with the dashed line representing the average radiation of the top 7 square profiles (above 4.8 kWh/m^2/day). This graph highlights November through to April exhibit excellent solar conditions. The map shading the locations of solar for Viet Nam is provided in Figure 29. This also highlights that the greatest potential for solar lies in the south central and southern regions of the country.

Figure 28 Monthly DNI Levels for Different Locations in Viet Nam



Source: NASA Atmosphere Science Data Centre, obtained via the SWERA Geospatial Toolkit

Figure 29 Main Locations with Solar Power Potential in Viet Nam based on DNI



3.8 Biomass and Biogas

As an agricultural country, Viet Nam has significant potentials for power generation from biomass and biogas sources. Typical forms include wood energy, crop waste and residues, animal waste, urban waste and other organic waste. Sustainable exploitation capacity of biomass for energy production in Viet Nam is estimated at about 150 million tons per year[22], with overall power generation potential of around 11-15 GW from biomass and 4-5 GW from biogas. IES projected estimates based on biomass and biogas data in an ADB report suggest a potential of 10 GW and 6 GW or 73 TWh and 40 TWh, respectively[23].

According to the latest Prime Minister's Decision No. 2068/QD-TTg dated 25 November 2015, approving the development strategy of renewable energy of Viet Nam by 2030 with a vision to 2050, total biomass electricity production would increase from 0.6 billion kWh in 2015 to nearly 7.8 billion kWh in 2020 (3% share), approximately 37 billion kWh in 2030 (6.3%) and 85 billion kWh in 2050 (8.1%).

[22] http://ievn.com.vn/tin-tuc/Tong-quan-ve-hien-trang-va-xu-huong-cua-thi-truong-nang-luong-tai-tao-cua-Viet-Nam-5-999.aspx

[23] Based on Viet Nam biomass and biogas fuel supply. Renewable Energy Developments and Potential in the Greater Mekong Subregion, ADB, 2015

Bagasse has been used for combined heat and power (CHP) production in about 40 sugar mills in Viet Nam for a long time. By 2009, the total installed power capacity of all CHP systems was around 150 MW. In 2007, sugar mills in Viet Nam have processed 9.4 million tons of sugar cane producing 2.8 million tons of bagasse (495 kTOE). However, only 70-80% of this amount (i.e. 2.1 million tons or 370 kTOE) was used for heat and power generation. This amount of bagasse could generate more than 300 GWh of electricity per year.

Biogas energy was introduced into Viet Nam in the early 1960s. Many biogas digester models were developed and widely disseminated by various local research and development institutions. At present, more than 200,000 biogas plants have been constructed in Viet Nam. Most operating biogas plants are family-sized with a digester capacity of 5 m3 to 20 m3. Biogas produced from these biogas plants is mainly used as fuel for cooking and lighting in the households. The total biogas production from the operating biogas plants could be estimated at 120 million m3, which contributed about 2.1 million GJ (50 kTOE) to the total energy balance of Viet Nam.

To provide support for investors, the Vietnamese Government has recently established the levels of feed in tariffs for biomass power generation projects and projects solid waste. The established prices for the buyer are 5.8 US cents / kWh for biomass sources, 10.05 US cents / kWh for generation sources on directly-burnt solid and 7.28 US cents / kWh for projects using combustion gas collected from the solid waste landfill.

3.9 Geothermal Energy

Presently there are no geothermal power plants in Viet Nam. However, based on surveys and studies carried out over the last few decades on geothermal energy resources, the country is recognised to have a limited amount of geothermal potential. Estimates suggest there is the potential for between 300 MW to 400 MW with the following areas / regions being identified as the prime candidates:

- A 1993 study “Study and Assessment of Geothermal Potential from Quang Nam – Da Nang to Ba Ria – Vung Tau” (Institute of Geology and Minerals), identified 6 potential sites: (i) Bang, (ii) Tu Bong, (iii) Hoi Van, (iv) Danh Thanh, (v) Mo Duc, and (vi) Nghia Thang;
- A study in 1996, “Assessment of Geothermal Potential in Northern Central Region” (also carried out by the Institute of Geology), refined some of these findings;
- ORMAT in coordination with EVN undertook a pre-feasibility study and it is understood that the findings lead to them applying in April 2012 for a license to build 5 geothermal energy plants in Le Thuy (Quang Binh), Mo Duc, Nghia Thang (Quang Ngai), Hoi Van (Binh Dinh) and Tui Bong (Khanh Hoa) with total capacity of the generators in the range from 150 to 200 MW;

- Viet Nam Geothermal Energy Corp is also reportedly working with Ormat as the major technical partner for two projects in Mo Duc and Tu Nghia district, Quang Ngai province with a designed capacity each being 18.7 MW; and
- In 2013, Quang Tri Province granted investment certificate and construction permit for a geothermal energy plant with a capacity of 25 MW at Dakrong and according to press, the project's price tag has been stated as US$46.3 million.

3.10 Ocean Energy

Viet Nam's 3,200 km coastline and thousands of islands present significant potential for wave and tidal-based energy technologies. The country is estimated to have a tidal energy potential of around 1,753 GWh per year and wave energy potential between 40 – 411 kW/m located around Binh Thuan and central Viet Nam[24]. The government has included ocean energy as part of its Viet Nam Marine Strategy to 2020[25].

3.11 Renewable Energy Potential and Diversity

In summary, the renewable energy potential for Viet Nam is provided in Table 4. The numbers presented here have been drawn from multiple sources and informed by analysis of IRENA Global Atlas data. Figure 30 shows on a monthly basis the normalised hydro inflows, solar radiation and wind speeds respectively for the north, central and south regions. This allows seasonal variation in the availability of solar, wind, hydro and its coincidence with average monthly demand profiles to be observed at the national level. It should be noted that the key issue in the charts is correlation but not amplitude, and furthermore, that the hydro inflows fall into reservoirs, some with significant amount of storage, which enables smoothing out generation throughout the year (within the limits of the storage capacity of the reservoirs), thus there is some scope for the role / operation of hydro power stations to change in Viet Nam to accommodate high levels of renewable energy. These charts show that there is some natural seasonal / monthly diversification between resources: wind speeds tend to be high as the wet season ends, solar radiation tends to reach a peak as wind speeds become lower. They not only highlight seasonal diversification among the solar, hydro and wind technologies; in Viet Nam there is also diversification between the main regions.

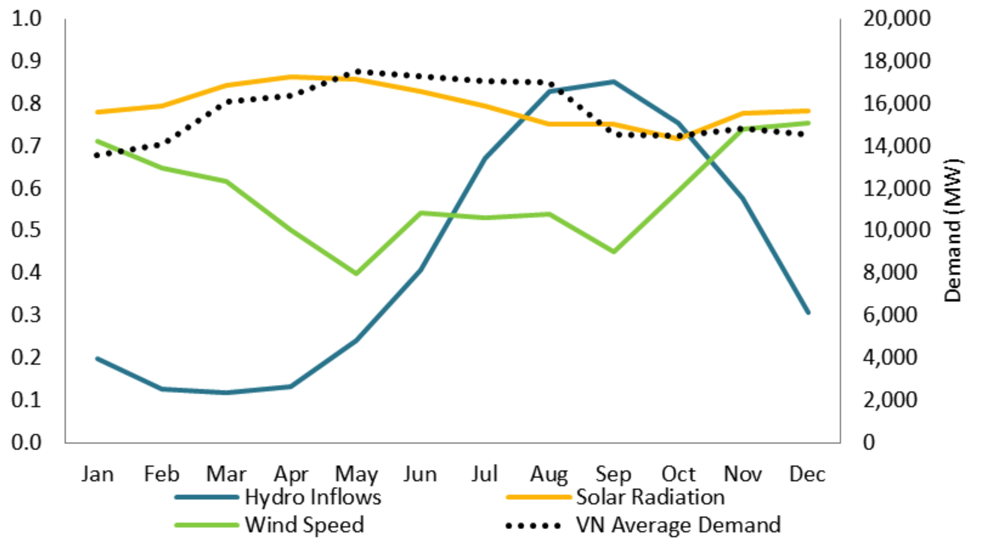
Table 4 Summary of Estimated Renewable Energy Potential (Compiled from Various Sources and Analysis)

Viet Nam	Potential (MW)	Source and comments
Hydro (Large)	More than 30,000	IES analysis, see Figure 19.
Hydro (Small)	24,334	IES analysis, see Section 3.5.2.

[24] Ocean renewable energy in Southeast Asia: A review (Quirapas, Lin, Abundo, Brahim, Santos, 2014)
[25] Refer to: http://english.vietnamnet.vn/fms/special-reports/144832/vietnam-and-the-marine-strategy.html

Pump Storage	8,000	Prime Minister's Decision No. 2068/QD-TTg (Nov 2015) capacity target.
Solar	119,863	Prime Minister's Decision No. 2068/QD-TTg (Nov 2015) production target converted to MW equivalent. Backed by analysis of data sourced from IRENA Global Atlas.
Wind Onshore	26,763 (SES) 29,356 (ASES)	SES was based on Renewable Energy Developments and Potential in the Greater Mekong Subregion (ADB, 2015), the ASES estimate based on government target set for 2050.
Wind Offshore	Significant	See World Bank Group, via IRENA resource maps (Figure 23, Figure 24).
Biomass	10,358	IES projections based on data from Renewable Energy Developments and Potential in the Greater Mekong Subregion (ADB, 2015).
Biogas	5,771	
Geothermal	400	See Section 3.9.
Ocean (Wave)	12,800	Ocean renewable energy in Southeast Asia: A review (2014), based on 40kW/m wave potential, 3200km coastline, 10% efficiency.

Figure 30 Seasonality in Renewable Resource Profiles and National Demand



Source: Consultant analysis

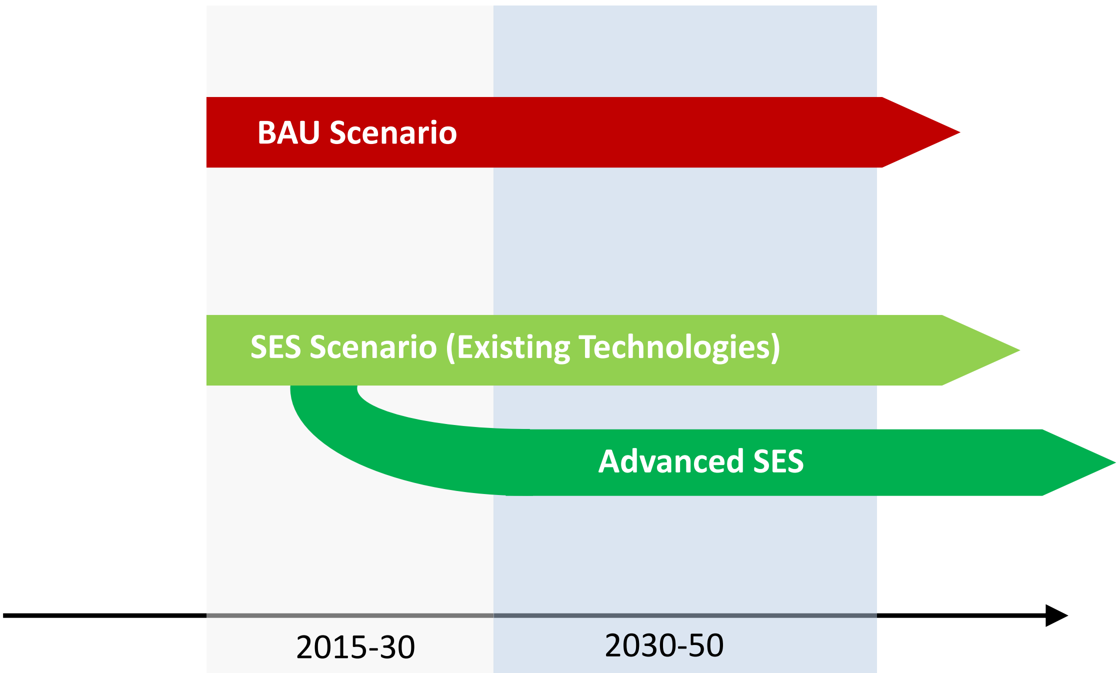
4 Viet Nam Development Scenarios

In this section, we define the three scenarios for Viet Nam's electricity sector that we have modelled: the Business as Usual (BAU), Sustainable Energy Sector (SES), and Advanced SES (ASES) scenarios. We also set out the assumptions made for technology costs and fuel prices before providing the details for a number of Viet Nam specific assumptions – in particular: our assumed economic outlook for Viet Nam, a list of generation projects that we consider committed[26] and comments on the status of power import projects. Further assumptions for each scenario are provided in sections 5, 6 and 7.

4.1 Scenarios

The three development scenarios (BAU, SES and ASES) for Viet Nam are conceptually illustrated in Figure 31.

Figure 31 GMS Power Sector Scenarios



The BAU scenario is characterised by electricity industry developments consistent with the current state of planning within the GMS countries and reflective of growth rates in electricity demand consistent with an IES view of base development, existing renewable energy targets, where relevant, aspirational targets for electrification rates, and energy efficiency gains that are largely consistent with the policies seen in the region.

[26] That is, construction is already in progress, the project is near to commissioning or it is in an irreversible / advanced state of the planning process.

In contrast, the SES seeks to transition electricity demand towards the best practice benchmarks of other developed countries in terms of energy efficiency, maximise the renewable energy development, cease the development of fossil fuel resources, and make sustainable and prudent use of undeveloped conventional hydro resources. Where relevant, it leverages advances in off-grid technologies to provide access to electricity to remote communities. The SES takes advantage of existing, technically proven and commercially viable renewable energy technologies.

Finally the ASES assumes that the power sector is able to more rapidly transition towards a 100% renewable energy technology mix under an assumption that renewable energy is deployed more than in the SES scenario with renewable energy technology costs declining more rapidly compared to BAU and SES scenarios. A brief summary of the main differences between the three scenarios is presented in Table 5[27].

Table 5 Brief Summary of Differences between BAU, SES and ASES

Scenario	Demand	Supply
BAU	Demand is forecast to grow in line with historical electricity consumption trends and projected GDP growth rates in a way similar to what is often done in government plans. Electric vehicle uptake was assumed to reach 20% across all cars and motorcycles by 2050.	Generator new entry follows that of power development plans for the country including limited levels of renewable energy but not a maximal deployment of renewable entry.
SES	• Assumes a transition towards energy efficiency benchmark for the industrial sector of Hong Kong[28] and of Singapore for the commercial sector by year 2050. • For the residential sector, it was assumed that urban residential demand per electrified capita grows to 975 kWh pa by 2050, 40% less than in the BAU. • Demand-response measures	• Assumes no further coal and gas new entry beyond what is already understood to be committed. • A modest amount of large scale hydro (between 4,000 to 5,000 MW) was deployed in Lao PDR and Myanmar above and beyond what is understood to be committed hydro developments in these countries[30]. • Supply was developed based on a least cost combination of renewable generation sources

[27] Note that we summarise the key drivers here. For further details, please refer to the separate IES assumptions document.

[28] Based on our analysis of comparators in Asia, Hong Kong had the lowest energy to GDP intensity for industrial sector while Singapore had the lowest for the commercial sector.

Scenario	Demand	Supply
	assumed to be phased in from 2021 with some 15% of demand being flexible[29] by 2050. • Slower electrification rates for the national grids in Cambodia and Myanmar compared to the BAU, but deployment of off-grid solutions that achieve similar levels of electricity access. • Mini-grids (off-grid networks) are assumed to connect to the national system in the longer-term. • Electric vehicle uptake as per the BAU.	limited by estimates of potential rates of deployment and judgments in on when technologies would be feasible for implementation to deliver a power system with the same level of reliability as the BAU. • Technologies used include: solar photovoltaics, biomass, biogas and municipal waste plants, CSP with storage, onshore and offshore wind, utility scale batteries, geothermal and ocean energy. • Transmission limits between regions were upgraded as required to support power sector development in the GMS as an integrated whole, and the transmission plan allowed to be different compared to the transmission plan of the BAU.
ASES	The ASES demand assumptions are done as a sensitivity to the SES: • An additional 10% energy efficiency applied to the SES demands (excluding transport). • Flexible demand assumed to reach 25% by 2050. • Uptake of electric vehicles doubled by 2050.	ASES supply assumptions were also implemented as a sensitivity to the SES, with the following main differences: • Allow rates of renewable energy deployment to be more rapid compared to the BAU and SES. • Technology cost reductions were accelerated for renewable energy technologies. • Implement a more rapid programme of retirements for fossil fuel based power stations. • Energy policy targets of 70% renewable generation by 2030, 90% by 2040 and 100% by 2050 across the region are in place.

[30] This is important to all countries because the GMS is modelled as an interconnected region.

[29] Flexible demand is demand that can be rescheduled at short notice and would be implemented by a variety of smart grid and demand response technologies.

Scenario	Demand	Supply
		• Assume that technical / operational issues with power system operation and control for a very high level of renewable energy are addressed[31].

4.2 Technology Cost Assumptions

Technology capital cost estimates from a variety of sources were collected and normalised to be on a consistent and uniform basis[32]. Mid-points were taken for each technology that is relevant to the GMS region. The data points collated reflect overnight, turnkey engineering procurement construction capital costs and are exclusive of fixed operating and maintenance costs, variable operating and maintenance costs and fuel costs. The capital costs by technology assumed in the study are presented in Figure 32for the BAU and SES scenarios. For the ASES scenario, we assumed that the technology costs of renewable technologies decline more rapidly. These technology cost assumptions are listed in Figure 33. Note that the technology capital costs have not included land costs, transmission equipment costs, nor decommissioning costs and are quoted on a Real USD 2014 basis.

Comments on the various technologies are discussed below in relation to the BAU and SES technology costs:

- Conventional thermal technology costs are assumed to decrease at a rate of 0.05% pa citing maturation of the technologies with no significant scope for cost improvement.
- Onshore wind costs were based on the current installed prices seen in China and India with future costs decreasing at a rate of 0.6% pa. Future offshore wind costs were developed by applying the current percentage difference between current onshore and offshore capital costs for all future years.
- Large and small-scale hydro costs are assumed to increase over time reflecting easy and more cost-efficient hydro opportunities being developed in the first instance. IRENA reported no cost improvements for hydro over the period from 2010 to 2014. Adjustments are made in the case of Lao PDR and Myanmar where significant hydro resources are developed in the BAU case[33].

[31] In particular: (1) sufficient real-time monitoring for both supply and demand side of the industry, (2) appropriate forecasting for solar and wind and centralised real-time control systems in place to manage a more distributed supply side, storages and flexible demand resources, and (3) power systems designed to be able to manage voltage, frequency and stability issues that may arise from having a power system that is dominated an asynchronous technologies.

[32] We standardised on Real 2014 USD with all technologies costs normalised to reflect turnkey capital costs.

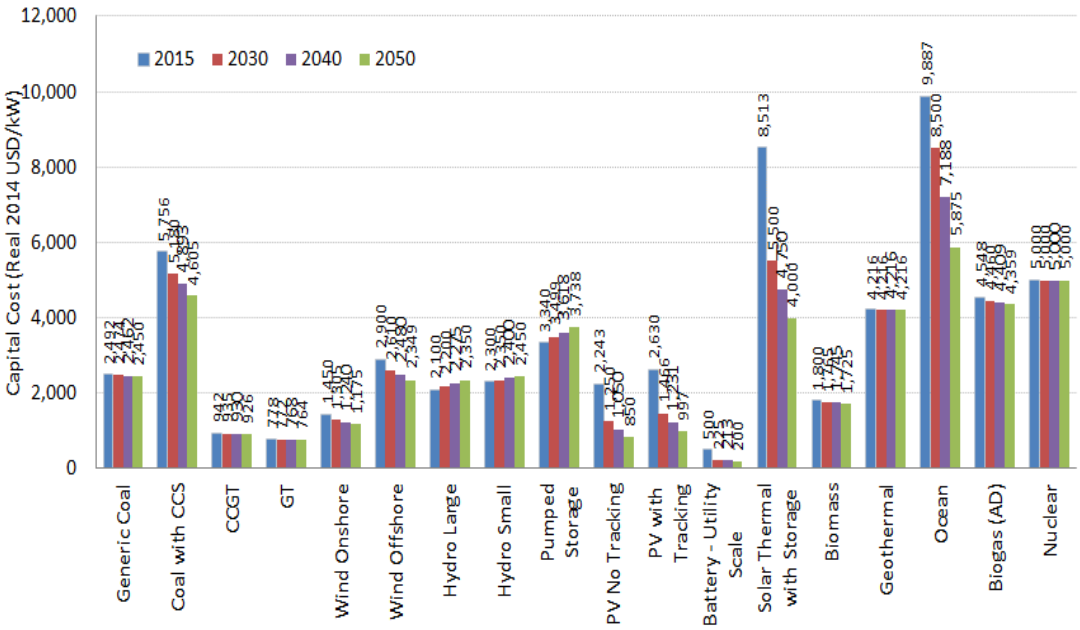
[33] Capital costs for large scale hydro projects are assumed to increase to $3,000/kW by 2050 consistent with having the most economically feasible hydro resources developed ahead of less economically feasible resources.

- Solar PV costs are based on the more mature crystalline silicon technology which accounts for up to 90% of solar PV installations (IRENA, 2015), and forecast to continue to drop (2.3% pa) albeit at a slower pace than in previous years.
- Utility scale battery costs are quoted on a $/kWh basis, and cost projections based on a report by Deutsche Bank (2015) which took into account several forecasts from BNEF, EIA and Navigant.
- Solar thermal (CSP) capital costs are projected to fall at 2.8% pa on the basis of the IRENA 2015 CSP LCOE projections. While globally there are many CSP installations in place, the technology has not taken off and the cost of CSP technology over the past 5 years has not been observed to have fallen as rapidly as solar PV.
- Biomass capital costs are based on costs observed in the Asia region which are significantly less than those observed in OECD countries. Capital costs were assumed to fall at 0.1% pa. Biogas capital costs were based on anaerobic digestion and assumed to decline at the same rate as biomass.
- Ocean energy (wave and tidal) technologies were based on learning rates in the 'Ocean Energy: Cost of Energy and Cost Reduction Opportunities' (SI Ocean, 2013) report assuming global installation capacities increase to 20 GW by 2050[34].
- Capital costs were discounted at 8% pa across all technologies over the project lifetimes. Decommissioning costs were not factored into the study.
- For technologies that run on imported coal and natural gas, we have factored in the additional capital cost of developing import / fuel management infrastructure in the modelling.

For reference, Appendix A tabulates the technology cost assumptions that we have used in the modelling.

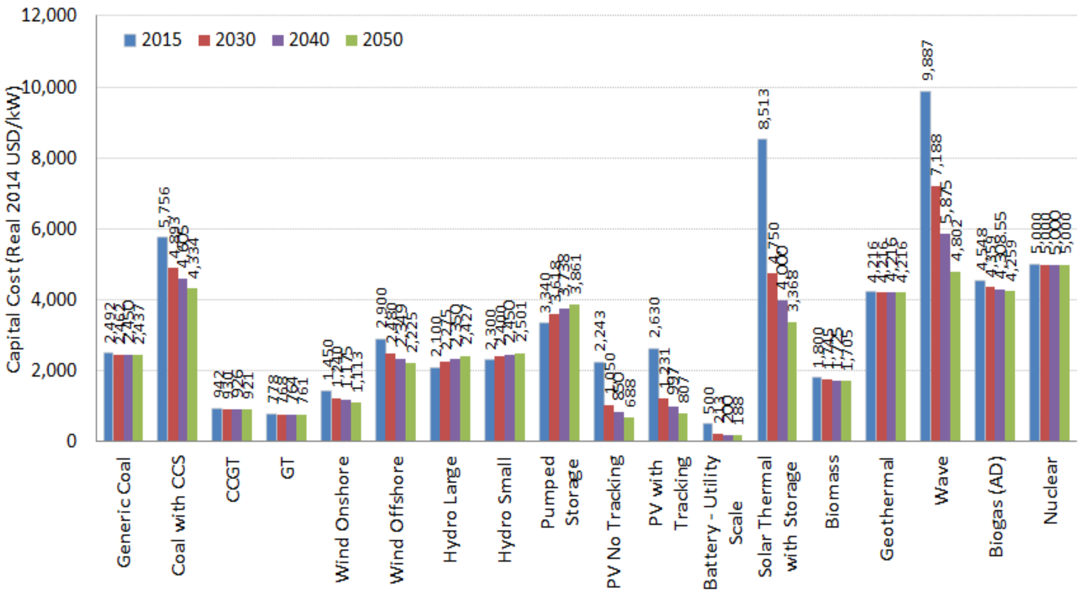
[34] Wave and tidal costs were averaged.

Figure 32 Projected Capital Costs by Technology for BAU and SES



* Battery costs are quoted on a Real 2014 USD $/kWh basis.

Figure 33 Projected Capital Costs by Technology for ASES



* Battery costs are quoted on a Real 2014 USD $/kWh basis.

4.3 Fuel Pricing Outlook

IES has developed a global fuel price outlook which is based on short-term contracts traded on global commodity exchanges before reverting towards long-term global fuel price forecasts based on the IEA's World Energy Outlook (WEO) 2015 450 scenario[35] and a set of relationships between different fuels that have been inferred from historical relations between different types of fuels. A summary of the fuel prices expressed on an energy-equivalent basis ($US/MMBtu HHV) is presented in Figure 34.

The 30% fall from 2014 to 2015 for the various fuels was the result of a continued weakening of global energy demand combined with increased stockpiling of reserves. Brent crude prices fell from $155/bbl in mid-2014 to $50/bbl in early 2015. OPEC at the November 2014 meeting did not reduce production causing oil prices to slump. However, fuel prices are then assumed to return from the current low levels to formerly observed levels within a 10 year timeframe based on the time required for there to be a correction in present oversupply conditions to satisfy softened demand for oil and gas[36].

To understand the implications of a lower and higher global fuel prices we also perform fuel price sensitivity analysis. One of the scenarios is based on a 50% fuel cost increase[37] to put the study's fuel prices in the range of the IEA's Current Policies scenario[38] which could be argued to be closer to the fuel pricing outlook that could be anticipated in a BAU outlook, while the SES and ASES scenarios could be argued to have fuel prices more consistent with the IEA's 450 scenario. We discuss the implications of fuel pricing on the BAU and SES within the context of electricity pricing in section 9.5.

For reference, we provide the base fuel pricing outlook for each year that was used in the fuel price modelling in Figure 34. These fuel prices were held constant in the BAU, SES and ASES scenarios.

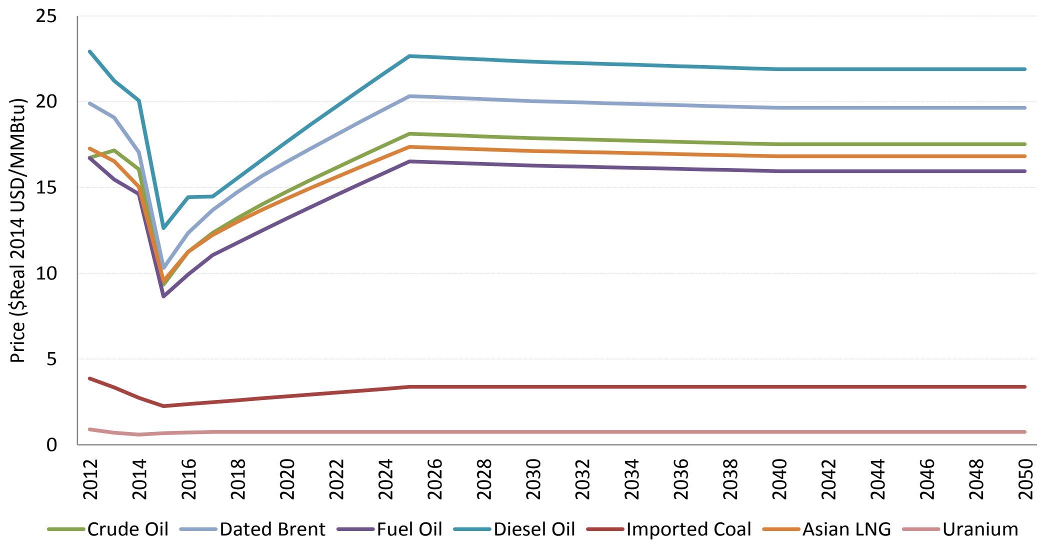
[35] The IEA's 450 scenario is an energy pathway consistent with the goal of limiting global increase in temperature to 2°C by limiting the concentration of greenhouse gases in the atmosphere to 450 parts per million CO2; further information available here: https://www.iea.org/media/weowebsite/energymodel/Methodology_450_Scenario.pdf.

[36] Reference: Facts Global Energy / Australian Institute of Energy, F. Fesharaki, "A New World Oil Order Emerging in 2016 and Beyond?" February 2016, suggest a rebound in prices levels over a 5 to 7 year period as the most "probable" scenario.

[37] Including biomass prices.

[38] The IEA's current policies scenario assumes no changes in policy from the year of WEO publication.

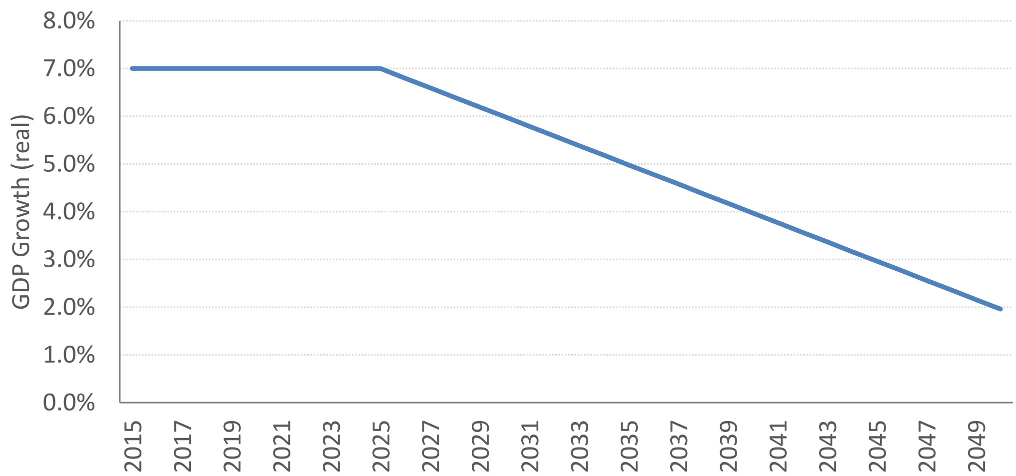
Figure 34 IES Base Case Fuel Price Projections to 2050



4.4 Viet Nam Real GDP Growth Outlook

Real GDP growth is assumed to maintain at 7% pa GDP growth rate to 2025 which is slightly higher than the 15-year historical average growth as Viet Nam continues to pursue industrialisation of its economy. Towards 2050, GDP growth is assumed to decline towards the world average of 1.96%[39] pa seen in Figure 35. The trend down is assumed to reflect the economic development cycle towards a developing country. This assumption is held constant in the BAU, SES and ASES scenarios.

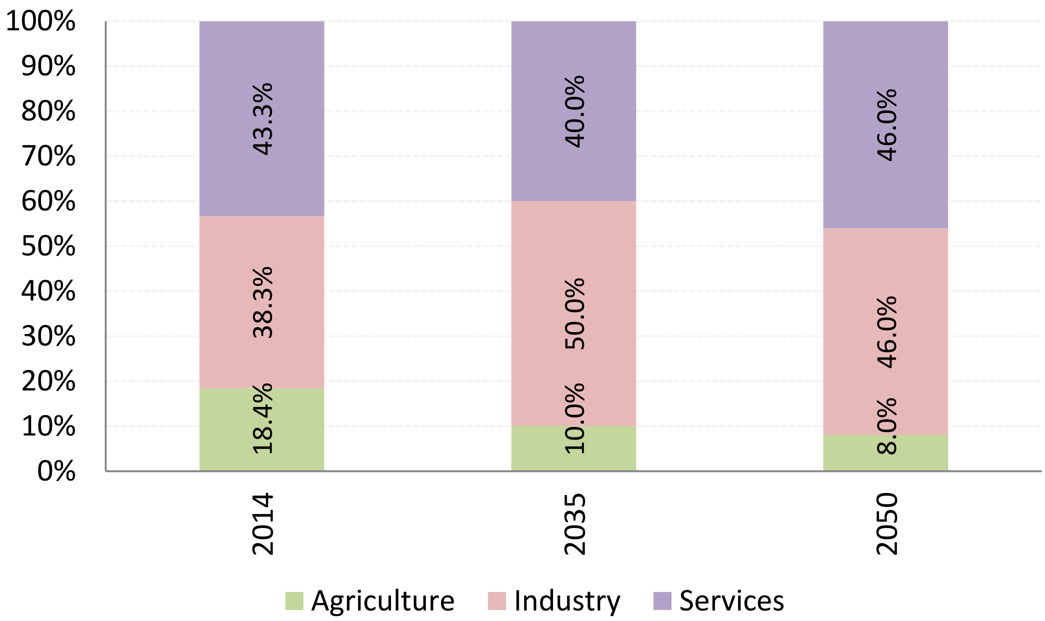
Figure 35 Viet Nam GDP Projection



[39] 1.96% reflects the previous 5 year GDP growth of the top 10 GDP countries in the world excluding Brazil, China and Russia.

The GDP composition of Viet Nam is weighted towards industry in line with the country's economic direction. The industry share of GDP in Viet Nam is assumed to increase from 38% in 2014 to 50% in 2035 and declining slightly to 46% by 2050. The GDP composition is plotted in Figure 36 below. Note that this assumption is held constant in the BAU, SES and ASES scenarios.

Figure 36 Viet Nam GDP Composition



4.5 Population Growth

Population was assumed to grow in line with the UN Medium Fertility scenario and is held constant across all scenarios[40].

4.6 Committed Generation Projects in BAU, SES and ASES Scenarios

Committed generation projects are the ones that are under construction or at a stage of development that is sufficiently advanced for decision for the project to come online to not be reversed. Table 6 lists the set of committed generation projects we understand for Viet Nam[41]. This is based on information from the most recent Power Development Plan as well as other research on the current status of various projects. The table shows the project's name, its understood capacity and the date it is expected to be commissioned by.

[40] UN Department of Economic and Social Affairs, World Population Prospects: The 2012 Revision.
[41] The list includes dedicated export projects from Lao PDR such as Xekaman 1. The capacity quoted for these projects has been adjusted to reflect the dedicated export quantity.

Table 6 Viet Nam Committed Generation Projects in All Scenarios

No.	Region	Project	Capacity MW	Generation Type	COD[42]
1	North	Ngoi Phat	72	Hydro	2015
2	North	Song Bac	42	Hydro	2015
3	Central	Song Bung 4	156	Hydro	2015
4	Central	Srepok 4A	64	Hydro	2015
5	North	Ba Thuoc 1	60	Hydro	2015
6	North	Bac Me	45	Hydro	2015
7	South	Dong Nai 5	150	Hydro	2015
8	North	Huoi Quang 1	260	Hydro	2015
9	North	Lai Chau 1-1	400	Hydro	2015
10	North	Nậm Mức	44	Hydro	2015
11	North	Nam Na 2	66	Hydro	2015
12	North	Nậm Na 3	84	Hydro	2015
13	North	Nam Toong	34	Hydro	2015
14	North	Ngoi Hut 2	48	Hydro	2015
15	Central	Nhan Hac	45	Hydro	2015
16	North	Nho Que	32	Hydro	2015
17	North	Nho Que 2	48	Hydro	2015
18	Central	Xekaman 3	200	Hydro	2015
19	Central	Song Bung 2	108	Hydro	2015
20	South	Sông Giang 2	37	Hydro	2015
21	Central	Song Tranh 3	62	Hydro	2015
22	South	Formosa HT	600	Coal	2015
23	North	An Khanh 2-1	50	Coal	2015
24	North	An Khanh 2-2	50	Coal	2015
25	South	Duyen Hai 1-1	600	Coal	2015
26	South	Formosa Ha Tinh 1-1	150	Coal	2015
27	South	Formosa Ha Tinh 1-2	150	Coal	2015
28	South	Formosa Ha Tinh 1-3	100	Coal	2015
29	South	Formosa Ha Tinh 1-4	100	Coal	2015
30	South	Formosa Ha Tinh 1-5	150	Coal	2015
31	North	Mong Duong 1-1	540	Coal	2015
32	North	Mong Duong 1-2	540	Coal	2015
33	North	Mong Duong 2-1	622	Coal	2015
34	North	Mong Duong 2-2	622	Coal	2015
35	Central	Nong Son	30	Coal	2015
36	North	Thai Binh 2-2	600	Coal	2015
37	North	Uong Bi Ext 2	330	Coal	2015

[42] Commercial operation date

No.	Region	Project	Capacity MW	Generation Type	COD[42]
38	Central	Dak Mi 2	98	Hydro	2016
39	Central	Dak Mi 3	45	Hydro	2016
40	North	Huoi Quang 2	260	Hydro	2016
41	North	Lai Chau 1-2	800	Hydro	2016
42	Central	Xekaman 1 80%	232	Hydro	2016
43	Central	Song Tranh 4	48	Hydro	2016
44	North	Trung Son	260	Hydro	2016
45	North	Yen Son	70	Hydro	2016
46	South	Duyen Hai 1-2	600	Coal	2016
47	South	Duyen Hai 3-1	600	Coal	2016
48	South	Formosa Dong Nai	150	Coal	2016
49	Central	Chi Khe	41	Hydro	2017
50	South	Da Nhim MR	80	Hydro	2017
51	North	Long Tao	42	Hydro	2017
52	Central	Xekaman Xanay	26	Hydro	2017
53	South	Thac Mo MR	75	Hydro	2017
54	Central	Tra Khuc	36	Hydro	2017
55	South	Duyen Hai 3-2	600	Coal	2017
56	South	Long Son 1-1	75	Coal	2017
57	North	Luc Nam 1-1	50	Coal	2017
58	North	Thai Binh 1-1	300	Coal	2017
59	North	Thai Binh 2-1	600	Coal	2017
60	North	A Lin	62	Hydro	2018
61	Central	Dak Mi 1	54	Hydro	2018
62	South	Hoi Xuan	102	Hydro	2018
63	South	La Ngau	36	Hydro	2018
64	Central	Xekaman 4 80%	64	Hydro	2018
65	North	Song Lo 6	44	Hydro	2018
66	North	Song Mien 4	38	Hydro	2018
67	South	Duyen Hai 3-Ext	660	Coal	2018
68	South	Long Son 1-2	150	Coal	2018
69	South	Long Phu 1-1	600	Coal	2018
70	North	Luc Nam 1-2	50	Coal	2018
71	North	Thai Binh 1-2	300	Coal	2018
72	North	Thai Binh 2-2	600	Coal	2018
73	North	Thang Long 1-1	300	Coal	2018
74	South	Vinh Tan 4-1	600	Coal	2018
1	South	Vinh Tan 4-2	600	Coal	2018

4.7 Regional Transmission System Integration

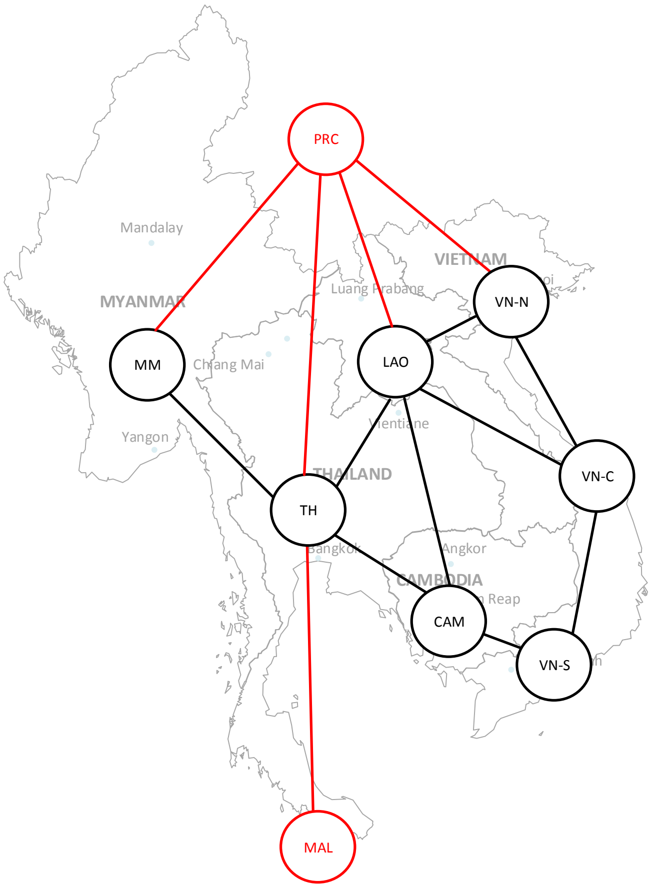
As described in section 2.6, Viet Nam imports power from PRC and a dedicated hydro project in Lao PDR. Viet Nam also exports power to Cambodia. The modelling presented in this report assumes transmission in the GMS becomes more tightly integrated than at present. Given the modelling period is for 35 years, we use a regional model for the interconnections as illustrated in Figure 37[43]. The figure shows the assumed topology of the GMS as well as connections to countries outside the region (PRC and Malaysia). Initially, not all transmission connections shown in the diagram are in place. However, over the modelling period the transmission connections are expanded as required to allow power exchange between regions to minimise costs and take advantage of diversity in demand and resource availabilities. Each scenario therefore effectively has a different high-level transmission development plan[44].

The main differences in the assumptions behind the transmission system enhancements in each scenario were:

- In the BAU, it was assumed that transmission developments occur slowly and a tightly integrated regional power system is in place from about 2030, but the power sectors are developed so that there is only a limited level of dependency on imports from neighbouring countries. This is consistent with power sector planning that seeks to not be overly dependent on power imports from neighbouring countries.
- In the SES and ASES, the transmission system evolves from 2025 and we allow the transmission system (based on a simplified model of the region) to expand as needed to optimise the use of a geographically disperse set of renewable energy resources. A consequence of this is that some countries become significant exporters of power while others take advantage of power imports from neighbouring countries. In particular Myanmar and Lao PDR become major power exporters with the beneficiaries being the other GMS countries.

[43] Currently, there is minimal physical interconnection between each GMS country. The model shows the topology that we have used in the modelling in order to gain an understanding of interregional power flows and to develop a very simple high-level transmission development plan.
[44] We only consider a high-level transmission development plan based on the regional model shown in order to gain insight on interregional power flows.

Figure 37 GMS Regional Transmission System Model



4.8 Imports and Exports

Note that for Viet Nam, it was assumed that the projects in Lao PDR (Table 7) export power to Viet Nam's national system initially on a dedicated basis but they naturally become part of an interconnected GMS power system over time as the countries are assumed to have their power systems become increasingly integrated. The capacities shown in the table have been de-rated based on the power purchase agreements that Viet Nam has with the host country for these projects; that is, they reflect just the power that is transferred to Viet Nam, not the portion that is available to the host country.

Some additional assumptions that are made in relation to imports and exports that apply to all scenarios:

- Imports from Malaysia into Thailand at 135 MW and imports from PRC into Lao PDR at 25 MW remaining constant throughout the modelling;
- Imports from PRC into Viet Nam start at 412 MW but declines steadily to 0 MW by 2025 as Viet Nam reduces its reliance on PRC power flows.

Table 7 Viet Nam Committed Import Projects

No.	Unit	Country	Capacity (MW)[45]	Type	COD
1	Xekaman 1	Lao PDR (power purchased from Lao PDR)	232	Hydro	2016
2	Xekaman 3	Lao PDR (power purchased from Lao PDR)	200	Hydro	2015
3	Xekaman 4	Lao PDR (power purchased from Lao PDR)	64	Hydro	2018

4.9 Technical-Economic Power System Modelling

Technical and economic modelling of the GMS was done in the PROPHET electricity planning and simulation models. It develops a least cost generation based plan and was used to simulate the operation of the GMS region as an integrated power system.

A brief overview of the various aspects is provided below:

- **Planning Module**: The Planning Module of Prophet allows for intertemporal constraints such as energy limits to be preserved when simulating the power system and developments. It also develops a least cost set of new entrants to satisfy demand over the 35 year modelling horizon.
- **Transmission**: The power system was modelled based on the configuration as per Figure 37 with fixed / scheduled flows (red lines) to power systems outside the GMS not being explicitly modelled while power transfers within the GMS countries were optimised as needed to allow supply and demand to balance. This is important with respect to modelling diversity in demand in the different regions and geographical variation in generation patterns from supply-driven renewable energy (solar and wind) and seasonal variation of inflows into the hydro storages (see Figure 30).
- **Economics:** Capital and operating costs relating to generation plants as per the assumptions covered in this report allow the Planning Module to model generation and transmission development in a least cost manner. On top of this, resource constraints had to be formulated to reflect actual limits such as the maximum renewable resource and development rates available to each country.
- **Demand:** Demand profiles were constructed from energy and peak demand forecasts for electricity based on regression models that were developed for each sector of the electricity industry (commercial, industrial, residential, agricultural and transport). The monthly and intraday construction of the profiles were performed in Prophet based on historical data and/or external data sources indicating the seasonal profile of demand for each country.
- **Flexible demand**: was modelled as MW and GWh/month quantities that can be scheduled as necessary to reduce system costs. This means that demand

[45] Capacity figures presented here are pro-rated based on the intended power flows between the countries.

tends to be shifted from periods when supply and demand would otherwise be tight to other times. The technology for rescheduling demand was assumed to be in place from 2020 in the SES and ASES scenarios.

- **Supply:** The approach taken for modelling generation supply technologies varied according to the technology type. This is discussed further below:
  - *Conventional thermal plant*: is modelled as capacity limited plants, with fuel take or pay contracts applied to generators where relevant and other fuel supply constraints in place where relevant – for example, gas supply limits applied to LNG facilities or offshore gas fields. Examples of such plants include coal, biomass, gas, and diesel generators.
  - *Energy limited plants*: such as large-scale hydros with reservoirs / storages and CSP have monthly energy limits corresponding to seasonal variations in energy inflows. The equivalent capacity factors are based on external reports for hydro and resource data for CSP (see next point).
  - *Supply-driven generation forms*: Seasonal profiles for wind, solar and run of river hydros without reservoirs were developed on an hourly basis. For wind and solar they were derived from monthly resource data collected from a variety of sources including NASA, NREL[46] and accessed via the Solar and Wind Energy Resource Atlas (SWERA) Toolkit and IRENA Global Atlas. Resource amounts were matched against actual generation data for known plants to develop equivalent monthly capacity factors at various high resource pockets in each country. Several traces were built from known generation traces to provide diversification benefits.
  - *Pump Storage and battery storage*: these are modelled in a similar way to flexible demand in that demand can be shifted with a capacity and energy limit but the scheduled demand is stored for generation later with an appropriate energy conversion efficiency (pumped storages assumed to be 70% and battery storage systems at 85%).

[46] DNI and Wind NASA Low Resolution and NREL DI Moderate Resolution data.

5 Business as Usual Scenario

5.1 Business as Usual Scenario

The BAU scenario assumes industry developments consistent with the current state of planning in Viet Nam and reflective of growth rates in electricity demand consistent with an IES view of base development, existing renewable energy targets, where relevant, aspirational targets for electrification rates, and energy efficiency gains that are largely consistent with the policies seen in the region. For Viet Nam, the Business as Usual (BAU) scenario was based on a strategy of conventional power sector planning for Viet Nam. The BAU scenario's strategy for Viet Nam's electricity industry is characterised by the following:

- Minimal advancements and efforts in the area of energy efficiency and demand-side management;
- Heavy use of domestic and imported coal resources, requiring the development of coal import and handling facilities;
- Ongoing exploitation of Viet Nam's offshore reserves of gas, and in the longer-term developing LNG regasification facilities to backfill gas reserves at international gas prices as offshore reserves become depleted;
- Continued development of nuclear power capability and eventually exercising that option to satisfy growing demand over the long-run;
- In relation to hydro power:
  - No further development of large scale hydro projects sited within Viet Nam beyond what is under construction, as it is well recognised that Viet Nam's large scale hydro potential has been almost fully exploited;
  - Development of small scale hydro potential continues as is presently planned, although it is not continued beyond the a total of the 5597 MW of potential that has been identified and which is considered sustainable to develop;
  - Development of pumped storage hydro power plants in line with current thinking in Viet Nam's power development plans;
- Limited deployment of the most readily exploited renewable energy projects in the country to achieve around 10% of the total generation mix by 2030, and 10% by 2050, including the following types of renewable energy (consistent with current BAU renewable energy planning in Viet Nam): solar photovoltaics, onshore wind farms and biomass and biogas projects; and
- Continued development of power import projects from neighbouring countries, including hydro projects in Cambodia and Lao PDR.
- Electric cars and motorcycles are expected to displace traditional fuel-based transport due to lower running and maintenance costs and the expectation of lower battery costs as global production increases.

The BAU scenario developed and presented in this report reflects future power sector developments that are largely consistent with our understanding of current power development plans, plans for renewable energy, plans for enhancing energy efficiency in Viet Nam, and measures currently in place for mitigating climate change.

5.2 Projected Demand Growth

Viet Nam's on-grid electricity demand (including transmission and distribution losses[47]) is plotted in Figure 38. Viet Nam's electricity demand is forecast to increase at a rate of 5.1% pa over the 35-year period to 2050 with a slowdown in growth beyond 2040 with economic growth rates trending towards growth rates of developed countries and population growth rates slowing.

To 2050, electricity demand attributable to the commercial sector has been projected to grow the fastest at 6.4% pa, followed by industrial sector growth at 5.2%, residential at 2.8% and the agricultural sector at 3.3%. This is in line with GDP composition transitioning towards industry and commercial services by 2030 and beyond, in line with the country's current economic strategies. Electricity consumption attributable to the transport sector becoming increasingly based on electric vehicles is forecast to reach some 29 TWh by 2050 as the number of cars and uptake of electric cars and motorbikes increase to 20% uptake. Viet Nam electricity demand is forecast to reach some 861 TWh by 2050 with the industrial sector accounting for 57% of total electricity demand.

Peak demand is plotted below in Figure 39 and shows peak demand growing at 4.8% pa and reaching 122 GW by 2050. The load factor is assumed to trend towards 80% by 2040 in line with having increasing levels of industrial load in the mix of electricity customers. Key drivers for demand growth and the demand projections are summarised in Table 8.

[47] Note that unless otherwise stated, all other demand charts and statistics include transmission and distribution losses.

Figure 38 Viet Nam Projected Electricity Demand (2015-2050, BAU)

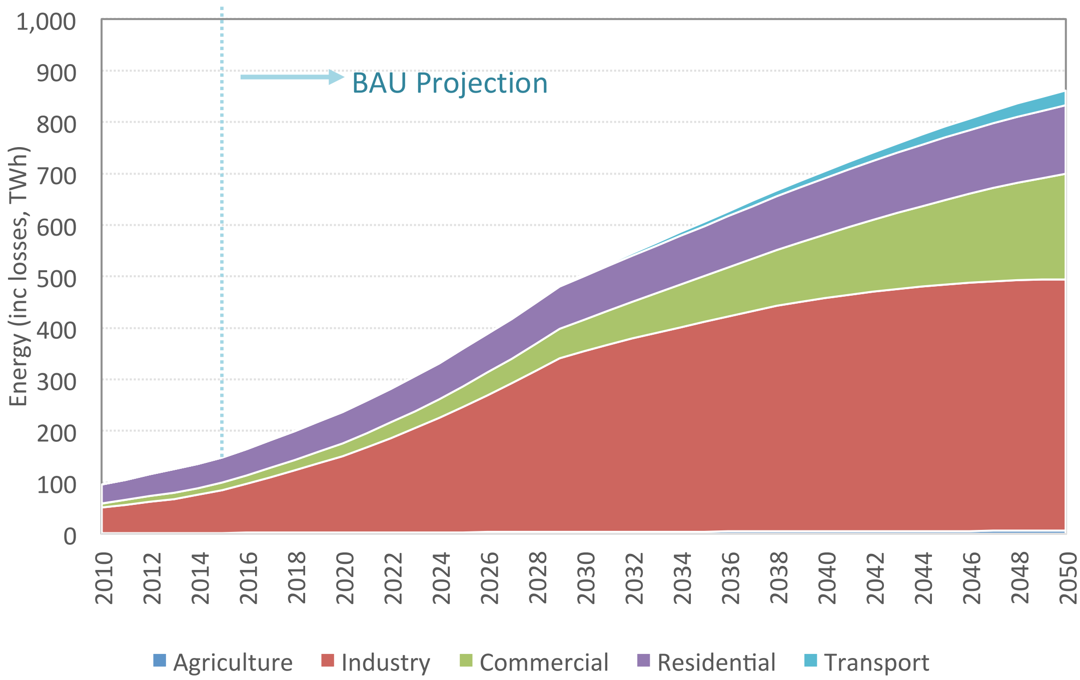
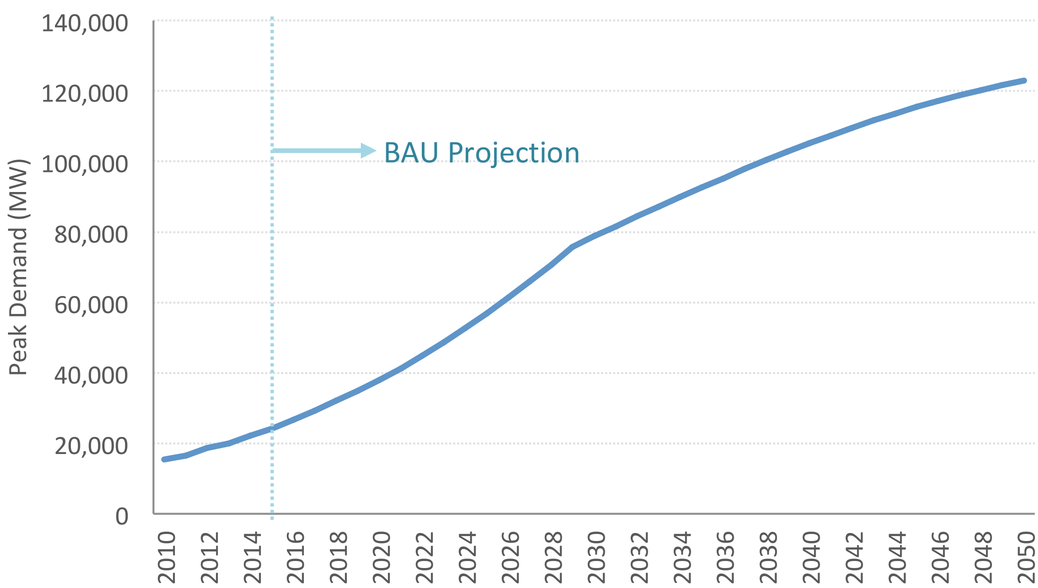


Figure 39 Viet Nam Projected Peak Demand[48] (BAU, MW)



[48] Note that this is peak demand before scheduling flexing demand, which reduces demand – we present the implication of flexing demand on peak demand later.

Table 8 Viet Nam Demand and Demand Drivers (BAU)

No.	Aspect	2015-30	2030-40	2040-50
1	Demand Growth (pa)	8.3%	2.9%	1.6%
2	GDP Growth (Real, pa)	6.8%	4.9%	2.9%
3	Electrification Rate (Population)	98%	99%	99%
4	Population Growth	0.60%	0.23%	-0.04%
5	Per Capita Consumption (kWh)	2,374	4,945	6,946
6	Electricity Elasticity*	4.26	2.08	1.40
7	Electricity Intensity (kWh/USD)	0.439	0.581	0.612

* Electricity elasticity is calculated as electricity demand growth divided by the population growth over the same period

5.3 Installed Capacity Development

The BAU installed capacity profile (MW) for Viet Nam is graphed in Figure 40 by type of generation. To illustrate Viet Nam's BAU installed capacity trends, the shares for selected years: 2010, 2015, 2020, 2030, 2040 and 2050 are shown in Figure 41. We provide the corresponding statistics to these charts in Table 9 and Table 10. Note that the installed capacity numbers include generation that is effectively available to Viet Nam as imports and where appropriate this has been adjusted to reflect the power that is available to Viet Nam under supply agreements.

Installed capacity in 2015 increases from 38 GW to 169 GW with coal-fired generation accounting for 41% of total installed capacity. Gas-fired and large-scale hydro capacity grows to 42 GW (2050) combined but decline in percentage terms from a combined 75% to 25% capacity share given the dominance of coal in the generation mix. The majority of the coal is based on coal import projects that would be supported by coal import and storage terminals, in line with current plans. It is assumed that as Viet Nam's offshore gas reserves become depleted, LNG terminals are established with LNG procured on global markets back-filling the gas-fired generators. By 2030, nuclear power plants start operation and Viet Nam continues to expand its nuclear industry with successive nuclear power projects developed and nuclear makes up 8.5 GW by 2050. Some 1.4 GW of pump storage capacity is developed in tandem with the nuclear developments to provide regulating reserves above and beyond other generators.

In the BAU Viet Nam is assumed to achieve 10% renewable energy in the generation mix by 2030 and this level is maintained with ongoing investment in renewable energy out to 2050. Installed capacity necessary to achieve this is shown in the charts of installed capacity. Solar consists of some 13% of total installed capacity by 2050. Wind and biomass generation developments occur in line with our understanding of government plans making contributions to the BAU's renewable energy target with some 19 GW and 3 GW of installed capacity by 2050 respectively.

Figure 40 Viet Nam Installed Capacity (BAU, MW)

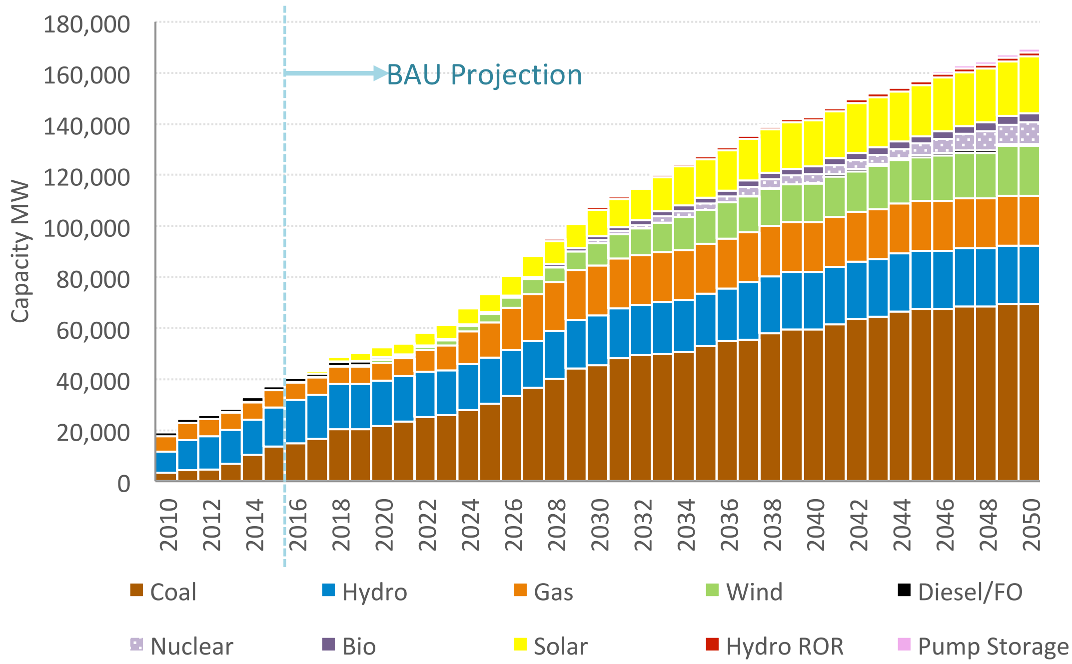


Figure 41 Viet Nam Installed Capacity Mix Percentages (BAU, %)

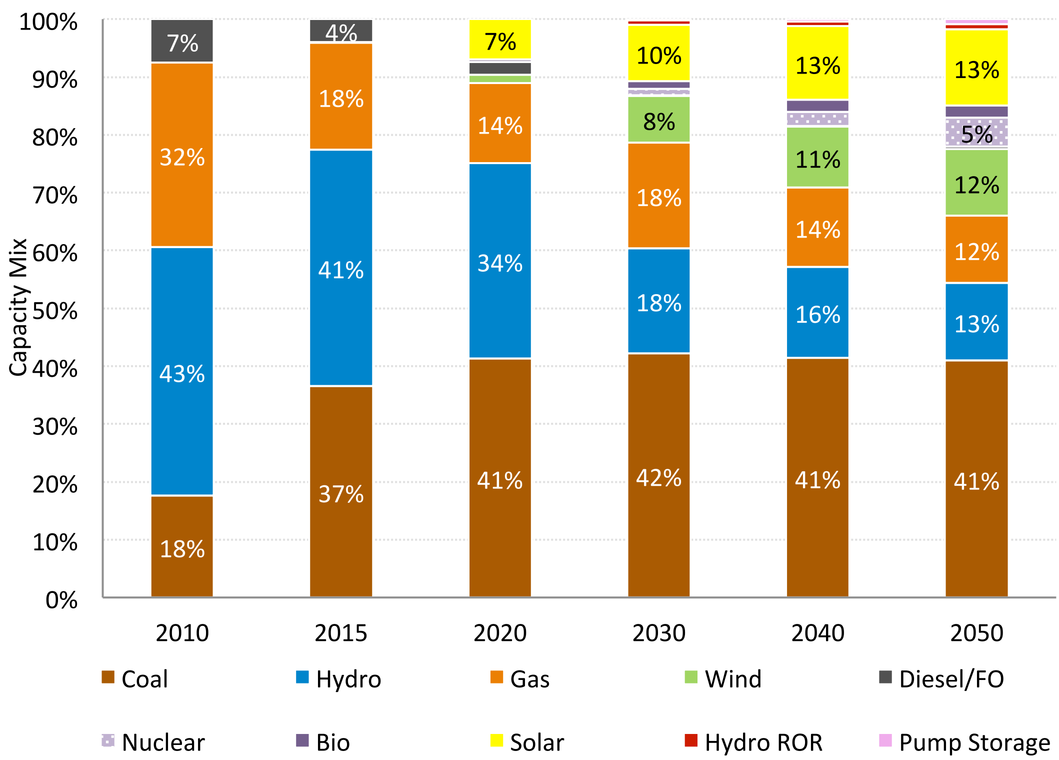


Table 9 Viet Nam Capacity (MW) by Type (BAU, MW)

Resource	2010	2015	2020	2030	2040	2050
Coal	3,360	13,605	21,640	45,438	59,438	69,438
Diesel	330	150	150	0	70	699
Fuel Oil	1,096	1,334	1,004	72	72	142
Gas	6,092	6,839	7,229	19,589	19,589	19,589
Nuclear	0	0	0	1,200	3,500	8,500
Hydro	8,200	15,175	17,688	19,529	22,509	22,775
Onshore Wind	0	50	771	8,721	15,121	19,521
Offshore Wind	0	0	0	0	0	0
Biomass	0	0	255	1,455	2,955	3,455
Biogas	0	0	0	0	0	0
Solar	0	0	3,623	10,423	18,223	22,423
CSP	0	0	0	0	0	0
Battery	0	0	0	0	0	0
Hydro ROR	0	0	0	900	1,200	1,500
Geothermal	0	0	0	0	0	0
Pump Storage	0	0	0	200	583	1,417
Ocean	0	0	0	0	0	0

Table 10 Viet Nam Capacity Share by Type (BAU, %)

Resource	2010	2015	2020	2030	2040	2050
Coal	18%	37%	41%	42%	41%	41%
Diesel	2%	0%	0%	0%	0%	0%
Fuel Oil	6%	4%	2%	0%	0%	0%
Gas	32%	18%	14%	18%	14%	12%
Nuclear	0%	0%	0%	1%	2%	5%
Hydro	43%	41%	34%	18%	16%	13%
Onshore Wind	0%	0%	1%	8%	11%	12%
Offshore Wind	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	0%	1%	2%	2%
Biogas	0%	0%	0%	0%	0%	0%
Solar	0%	0%	7%	10%	13%	13%
CSP	0%	0%	0%	0%	0%	0%
Battery	0%	0%	0%	0%	0%	0%
Hydro ROR	0%	0%	0%	1%	1%	1%
Geothermal	0%	0%	0%	0%	0%	0%
Pump Storage	0%	0%	0%	0%	0%	1%
Ocean	0%	0%	0%	0%	0%	0%

5.4 Projected Generation Mix

Figure 42 plots the generation mix (on an as generated basis[49]) over time in the BAU case and Figure 43 charts the corresponding percentage shares. Table 11 and Table 12 show the generation share by snapshot year to 2050. Generation reflects additional generation required to export power to Cambodia from 2025 onwards.

Over time the share in generation for coal increases markedly from 20 TWh in 2015 to 306 TWh in 2030 before doubling to 497 TWh by 2050, in line with the significant increases in capacity consistent with the current power planning in Viet Nam. The majority of the coal to power these plants is imported from Indonesia and Australia increasing Viet Nam's dependency on importing primary energy from other countries and linking fuel prices more closely in Viet Nam to those of international fuel markets. Hydro generation increases three-fold to 88 TWh, the result of the hydro projects presently under construction in Viet Nam, hydro projects in Lao PDR[50] that are dedicated to exporting power to Viet Nam, and a number of pumped storage hydro projects. Gas-fired generation also increases albeit at a slower pace. As noted earlier, in the BAU Viet Nam exploits all of its offshore natural gas reserves and develops LNG regasification and import facilities to back-fill power projects, again linking fuel pricing in Viet Nam to international prices and increasing the country's dependence for primary energy on global markets.

As renewable capacity increases, the generation share slowly picks up from approximately less than 1% in 2015, to about 11% by 2030, and 14% by 2050. In 2050, biomass generation accounts for some 3%, solar PV 5% and wind 6% of the system total.

[49] Unless otherwise stated, all generation charts and statistics in this report are presented on an "as generated" basis, meaning that generation to cover generator's auxiliary consumption accounted for.
[50] Xekaman 1, Xekaman 3, and Xekaman 4. These projects are expected to supply Vietnam 80% of their generation.

Figure 42 Viet Nam Generation Mix (BAU, GWh)

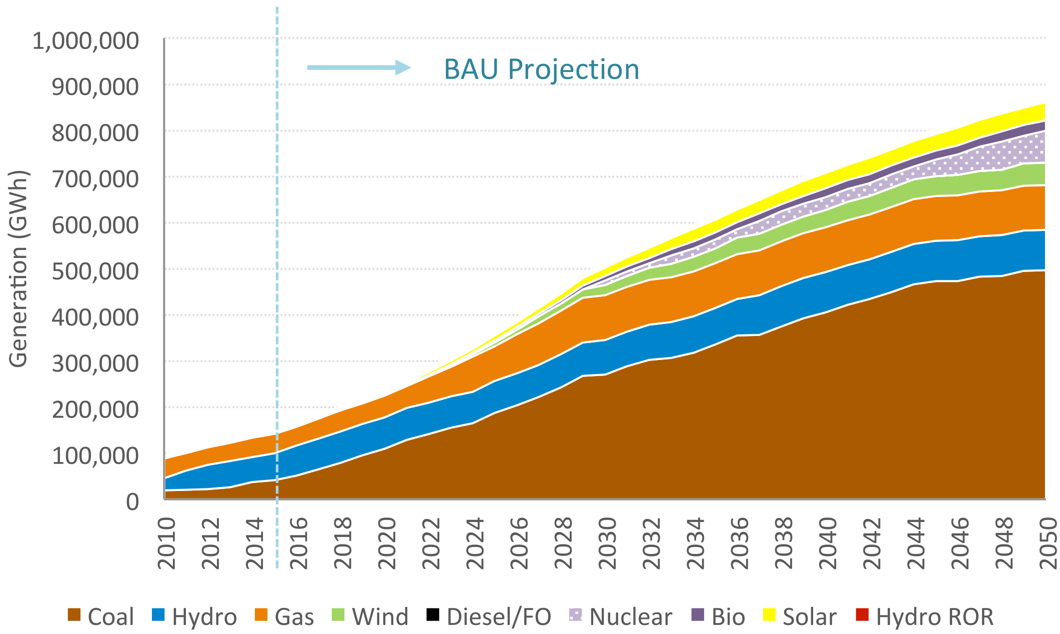


Figure 43 Viet Nam Generation Mix Percentages (BAU, %)

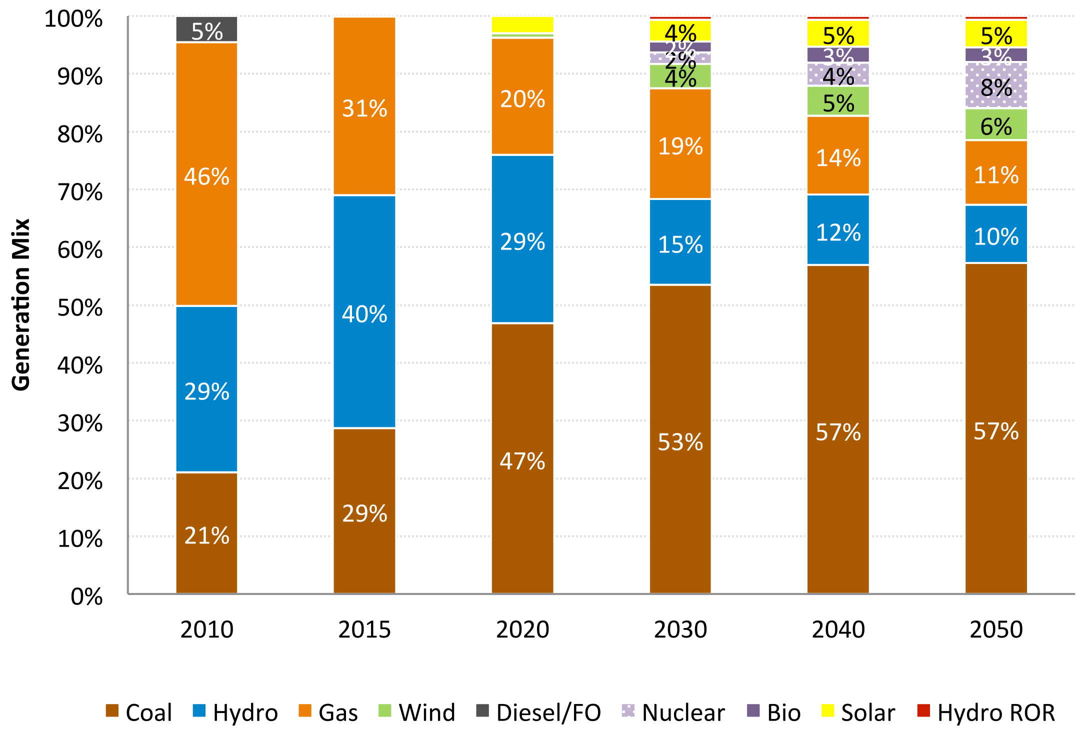


Table 11 Viet Nam Generation by Type (BAU, GWh)

Generation	2010	2015	2020	2030	2040	2050
Coal	19,500	41,755	109,714	270,890	405,355	496,786
Diesel	0	0	0	0	0	1
Fuel Oil	4,160	0	0	0	0	0
Gas	42,200	44,932	47,495	97,164	97,169	97,170
Nuclear	0	0	0	9,750	28,441	68,927
Hydro	26,560	58,491	68,177	75,271	86,757	87,782
Onshore Wind	0	125	1,930	21,605	37,359	48,256
Offshore Wind	0	0	0	0	0	0
Biomass	0	0	0	9,557	19,465	22,697
Biogas	0	0	0	0	0	0
Solar	0	0	6,915	18,985	33,302	40,885
CSP	0	0	0	0	0	0
Hydro ROR	0	0	0	3,469	4,654	5,782
Geothermal	0	0	0	0	0	0
Pump Storage	0	0	0	204	609	1,650
Ocean	0	0	0	0	0	0

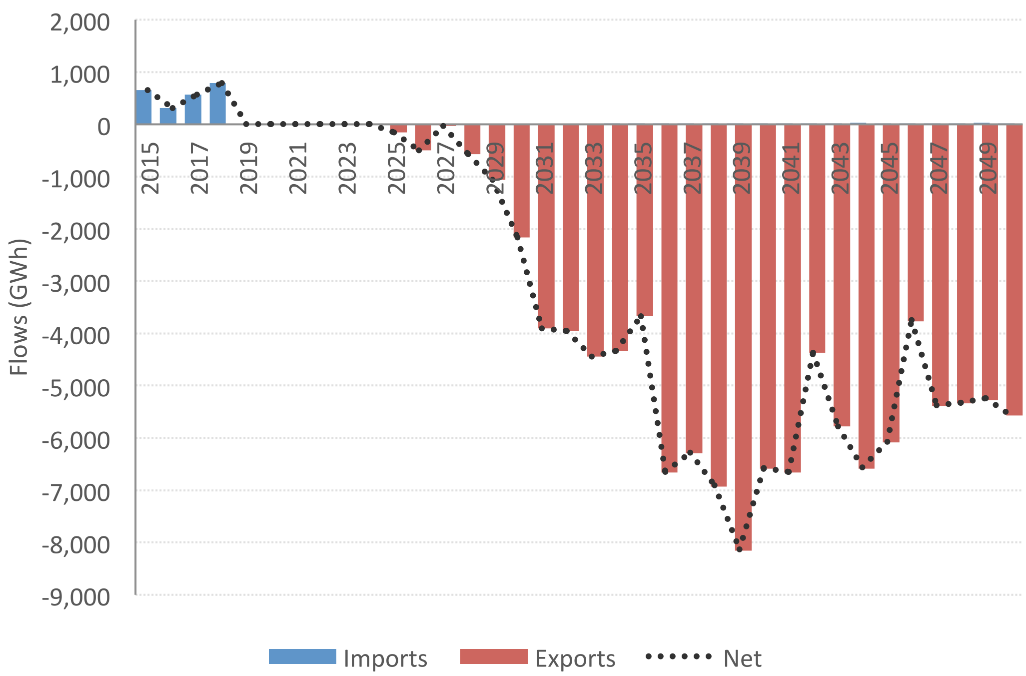
Table 12 Viet Nam Generation share by Type (BAU, %)

Generation	2010	2015	2020	2030	2040	2050
Coal	21%	29%	47%	53%	57%	57%
Diesel	0%	0%	0%	0%	0%	0%
Fuel Oil	5%	0%	0%	0%	0%	0%
Gas	46%	31%	20%	19%	14%	11%
Nuclear	0%	0%	0%	2%	4%	8%
Hydro	29%	40%	29%	15%	12%	10%
Onshore Wind	0%	0%	1%	4%	5%	6%
Offshore Wind	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	0%	2%	3%	3%
Biogas	0%	0%	0%	0%	0%	0%
Solar	0%	0%	3%	4%	5%	5%
CSP	0%	0%	0%	0%	0%	0%
Hydro ROR	0%	0%	0%	1%	1%	1%
Geothermal	0%	0%	0%	0%	0%	0%
Pump Storage	0%	0%	0%	0%	0%	0%
Ocean	0%	0%	0%	0%	0%	0%

5.5 Grid to Grid Power Flows

Figure 44 plots the imports and exports in the BAU with the dotted line representing the net interchange. Overall flows in the BAU are relatively low up to 2025 when exports into Cambodia start to increase with transmission capability (an additional 500 MW in 2030 and 2035) developed between Cambodia and southern Viet Nam. Flows into Cambodia are driven by the amount of energy limited large-scale hydro built in Cambodia[51]. Outside of the dedicated Lao PDR hydro projects, there are no significant flows between Viet Nam and Lao PDR as both countries are assumed to develop generation to sufficiently meet its own growing demands.

Figure 44 Viet Nam Imports and Exports (BAU, GWh)



5.6 Generation Fleet Structure

Figure 45 shows the installed generation capacity by the main categories of generation: fossil fuel[52], renewable and large scale hydro, in order to provide greater insight into the basic structure of installed capacity under the BAU. This highlights that Viet Nam's BAU projection is as anticipated heavily dominated by fossil-fuel based generation and conventional large-scale hydro projects. However,

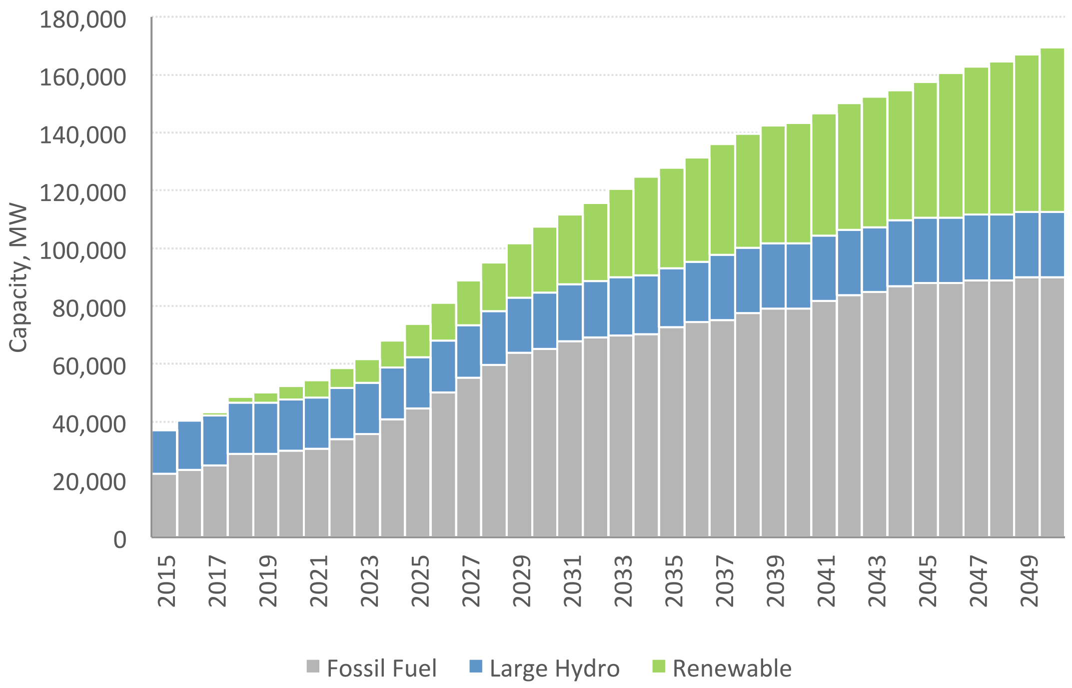
[51] The amount of energy that a hydro power station can generate depends on the size of its reservoir and the volume of water storage in the reservoir, which in turn increases with inflows to the reservoir and decreases when the hydro power station generates electricity (or water is released or spilled). The term "energy limited" means that at any point in time, based on the volume of water in the reservoir, the hydro generator would be able to generate a certain amount of electrical energy.

[52] Including power stations that run on coal, gas, fuel oil, diesel oil, and nuclear.

renewable capacity and generation increase over time. Figure 46 shows the on-grid composition of generation by major categories of generation: thermal, large hydro and renewable. As could be anticipated generation closely reflects the BAU's installed capacity mix.

To facilitate later comparison with the SES, Figure 47 plots installed capacity with capacity being distinguished between the following basic categories: (1) dispatchable capacity, (2) non-dispatchable capacity; and (3) semi-dispatchable capacity[53]. This provides some insight into the operational flexibility of the generation fleet to match demand uncertainty. The dispatchable category relates to generation that can be controlled and dispatched at short notice to ramp up or down, non-dispatchable means that the generation is not able to respond readily to dispatch instructions while the semi-dispatchable category means that the resource can respond within limits, and in particular is capable of being backed off should the need arise to for example, avoid overloading the network or "spill" energy in the event that an over generation situation emerges; solar photovoltaics and windfarms with appropriately installed control systems can be classified in this category. In the BAU, over time, as renewable generation trends towards 29% of the total installed capacity by 2050, the dispatchable percentage declines to 74% although still suggests a high level of dispatch control.

Figure 45 Viet Nam Installed Capacity by Generation Type (BAU, MW)



[53] Wind and solar are classified as semi-dispatchable, geothermal and hydro run-of-river are classified as non-dispatchable and all other technologies are classified as dispatchable.

Figure 46 Viet Nam Generation Mix by Generation Type (BAU, GWh)

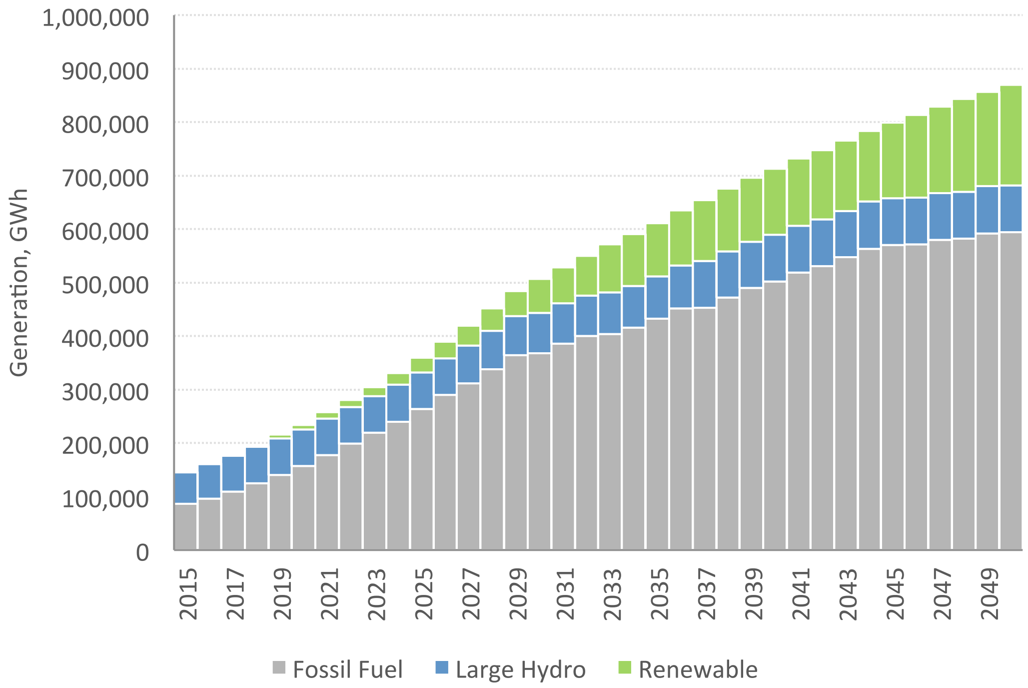
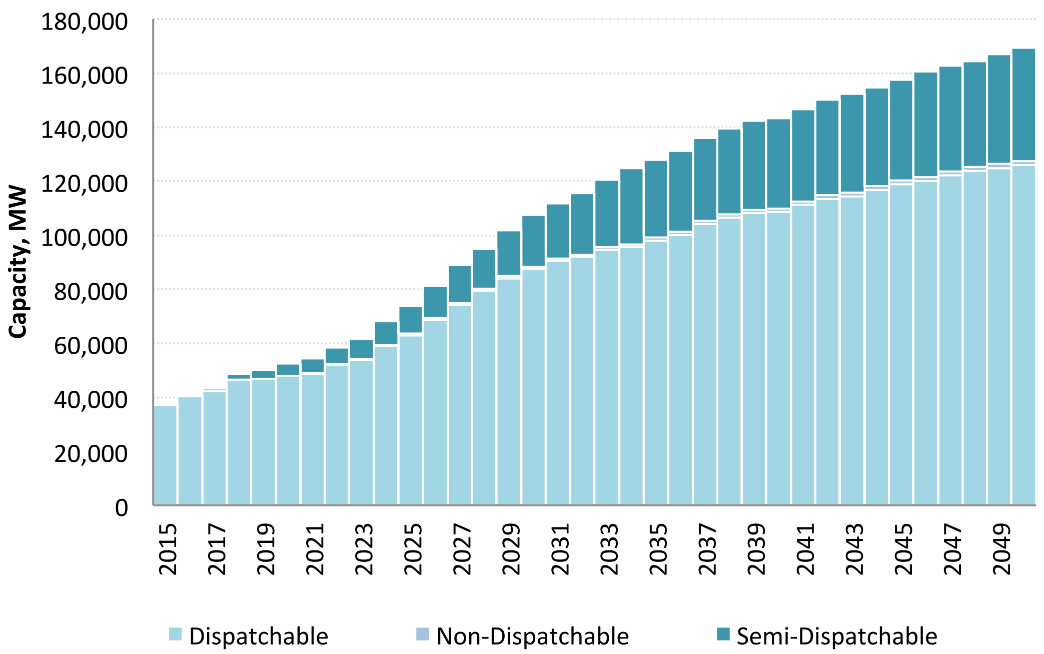


Figure 47 Viet Nam Installed Capacity by Dispatch Status (BAU, MW)



5.7 Reserve Margin and Generation Trends

Figure 48 plots the reserve margin based on nameplate capacity and annual peak demand. The Viet Nam reserve margin in the BAU hovers between 30-40% over the forecast horizon. From 2025 to 2035, as renewable capacity starts to ramp up the reserve margin increases consistent with the lower capacity factors relative to conventional technologies. Post 2035 the reserve margin stabilises as the non-hydro renewable capacity share increases slowly to 29% in 2050. Thermal capacity stays round 60% and hydro capacity declines to 14% by 2050.

To obtain a better understanding of the broad mix of generation capacity and generation mix, Figure 49 and Figure 50 show shares in installed capacity and in generation grouped by the main categories of generator: thermal, large hydro, renewable energy (RE) and large hydro plus renewable energy.

Figure 50 plots the generation shares by several different categories of generation. In the BAU the thermal based generation share increases as a result of its relatively high capacity factor compared to other generation forms and renewable energy and the type of resource mix that is allowed under the BAU. The thermal generation share increases from some 60% in 2015 to 68% by 2050. Renewable energy including large-hydro decreases from around 40% to 25% in 2030 before slowly increasing as more renewable plants enter the system – due to large-scale hydro being largely exploited and renewable energy deployment occurring in a way consistent with understood BAU plans.

Figure 48 Viet Nam Reserve Margin (BAU)

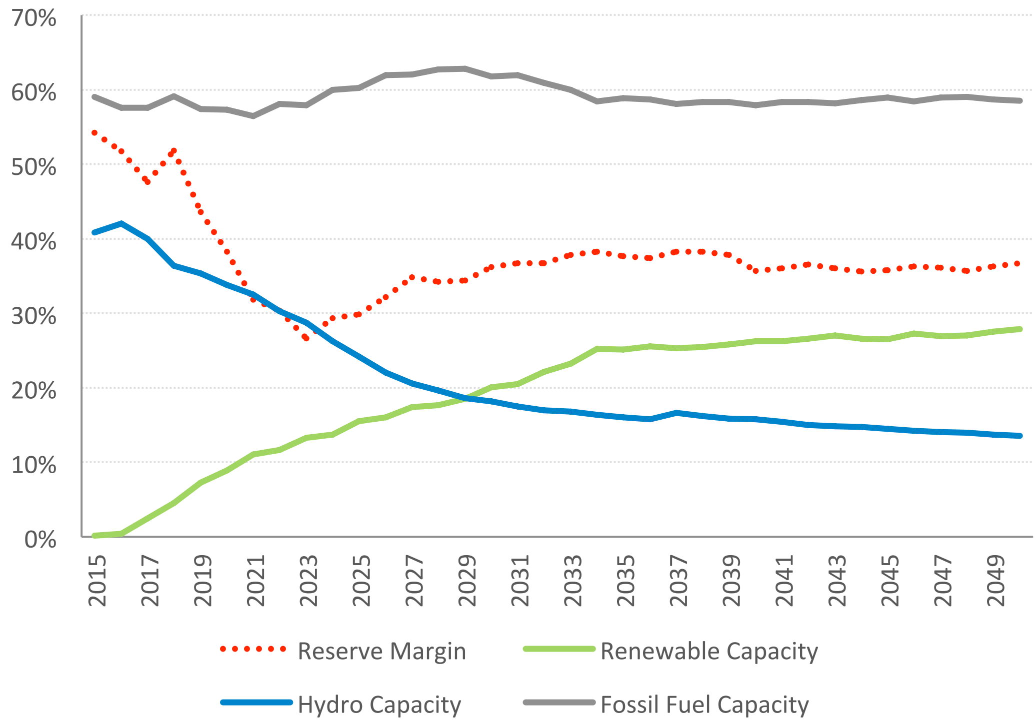


Figure 49 Viet Nam Capacity Shares by Generation Type (BAU)

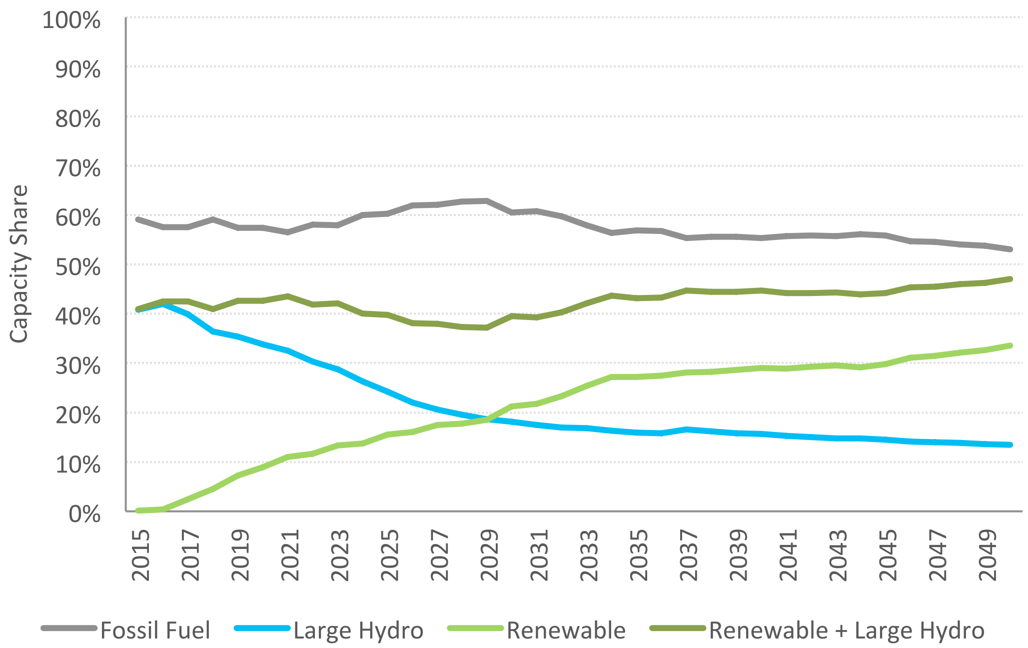
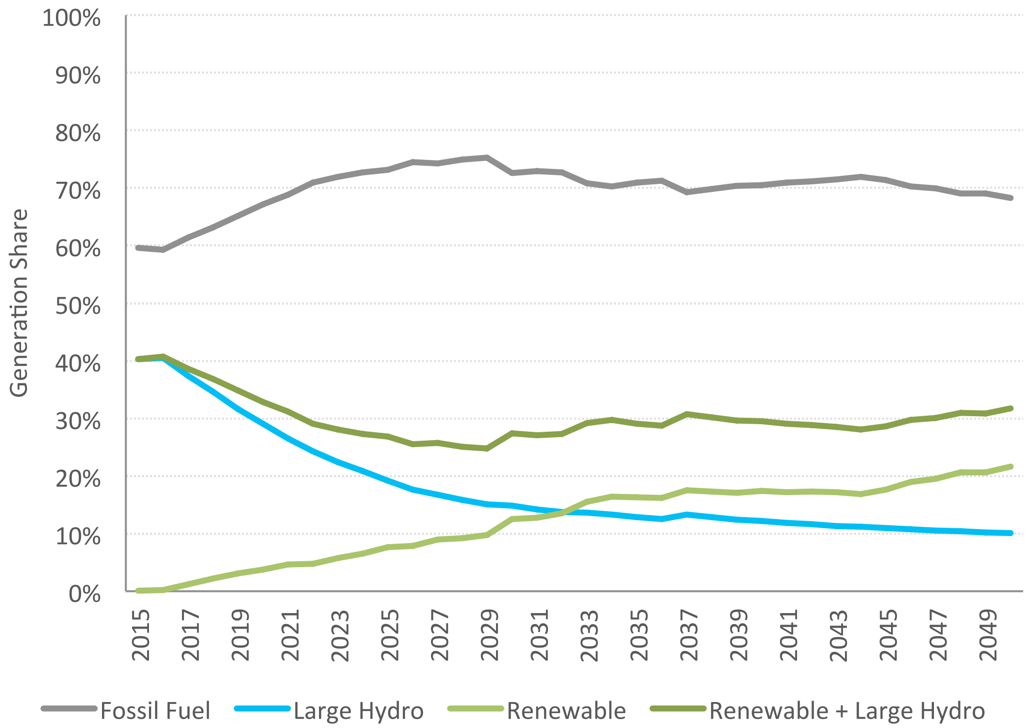


Figure 50 Viet Nam Generation Shares by Generation Type (BAU)



5.8 Electrification and Off-Grid

Viet Nam's grid electrification rate for its urban and rural population is already very close to 100% and in the BAU we have assumed that it remains this way.

6 Sustainable Energy Sector Scenario

6.1 Sustainable Energy Sector Scenario

As noted earlier, Viet Nam has experienced a period of very high demand growth in the recent past and this has placed pressure on the Government to formulate appropriate plans to ensure that the electricity industry can continue to provide a stable supply of electricity to end users, thereby ensuring the country's economy can continue to expand. As outlined in section 3, Viet Nam has a wide range of options that can be exploited. The strategy adopted in the BAU was based largely on the development of fossil fuel options, a limited number of resources in neighbouring Lao PDR and Cambodia to export power to Viet Nam, minimise further exploitation of large scale hydro resources within Viet Nam as it is considered to be an exhausted resource, and make some progress in terms of integration of renewable energy into the national power system and to enhance energy efficiency. In contrast to the BAU scenario, the SES seeks to transition electricity demand towards the best practice benchmarks of other developed countries in terms of energy efficiency, maximise the renewable energy development, cease the development of fossil fuel resources, and make sustainable and prudent use of undeveloped conventional hydro resources. The SES takes advantage of existing, technically proven and commercially viable renewable energy technologies.

6.2 Projected Demand Growth

Figure 51 plots Viet Nam's forecast energy consumption from 2015 to 2050 with the BAU trajectory charted with a dashed line for comparison. The energy savings are due to allowing Viet Nam's energy demand to transition towards energy intensity benchmarks of comparable developed countries in Asia[54]. The SES demand grows at a slower rate of 4.0% pa over the period from 2015 to 2050 with the commercial sector at 6.3% pa, industry growing at 4.3% pa and residential sector growing at 1.3% pa. Uptake of electric transport options occur from 2025 onwards and grows to 28 TWh accounting for 5% of total demand by 2050, or 20% of all vehicles.

Figure 52 plots peak demand of Viet Nam. The firm blue line represents peak demand before any flexible demand side resources have been scheduled[55]. Flexible demand response is "dispatched" in the model in line with the least cost dispatch of all resources in the power system. The dashed line represents what peak demand became as a consequence of scheduling ("time-shifting")

[54] Vietnam's industrial intensity was trended towards levels commensurate with South Korea (2014) by 2035 and allowed to decline at the same rate to 2050.

[55] Flexible demand response is "dispatched" in the model in line with the least cost dispatch of all resources. The solid line represents peak demand as put in the model, while the dashed line represents what peak demand ended up being as a consequence of shifting demand from one period of time to another. This includes scheduling of loads associated with battery storage devices and rescheduling (time-shifting) commercial, industrial and residential loads.

commercial, industrial and residential loads to minimise system costs. From 2020, the amount of flexible demand was assumed to grow to 10% of total demand across all sectors by 2050, or 15% if storage methods are included. The load factor associated with the SES was also assumed to reach 80% by 2030 compared to 80% by 2050 in the BAU as a further consequence of enhanced demand side management measures relative.

Key drivers for demand growth and the demand projections are summarised in Table 13.

Figure 51 Viet Nam Projected Electricity Demand (2015-2050, SES)

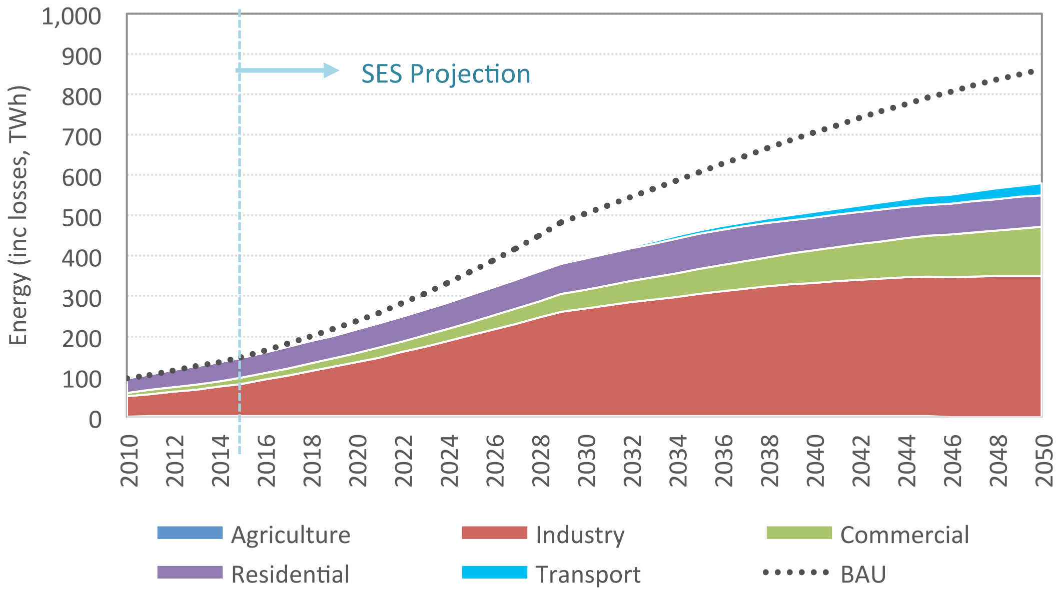


Figure 52 Viet Nam Projected Electricity Demand (SES, MW)

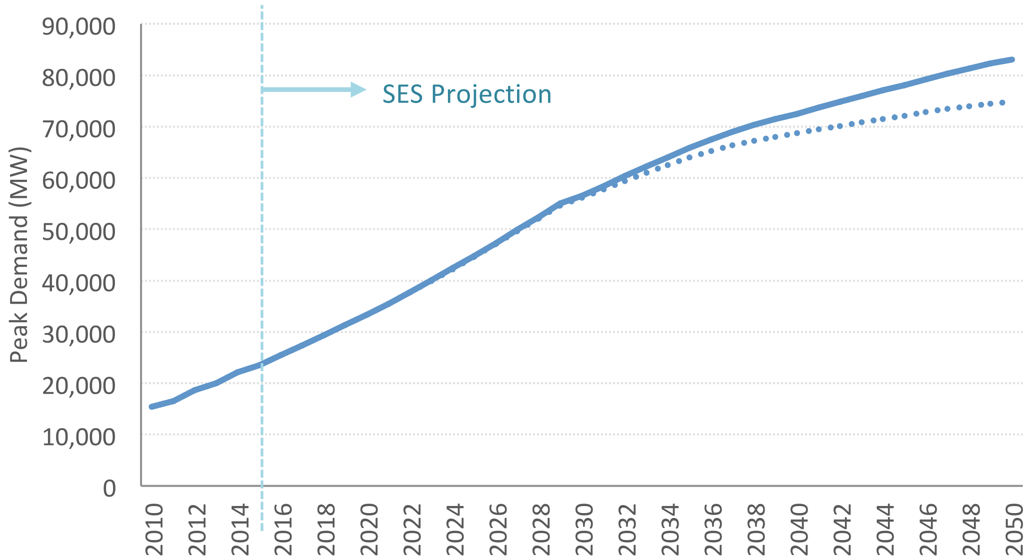


Table 13 Viet Nam Demand and Demand Drivers (SES)

No.	Aspect	2015-30	2030-40	2040-50
1	Demand Growth (pa)	6.1%	2.5%	1.4%
2	GDP Growth (Real, pa)	6.8%	4.9%	2.9%
3	Electrification Rate (Population)	98.2%	98.8%	99.1%
4	Population Growth	0.60%	0.23%	-0.04%
5	Per Capita Consumption (kWh)	2,164	3,889	5,007
6	Electricity Elasticity*	3.88	1.80	1.29
7	Electricity Intensity (Demand/GDP)	0.400	0.457	0.441

* Electricity elasticity is calculated as the electricity demand growth divided by the population growth over the same period

6.3 Installed Capacity Development

Figure 53 plots the installed capacity developments under the SES and Figure 54 plots the corresponding percentage shares. Table 14 and Table 15 provide the statistical details of the installed capacity and capacity shares by type including the 2010 levels.

Committed and existing plants are assumed to come online as per the BAU but aren't replaced when retired. Planned and proposed thermal and large-scale hydro developments are assumed to not occur[56] as all future loads are instead met by renewable technologies. Coal and gas fired-generation in the earlier years is very similar to the BAU due to committed projects. Over time, fossil fuel-based technologies drop off due to plant retirements and account for a combined total of

[56] Exceptions may be made for additional diesel developments to satisfy reliability issues.

8% of total installed capacity by 2050 compared to 58% in 2015. Large-hydro penetration also decreases with planned large-scale hydro replaced with renewable energy.

Timing of renewable energy developments are based on the maturity of the technology and judgments of when it could be readily deployed in Viet Nam. Additional demand in the SES is predominantly met by renewables with 148 GW required to meet 2050 electricity demand from a small capacity base of large-scale and grid connected to some 54 GW of solar, CSP 17 GW, 12 GW of bioenergy and 28 GW of wind resources by 2050. Battery storage of 30 GW equivalent is also developed in conjunction with the significant solar PV capacity to support off-peak requirements. Small amounts of run-of-river hydro, ocean energy and geothermal are also developed in the later stages.

Figure 53 Viet Nam Installed Capacity by Type (SES, MW)

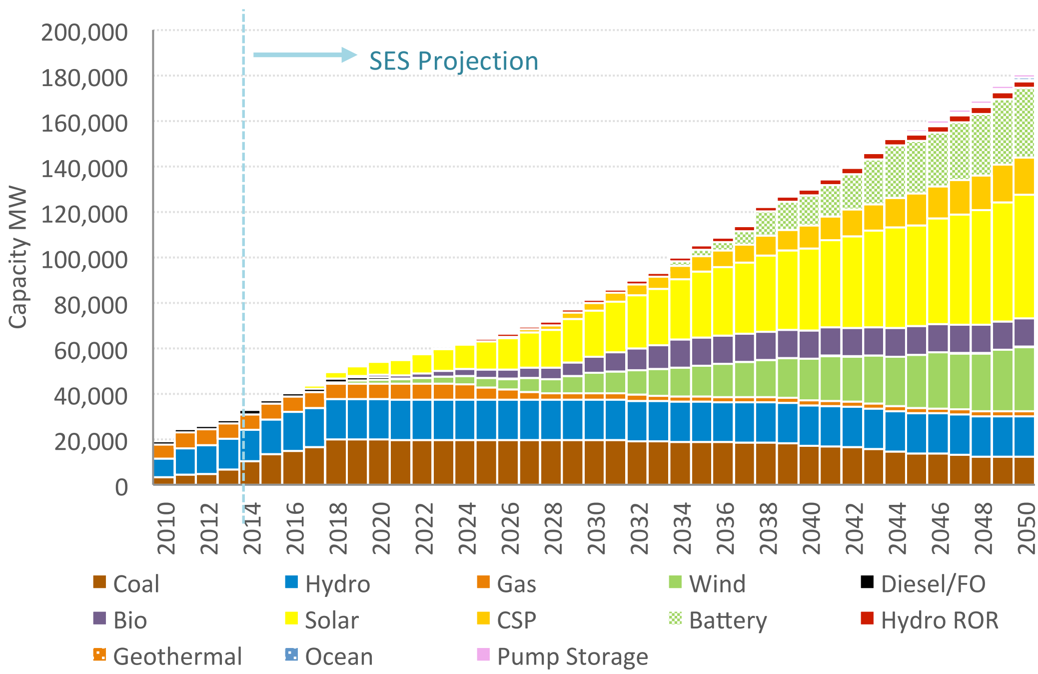


Figure 54 Viet Nam Capacity Shares (SES, %)

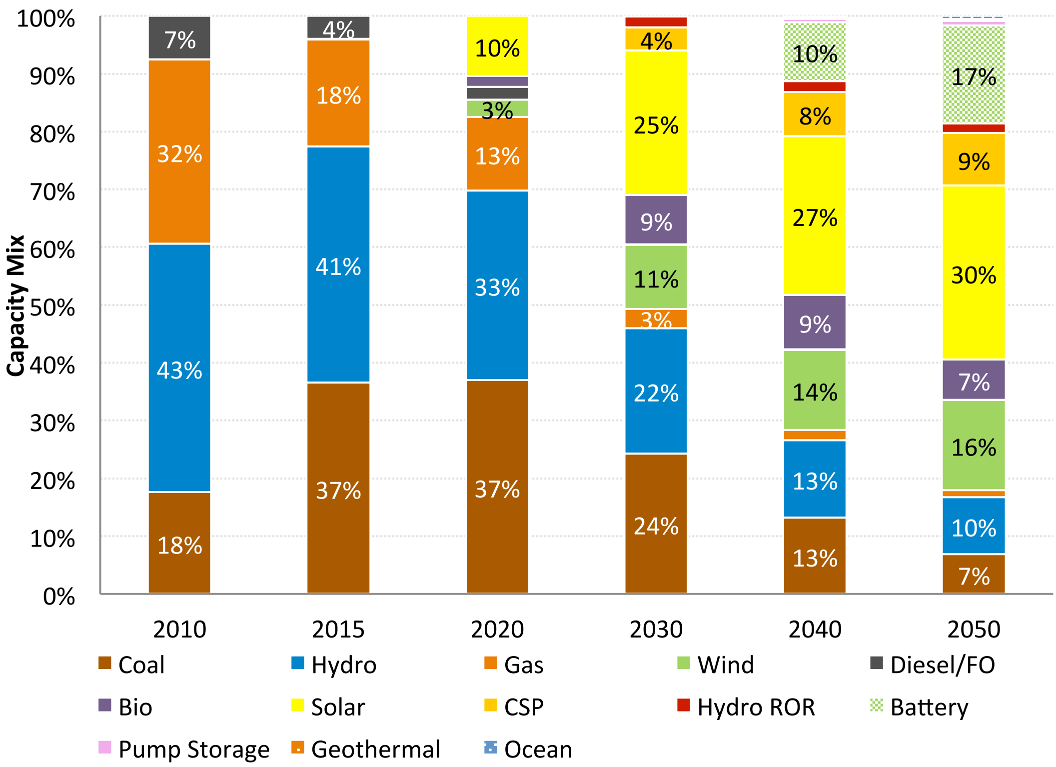


Table 14 Viet Nam Capacity by Type (SES, MW)

Resource	2010	2015	2020	2030	2040	2050
Coal	3,360	13,605	20,000	19,790	17,260	12,450
Diesel	330	150	150	0	0	0
Fuel Oil	1,096	1,334	1,004	72	72	72
Gas	6,092	6,839	6,839	2,700	2,250	2,250
Nuclear	0	0	0	0	0	0
Hydro	8,200	15,175	17,688	17,688	17,688	17,688
Onshore Wind	0	50	1,650	8,910	16,198	20,586
Offshore Wind	0	0	0	90	2,002	7,614
Biomass	0	0	1,055	6,086	8,085	8,085
Biogas	0	0	0	869	4,370	4,370
Solar	0	0	5,579	20,379	35,979	54,379
CSP	0	0	0	3,300	10,050	16,500
Battery	0	0	0	0	13,440	30,499
Hydro ROR	0	0	0	1,500	2,400	3,000
Geothermal	0	0	0	75	300	450
Pump Storage	0	0	0	0	600	1,500
Ocean	0	0	0	0	450	1,050

Table 15 Viet Nam Capacity Share by Type (SES, %)

Resource	2010	2015	2020	2030	2040	2050
Coal	18%	37%	37%	24%	13%	7%
Diesel	2%	0%	0%	0%	0%	0%
Fuel Oil	6%	4%	2%	0%	0%	0%
Gas	32%	18%	13%	3%	2%	1%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	43%	41%	33%	22%	13%	10%
Onshore Wind	0%	0%	3%	11%	12%	11%
Offshore Wind	0%	0%	0%	0%	2%	4%
Biomass	0%	0%	2%	7%	6%	4%
Biogas	0%	0%	0%	1%	3%	2%
Solar	0%	0%	10%	25%	27%	30%
CSP	0%	0%	0%	4%	8%	9%
Battery	0%	0%	0%	0%	10%	17%
Hydro ROR	0%	0%	0%	2%	2%	2%
Geothermal	0%	0%	0%	0%	0%	0%
Pump Storage	0%	0%	0%	0%	0%	1%
Ocean	0%	0%	0%	0%	0%	1%

6.4 Projected Generation Mix

Grid generation is plotted in Figure 55 and Figure 56[57]. The corresponding statistics for snapshot years are provided in Table 16 and Table 17. Viet Nam's generation mix in the earlier years to 2020 is similar to the BAU case as committed new generation projects are commissioned and this has largely been kept the same. A notable difference is that there is an increase in wind and solar projects from 2016. Further non-renewable developments beyond 2019 cease; gas and coal-fired generation levels decline as units are retired while large-scale hydro generation continues at current levels into the future, but the share of hydro generation decreases as there is no further large scale hydro development.

Of the renewable technologies, by 2050, solar PV contributes the highest generation share (99 TWh) followed by CSP (82 TWh), bioenergy split between biomass and biogas (86 TWh), then onshore and offshore wind (69 TWh). Smaller contributions come from geothermal, ocean/marine energy and run-of-river hydro. By 2050 new renewable energy sources (excluding large-scale hydro) make up some 68% of the total generation requirement, or 81% including large-scale hydro.

[57] Battery storage is not included as they are generation neutral (before efficiency losses).

Figure 55 Viet Nam Generation Mix (SES, GWh)

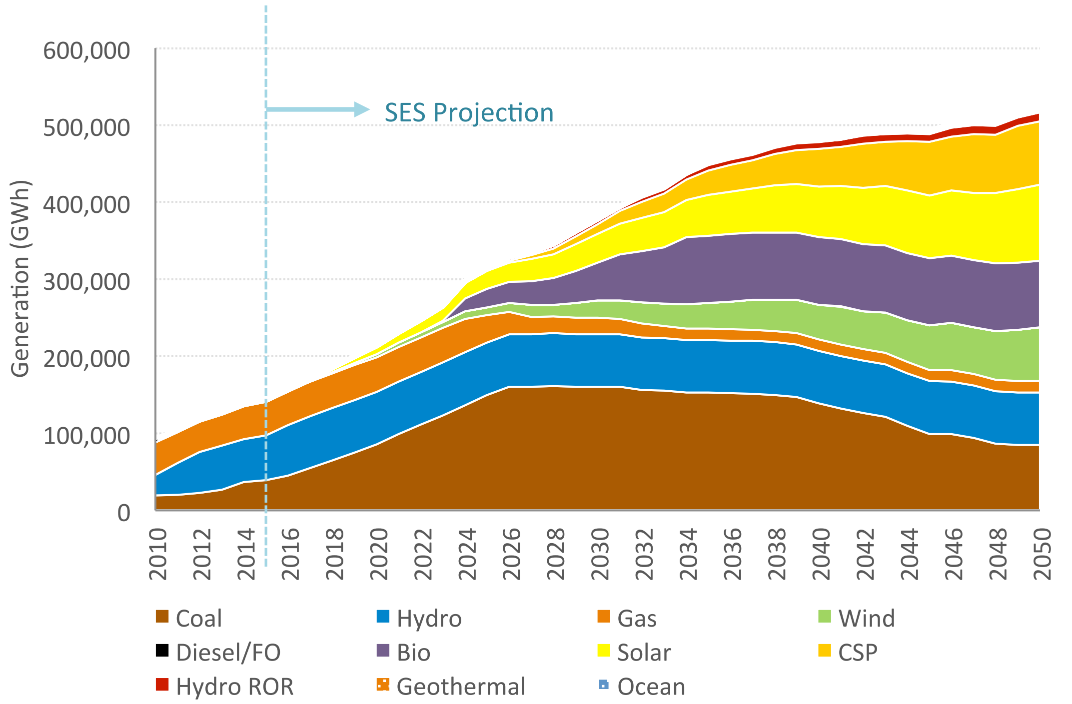


Figure 56 Viet Nam Generation Mix (SES, %)

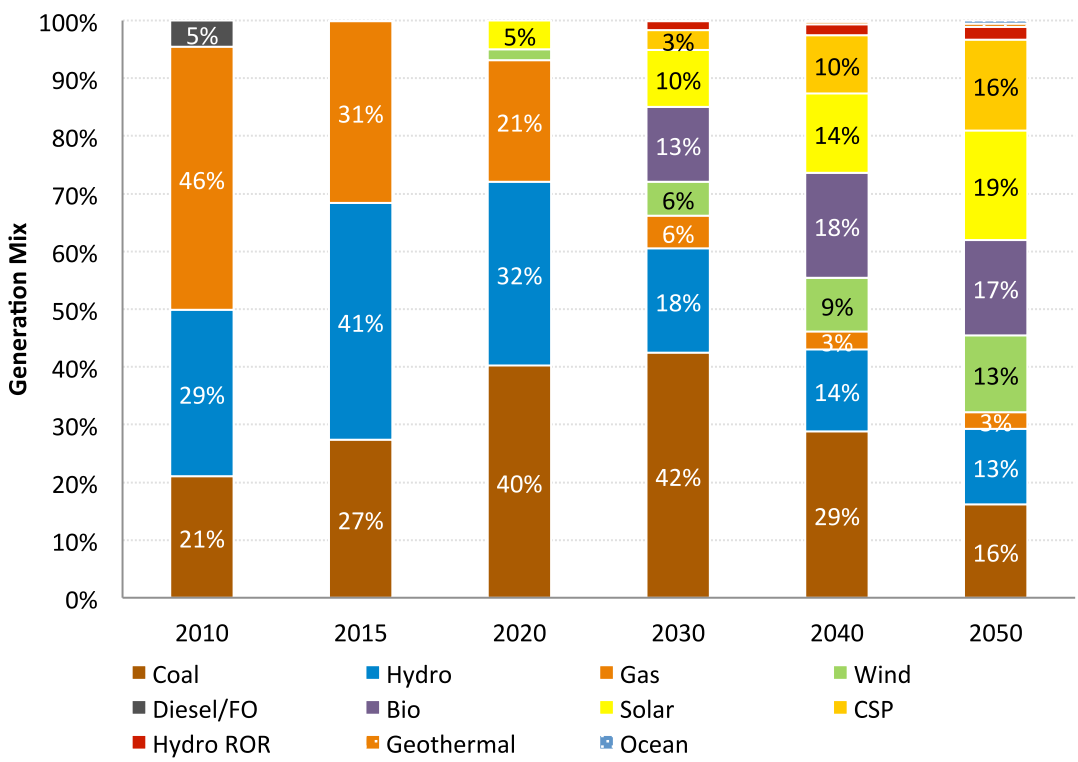


Table 16 Viet Nam Generation by Fuel (SES, GWh)

Generation	2010	2015	2020	2030	2040	2050
Coal	19,500	39,130	85,925	160,405	138,944	84,675
Diesel	0	0	0	0	0	0
Fuel Oil	4,160	0	0	0	147	0
Gas	42,200	44,932	44,932	21,564	14,783	14,783
Nuclear	0	0	0	0	0	0
Hydro	26,560	58,491	68,177	68,177	68,177	68,177
Onshore Wind	0	125	4,131	22,073	40,020	50,888
Offshore Wind	0	0	0	223	4,946	18,822
Biomass	0	0	0	42,648	56,812	56,106
Biogas	0	0	0	6,093	30,712	30,330
Solar	0	0	10,571	37,399	66,030	99,022
CSP	0	0	0	13,000	48,538	82,032
Hydro ROR	0	0	0	5,782	9,308	11,563
Geothermal	0	0	0	491	1,976	2,970
Pump Storage	0	0	0	0	476	1,568
Ocean	0	0	0	0	1,186	2,759

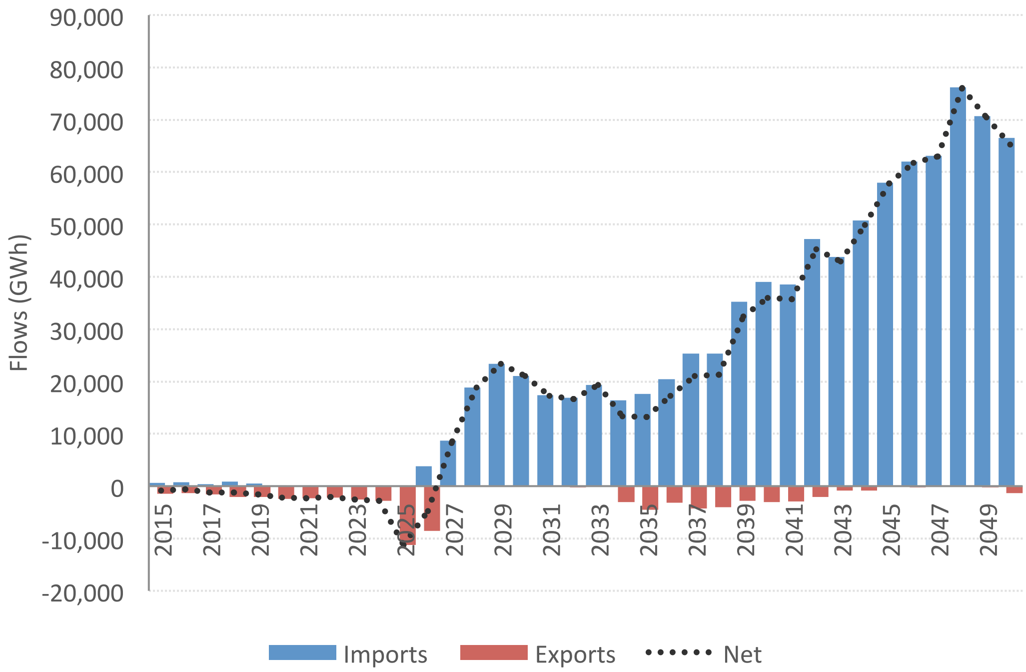
Table 17 Viet Nam Generation Share by Fuel (SES, %)

Generation	2010	2015	2020	2030	2040	2050
Coal	21%	27%	40%	42%	29%	16%
Diesel	0%	0%	0%	0%	0%	0%
Fuel Oil	5%	0%	0%	0%	0%	0%
Gas	46%	31%	21%	6%	3%	3%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	29%	41%	32%	18%	14%	13%
Onshore Wind	0%	0%	2%	6%	8%	10%
Offshore Wind	0%	0%	0%	0%	1%	4%
Biomass	0%	0%	0%	11%	12%	11%
Biogas	0%	0%	0%	2%	6%	6%
Solar	0%	0%	5%	10%	14%	19%
CSP	0%	0%	0%	3%	10%	16%
Hydro ROR	0%	0%	0%	2%	2%	2%
Geothermal	0%	0%	0%	0%	0%	1%
Pump Storage	0%	0%	0%	0%	0%	0%
Ocean	0%	0%	0%	0%	0%	1%

6.5 Grid to Grid Power Flows

Figure 57 plots the imports and exports in the BAU with the dotted line representing the net interchange. Due to the significant demand growth in Viet Nam relative to the other GMS countries and limitations on renewable resource potential, Viet Nam requires power generated from Lao PDR and Thailand via Cambodia to support up to 10% of its power requirements. By the late 2040's up to 76,000 GWh is traded across the Lao PDR and Cambodia borders.

Figure 57 Viet Nam Imports (positive) and Exports (negative) (SES, GWh)



6.6 Generation Fleet Structure

As for the BAU, to gain insight into the nature of the mix of generation technologies deployed in the SES, we present a number of additional charts. Figure 58 and Figure 59 show Viet Nam's installed capacity by generation type for the SES – this is clearly heavily biased towards renewable generation forms and there is a steady reduction in the thermal power plants. For Viet Nam, a considerable amount of non-renewable energy continues to feature in the generation mix and relates to the significant early investment in coal-fired projects which have project lives of 30 years and the long-term nature of existing large-scale hydro projects.

Figure 60, shows the dispatchable, semi-dispatchable and non-dispatchable components of installed capacity and it can be seen that semi-dispatchable increases to around 54% of the total system capacity compared to around 26% in the BAU by 2050. Based on operational simulations with this resource mix, it appears to be operationally feasible. The reliance on generation forms that provide storage and having flexibility in the demand side play important roles. It is clear that short-term renewable energy solar and wind forecasting systems will be important, as will real-time updates on demand that can be controlled. Furthermore, control systems that can allow the dispatch of flexible resources on both supply and demand sides of the industry will be required.

Figure 58 Viet Nam Installed Capacity by Generation Type (SES, MW)

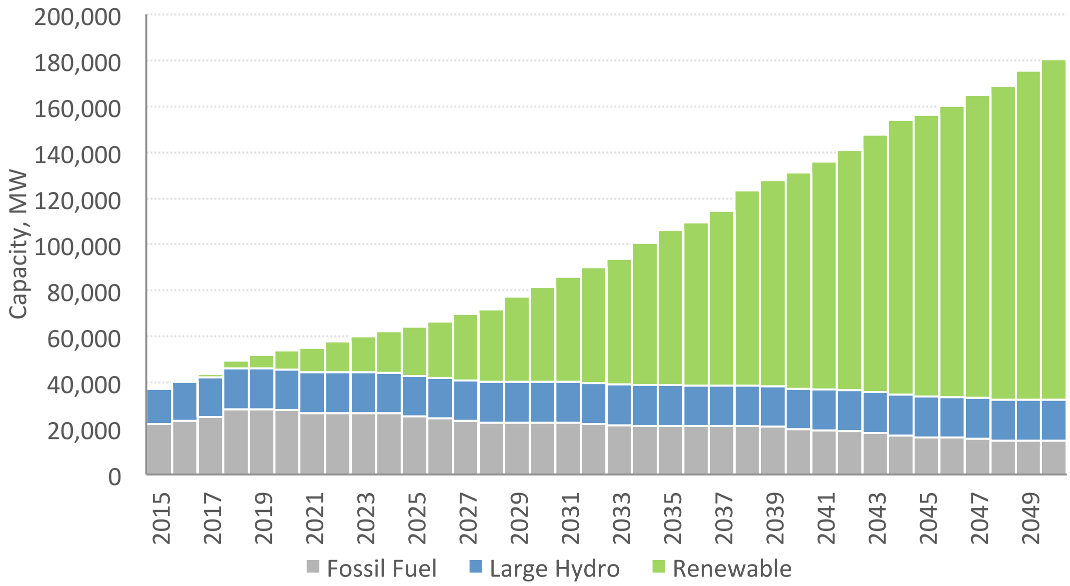


Figure 59 Viet Nam Generation Mix by Generation Type (SES, GWh)

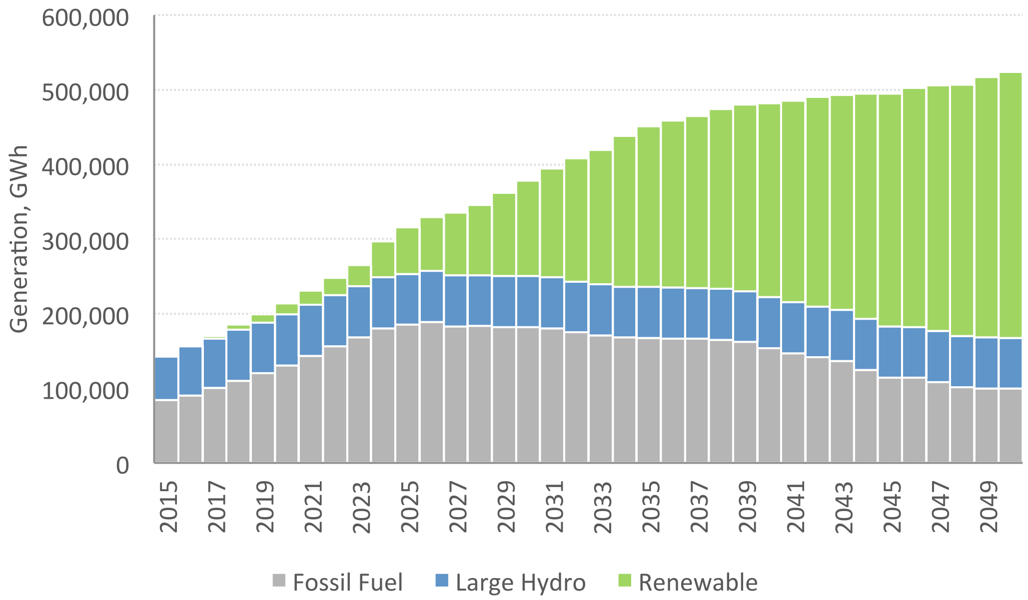
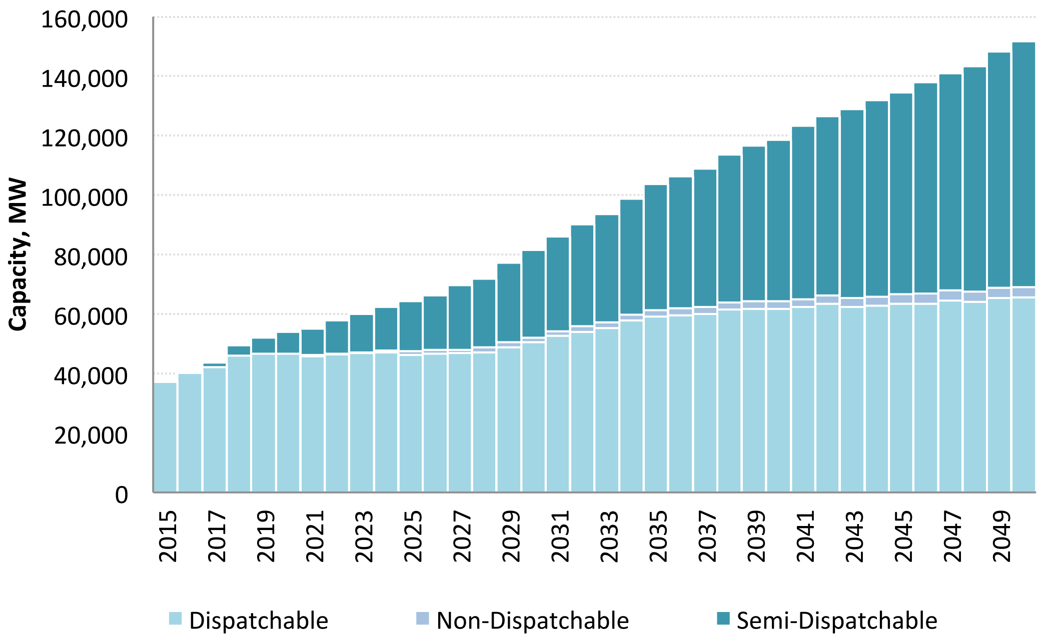


Figure 60 Viet Nam Installed Capacity by Dispatch Status (SES, MW)



6.7 Reserve Margin and Generation Trends

Figure 61 plots the reserve margin under the SES. Figure 62 and Figure 63 respectively show the installed capacity mix and generation mix for different categories of generation in the power system. The reserve margin in the SES increases towards 80% by 2050 as installed renewable capacity increases to almost 80% of the mix. Conventional reserve margin measures are generally not suited to measuring high renewable energy systems in the same context used for thermal-based systems. Renewable technologies generally have much lower capacity factors and require more capacity to meet the same amount of energy produced from thermal-based technologies.

Figure 61 Viet Nam Reserve Margin (SES)

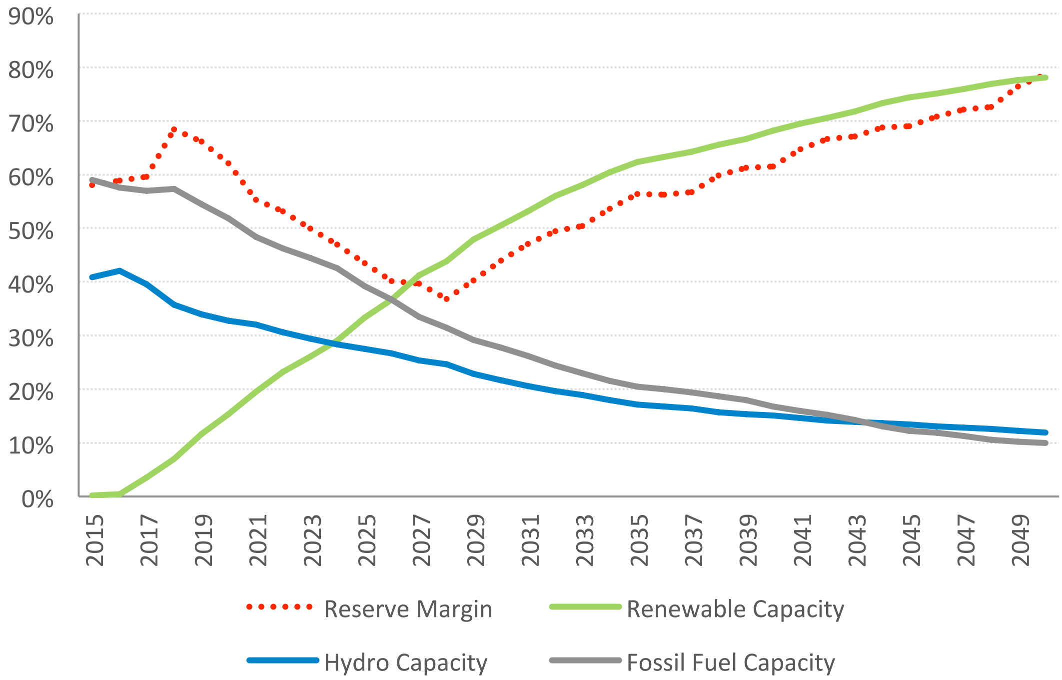


Figure 62 Viet Nam Installed Capacity Shares for SES by Generation Type

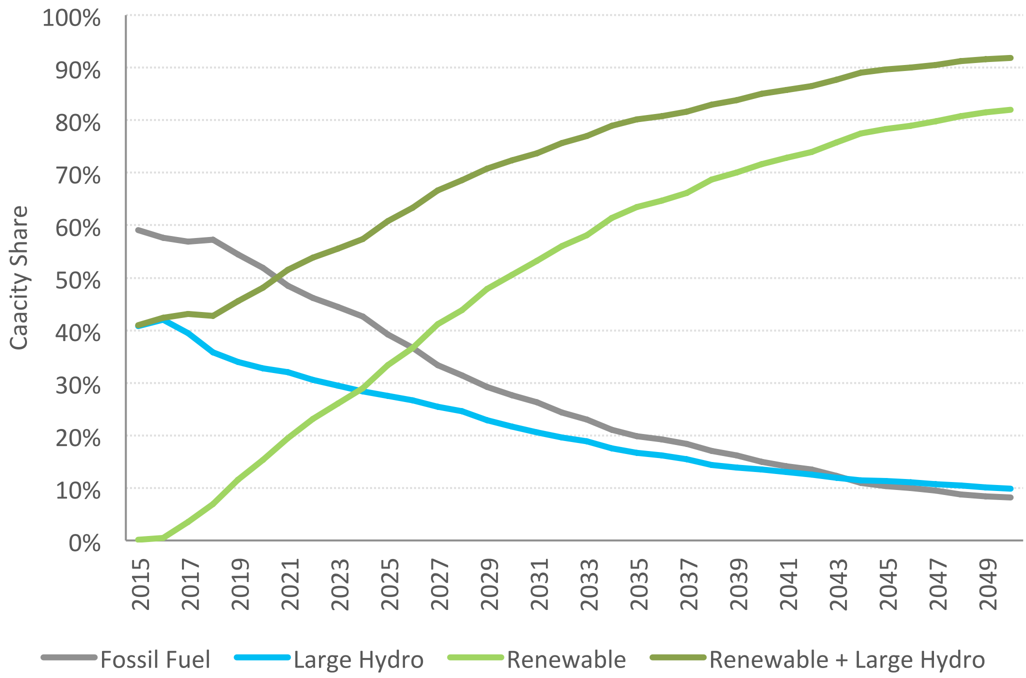
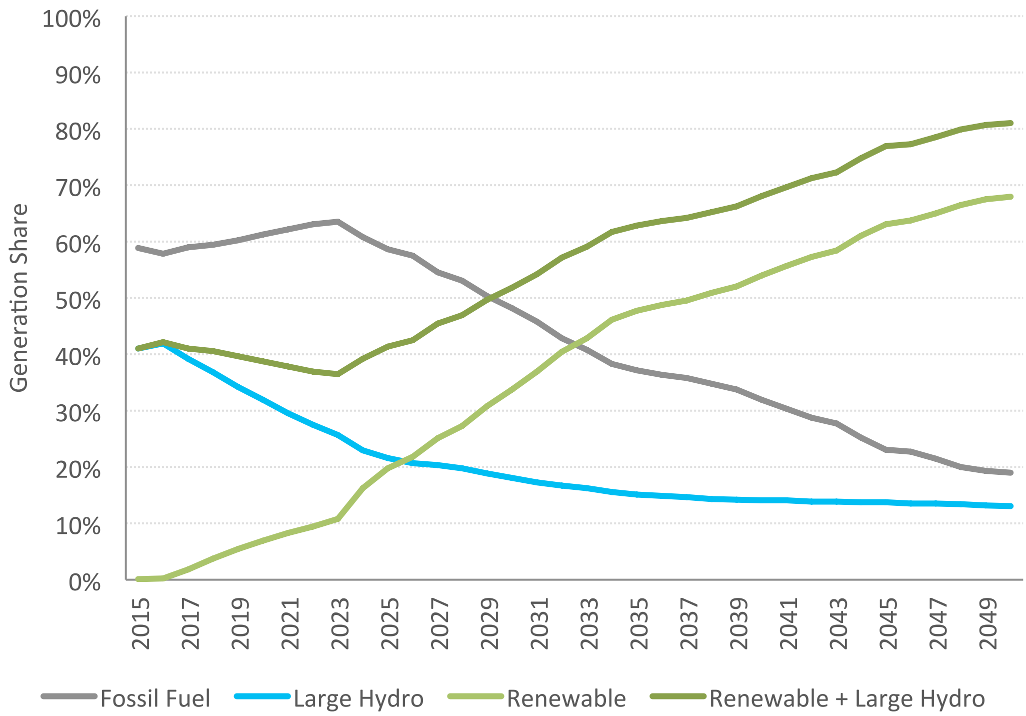


Figure 63 Viet Nam Generation Shares for SES by Generation Type



6.8 Electrification and Off-Grid

Most of Viet Nam is already electrified and as per the BAU in the SES we have assumed that the grid remains centrally interconnected into the future.

7 Advanced Sustainable Energy Sector Scenario

7.1 Advanced Sustainable Energy Sector Scenario

The ASES assumes that the power sector is able to more rapidly transition towards a 100% renewable energy technology mix under an assumption that renewable energy is deployed more than in the SES scenario with renewable energy technology costs declining more rapidly compared to BAU and SES scenarios.

7.2 Projected Demand Growth

Figure 64 plots Viet Nam's forecast energy consumption from 2015 to 2050 with the BAU and SES energy trajectory charted with a dashed line for comparison. The SES energy savings against the BAU are due to allowing Viet Nam's energy demand to transition towards energy intensity benchmarks of comparable developed countries in Asia[58]. The ASES applies an additional 10% energy efficiency against the incremental SES demands.

The SES demand grows at a slower rate of 3.9% pa over the period from 2015 to 2050 with the commercial sector at 6.0% pa, industry growing at 4.0% pa and residential sector growing at 1.3% pa. Demand from the transport sector in the ASES is doubled and grows to 58 TWh, 10% of total electricity demand or 40% of all vehicles by 2050.

Figure 65 plots the peak demand of Viet Nam. The firm blue line represents peak demand without any demand side management impacts. Demand side management reflects demand responses to tight supply and network conditions. This is assumed to grow to as much as 17.5% of demand across all sectors by 2050, representing the portion of flexible demand that is not met through technology means (i.e. battery storage). The load factor is the same as in the SES i.e. assumed to reach 80% by 2030 compared to 80% by 2050 in the BAU as a further consequence of enhanced demand side management measures. Key drivers for demand growth and the demand projections are summarised in Table 18.

[58] Vietnam's industrial intensity was trended towards levels commensurate with South Korea (2014) by 2035 and allowed to decline at the same rate to 2050 which represents an energy savings potential of 62%.

Figure 64 Viet Nam Projected Electricity Demand (2015-2050, ASES)

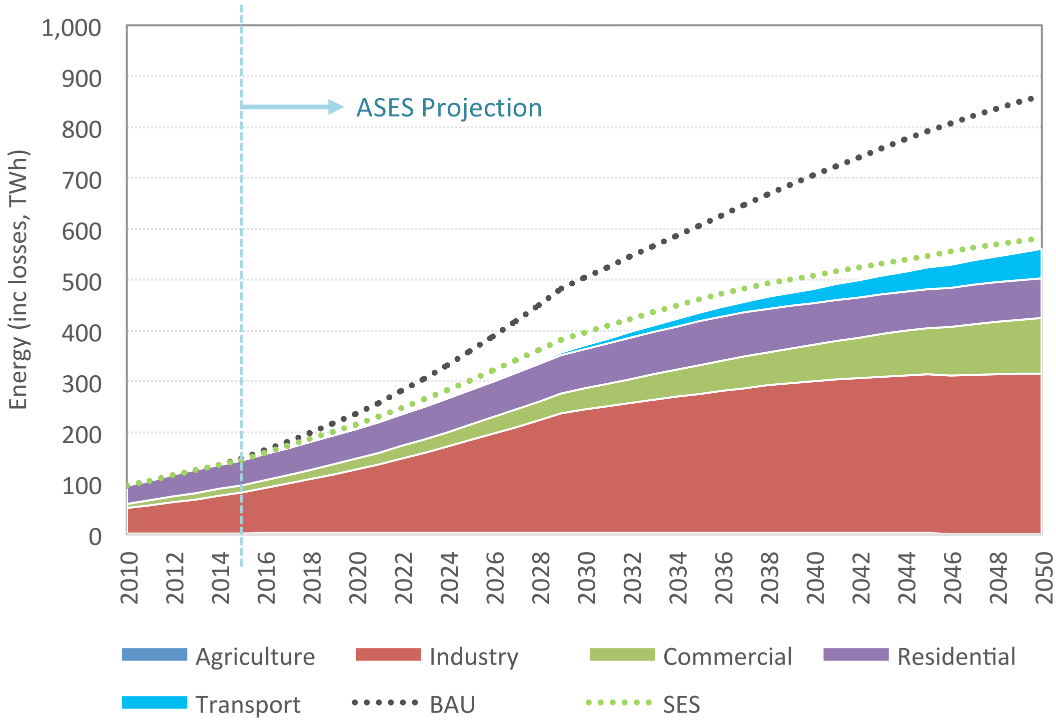


Figure 65 Viet Nam Projected Electricity Demand (ASES, MW)

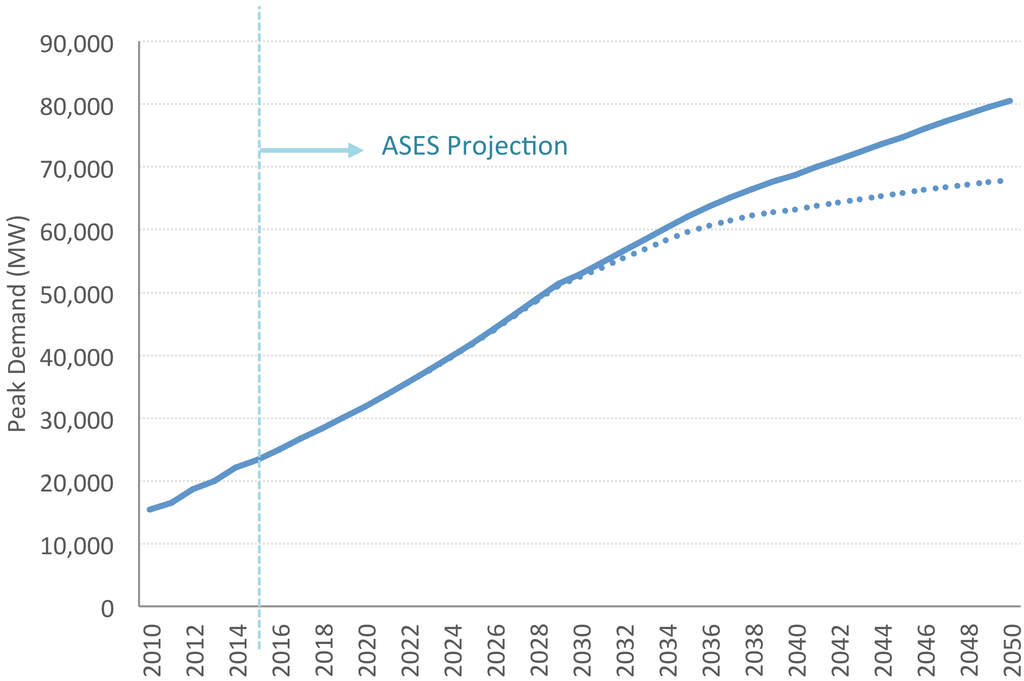


Table 18 Viet Nam Demand and Demand Drivers (ASES)

No.	Aspect	2015-30	2030-40	2040-50
1	Demand Growth (pa)	5.7%	2.7%	1.6%
2	GDP Growth (Real, pa)	6.8%	4.9%	2.9%
3	Electrification Rate (Population)	98.2%	98.8%	99.1%
4	Population Growth	0.60%	0.23%	-0.04%
5	Per Capita Consumption (kWh)	2,068	3,638	4,749
6	Electricity Elasticity*	3.71	1.76	1.31
7	Electricity Intensity (Demand/GDP)	0.382	0.427	0.419

* Electricity elasticity is calculated as the electricity demand growth divided by the population growth over the same period

7.3 Installed Capacity Development

Figure 66 plots the installed capacity developments under the SES and Figure 67 plots the corresponding percentage shares. Table 19 and Table 20 provide the statistical details of the installed capacity and capacity shares by type including the 2010 levels.

Committed and existing plants are assumed to come online as per the BAU but aren't replaced when retired. Existing thermal plant are retired early to meet the imposed renewable generation targets across the region. Renewable technologies ramp up much faster than in the SES to replace retirements of conventional generation technologies. By 2030 less than 25% of the installed capacity is based on fossil fuels; fossil fuels areentirely phased out by 2050.

By 2050 there is 68 GW of installed solar PV supported by 52 GW of battery storage (not including car batteries) capability mainly to defer generation for off-peak periods. Significant investment in offshore wind, bioenergy and CSP technologies occur to meet the rising demands, accounting for 5%, 7%, and 8%, respectively, of total installed capacity by 2050.

Figure 66 Viet Nam Installed Capacity by Type (ASES, MW)

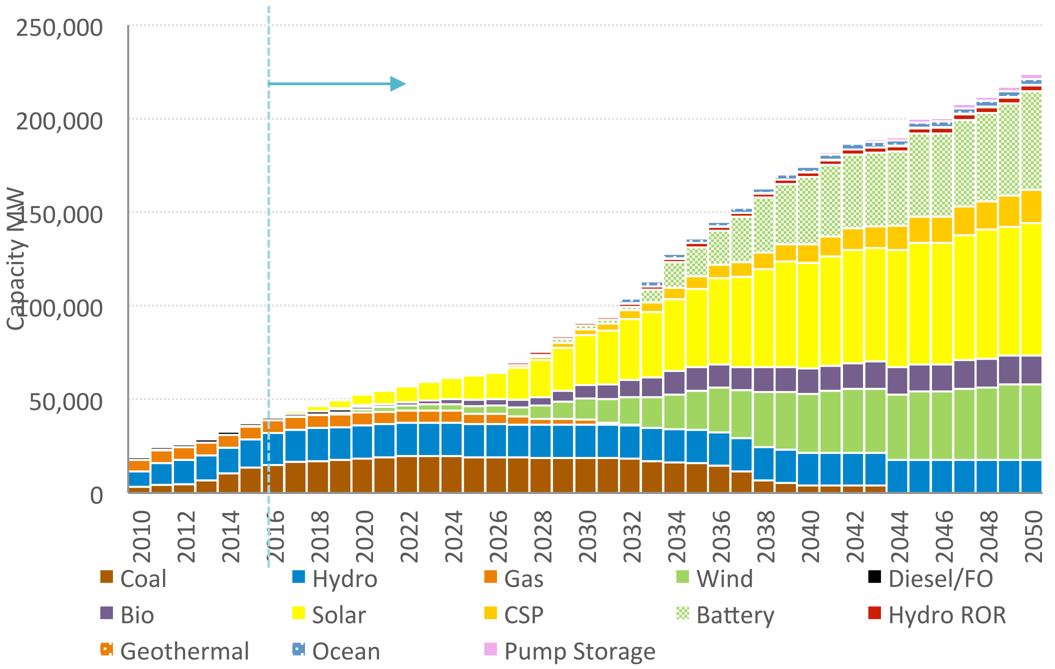


Figure 67 Viet Nam Capacity Shares (ASES, %)

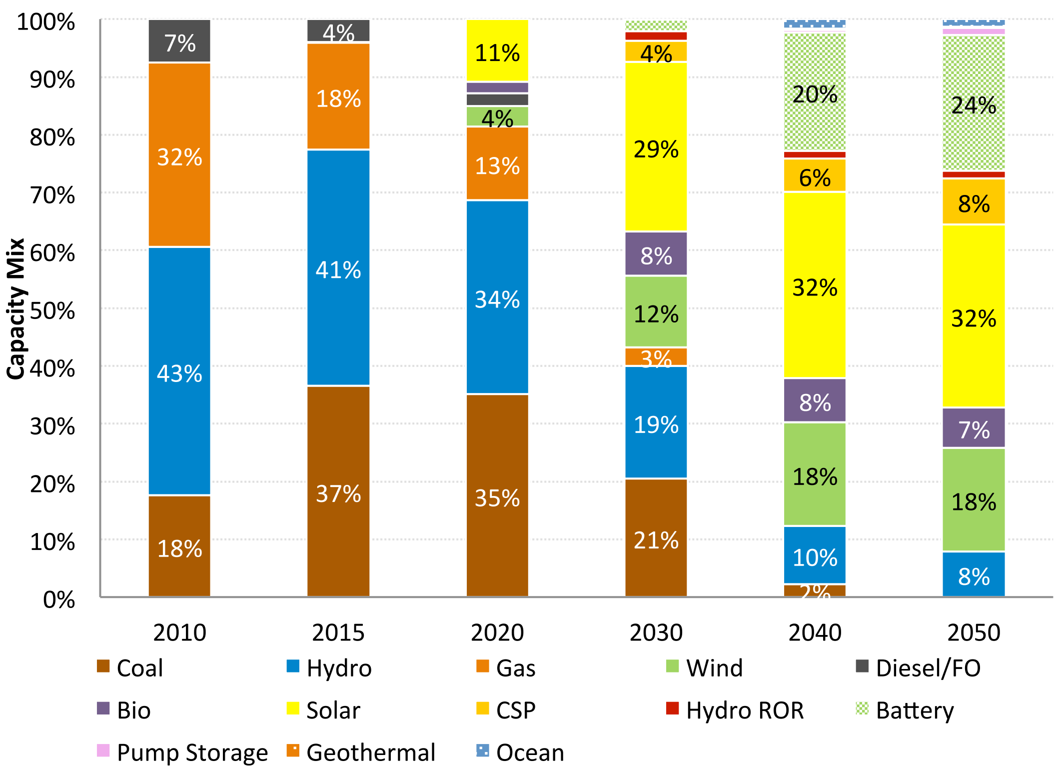


Table 19 Viet Nam Capacity by Type (ASES, MW)

Resource	2010	2015	2020	2030	2040	2050
Coal	3,360	13,605	18,500	18,680	3,860	0
Diesel	330	150	150	0	0	0
Fuel Oil	1,096	1,334	1,004	0	0	0
Gas	6,092	6,839	6,669	2,915	0	0
Nuclear	0	0	0	0	0	0
Hydro	8,200	15,175	17,688	17,688	17,688	17,688
Onshore Wind	0	50	1,914	11,201	27,958	29,356
Offshore Wind	0	0	0	113	3,456	10,858
Biomass	0	0	1,055	6,037	9,845	10,443
Biogas	0	0	0	918	3,610	5,012
Solar	0	0	5,579	26,699	56,443	71,003
CSP	0	0	0	3,300	10,050	17,700
Battery	0	0	0	1,859	35,882	52,702
Hydro ROR	0	0	0	1,500	2,400	3,000
Geothermal	0	0	0	75	300	450
Pump Storage	0	0	0	0	900	2,700
Ocean	0	0	0	0	2,875	2,875

Table 20 Viet Nam Capacity Share by Fuel (ASES, %)

Resource	2010	2015	2020	2030	2040	2050
Coal	18%	37%	35%	21%	2%	0%
Diesel	2%	0%	0%	0%	0%	0%
Fuel Oil	6%	4%	2%	0%	0%	0%
Gas	32%	18%	13%	3%	0%	0%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	43%	41%	34%	19%	10%	8%
Onshore Wind	0%	0%	4%	12%	16%	13%
Offshore Wind	0%	0%	0%	0%	2%	5%
Biomass	0%	0%	2%	7%	6%	5%
Biogas	0%	0%	0%	1%	2%	2%
Solar	0%	0%	11%	29%	32%	32%
CSP	0%	0%	0%	4%	6%	8%
Battery	0%	0%	0%	2%	20%	24%
Hydro ROR	0%	0%	0%	2%	1%	1%
Geothermal	0%	0%	0%	0%	0%	0%
Pump Storage	0%	0%	0%	0%	1%	1%
Ocean	0%	0%	0%	0%	2%	1%

7.4 Projected Generation Mix

ASES grid generation is plotted in Figure 55 and Figure 56[59]. The corresponding statistics for snapshot years are provided in Table 16 and Table 17. Viet Nam's generation mix in the earlier years to 2020 is similar to the BAU case as committed new generation projects are commissioned and this has largely been kept the same. A notable difference is that there is an increase in wind and solar projects from 2016. Further non-renewable developments beyond 2019 cease; gas and coal-fired generation levels decline as units are retired while large-scale hydro generation continues at levels similar to current into the future, but the share of hydro generation decreases as there is no further large scale hydro development.

Of the renewable technologies, by 2050, solar contributes the highest generation share (128 TWh) with 71 GW of installed capacity at 25% followed by wind at 20% then bioenergy and CSP at 19% and 17% respectively. By 2050 new renewable energy sources (excluding large-scale hydro) make up some 86% of the total generation requirement, or 100% if large-scale hydro generation is included.

[59] Battery storage and pump storage is not included as storage technologies are generation neutral.

Figure 68 Viet Nam Generation Mix (ASES, GWh)

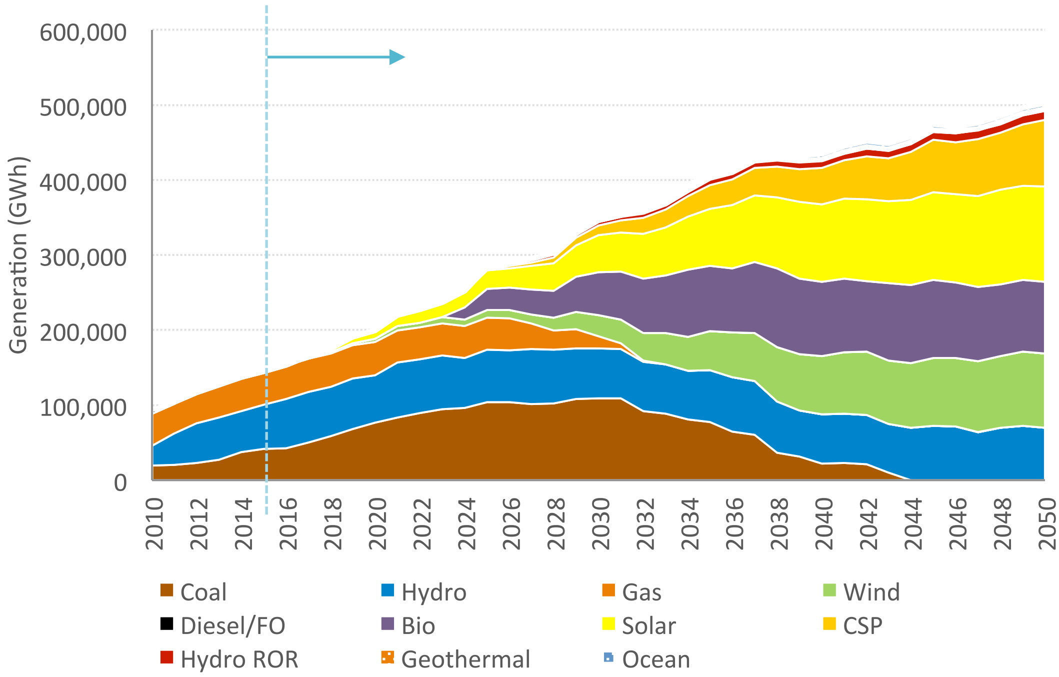


Figure 69 Viet Nam Generation Mix (ASES, %)

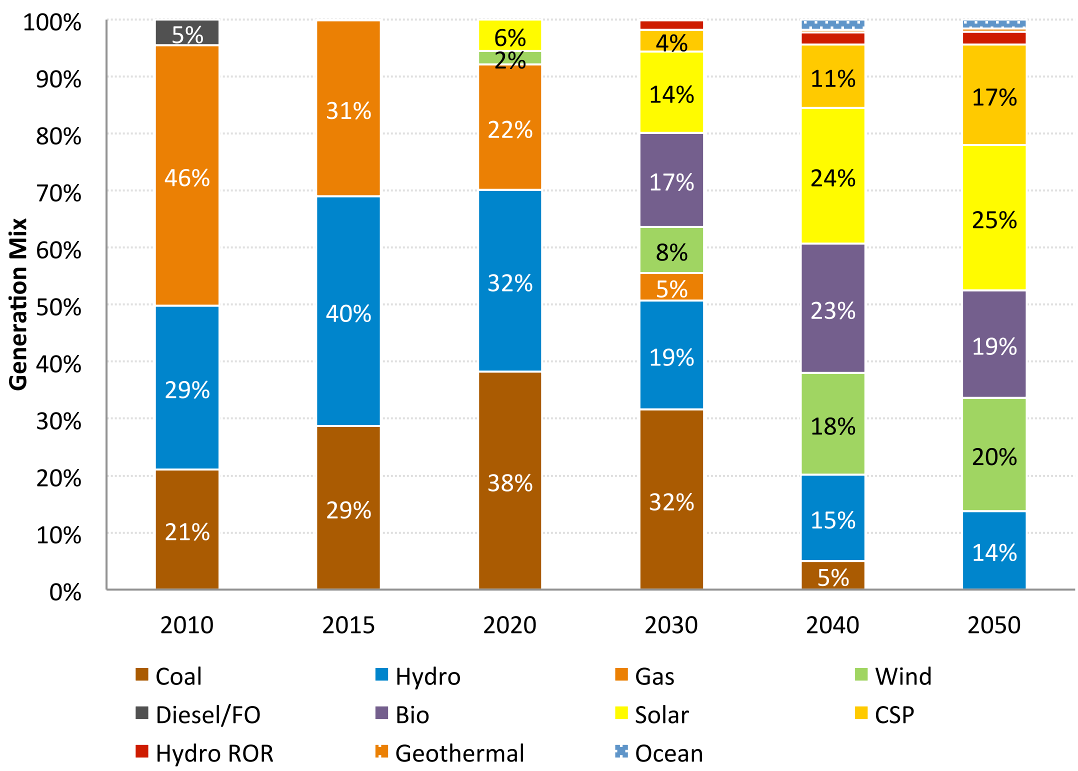


Table 21 Viet Nam Generation by Type (ASES, GWh)

Generation	2010	2015	2020	2030	2040	2050
Coal	19,500	41,755	76,450	109,205	21,979	0
Diesel	0	0	0	0	0	0
Fuel Oil	4,160	0	0	0	0	0
Gas	42,200	44,932	43,815	16,576	0	0
Nuclear	0	0	0	0	0	0
Hydro	26,560	58,491	63,762	66,334	65,714	69,443
Onshore Wind	0	125	4,792	27,748	69,076	72,568
Offshore Wind	0	0	0	280	8,537	26,840
Biomass	0	0	0	49,599	72,452	64,261
Biogas	0	0	0	7,543	26,567	30,837
Solar	0	0	10,993	49,326	103,312	127,879
CSP	0	0	0	13,000	48,538	88,306
Battery	0	0	0	0	0	0
Hydro ROR	0	0	0	5,782	9,308	11,563
Geothermal	0	0	0	491	1,976	2,970
Pump Storage	0	0	0	0	1,019	2,950
Ocean	0	0	0	0	7,576	7,556

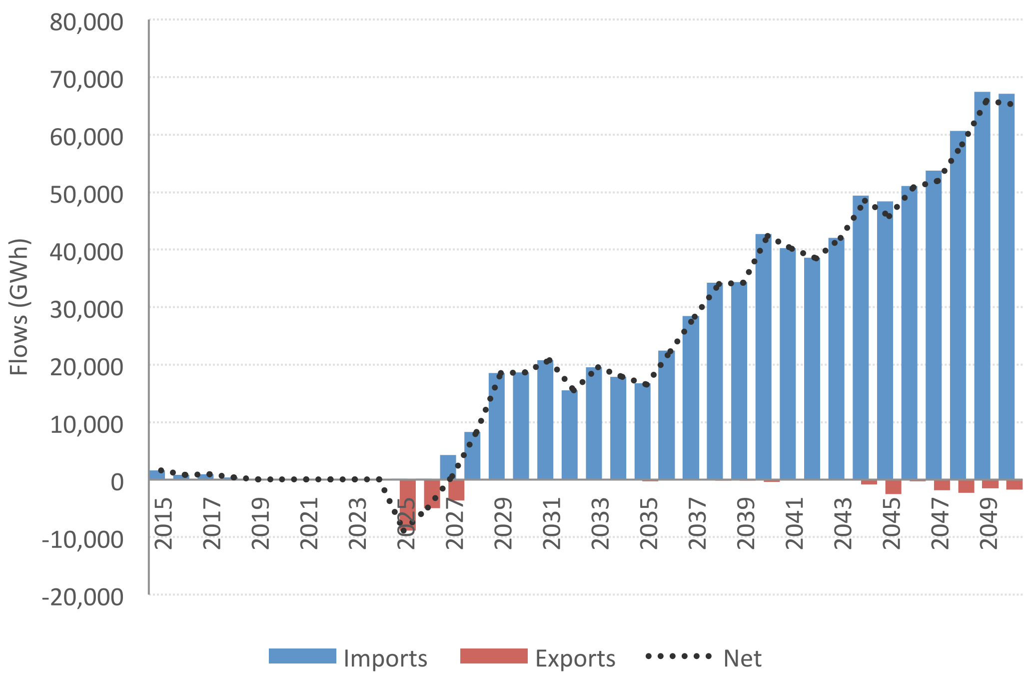
Table 22 Viet Nam Generation Share by Type (ASES)

Generation	2010	2015	2020	2030	2040	2050
Coal	21%	29%	38%	32%	5%	0%
Diesel	0%	0%	0%	0%	0%	0%
Fuel Oil	5%	0%	0%	0%	0%	0%
Gas	46%	31%	22%	5%	0%	0%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	29%	40%	32%	19%	15%	14%
Onshore Wind	0%	0%	2%	8%	16%	14%
Offshore Wind	0%	0%	0%	0%	2%	5%
Biomass	0%	0%	0%	14%	17%	13%
Biogas	0%	0%	0%	2%	6%	6%
Solar	0%	0%	6%	14%	24%	25%
CSP	0%	0%	0%	4%	11%	17%
Hydro ROR	0%	0%	0%	0%	0%	0%
Geothermal	0%	0%	0%	2%	2%	2%
Pump Storage	0%	0%	0%	0%	0%	1%
Ocean	0%	0%	0%	0%	0%	1%

7.5 Grid to Grid Power Flows

Figure 70 plots the imports and exports in the BAU with the dotted line representing the net interchange. The power flows in the ASES is similar in magnitude to the SES with most of the power imported from Lao PDR with almost 14,000 MW of interconnectors connecting Lao PDR to northern and central Viet Nam.

Figure 70 Viet Nam Imports and Exports (ASES)



7.6 Generation Fleet Structure

To gain insight into the nature of the mix of generation technologies deployed in the ASES, we present a number of additional charts. Figure 71 and Figure 72 show Viet Nam's installed capacity by generation type for the SES – this is clearly heavily biased towards renewable generation forms and there is a steady reduction in the thermal power plants. For Viet Nam, a considerable amount of non-renewable energy continues to feature in the generation mix in the earlier years before declining to 0 by 2045.

Figure 73 shows the dispatchable, semi-dispatchable and non-dispatchable components of installed capacity and it can be seen that semi-dispatchable increases to around 62% of the total system capacity compared to around 25% in the BAU by 2050. Based on operational simulations with this resource mix, it appears to be operationally feasible; the reliance on generation forms that provide storage and having flexibility in the demand side play important roles. It is clear that short-term renewable energy solar and wind forecasting systems will be important, as will real-time updates on demand that can be controlled. Furthermore, control systems that can allow the dispatch of flexible resources on both supply and demand sides of the industry will be required.

Figure 71 Viet Nam Installed Capacity by Type (ASES)

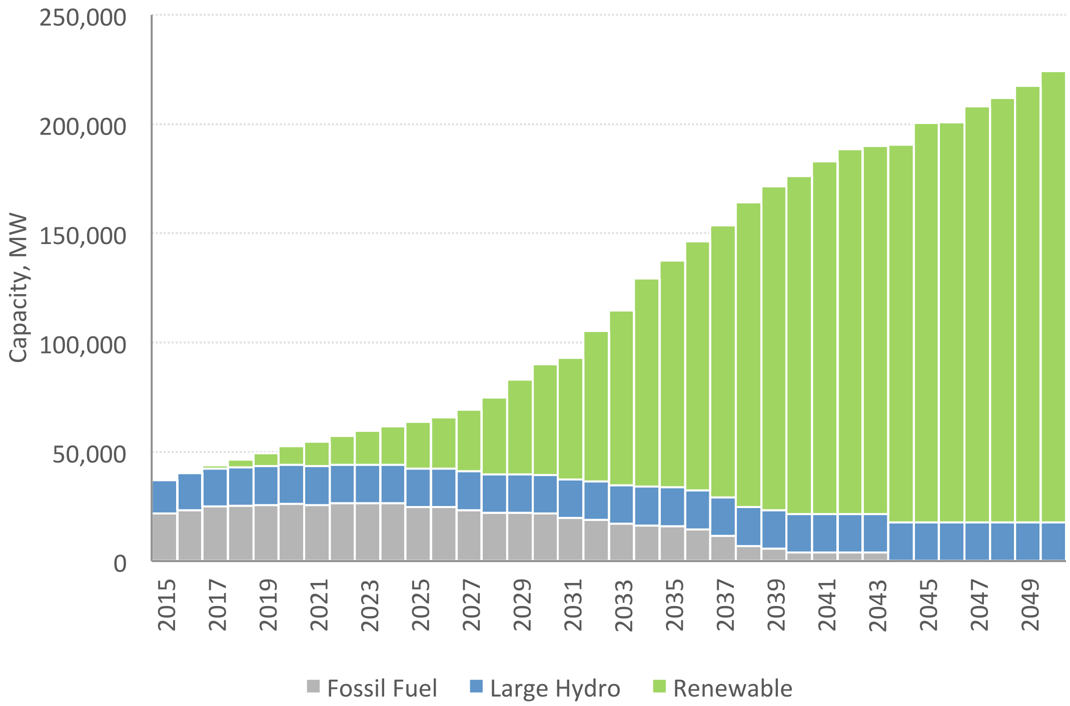


Figure 72 Viet Nam Generation Mix by Type (ASES)

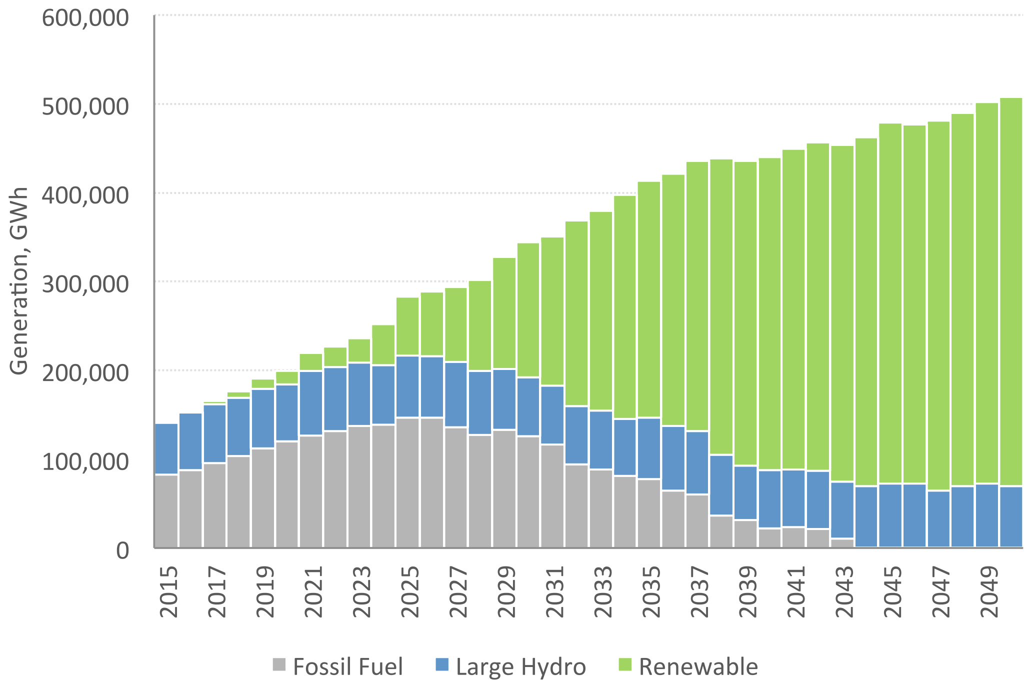
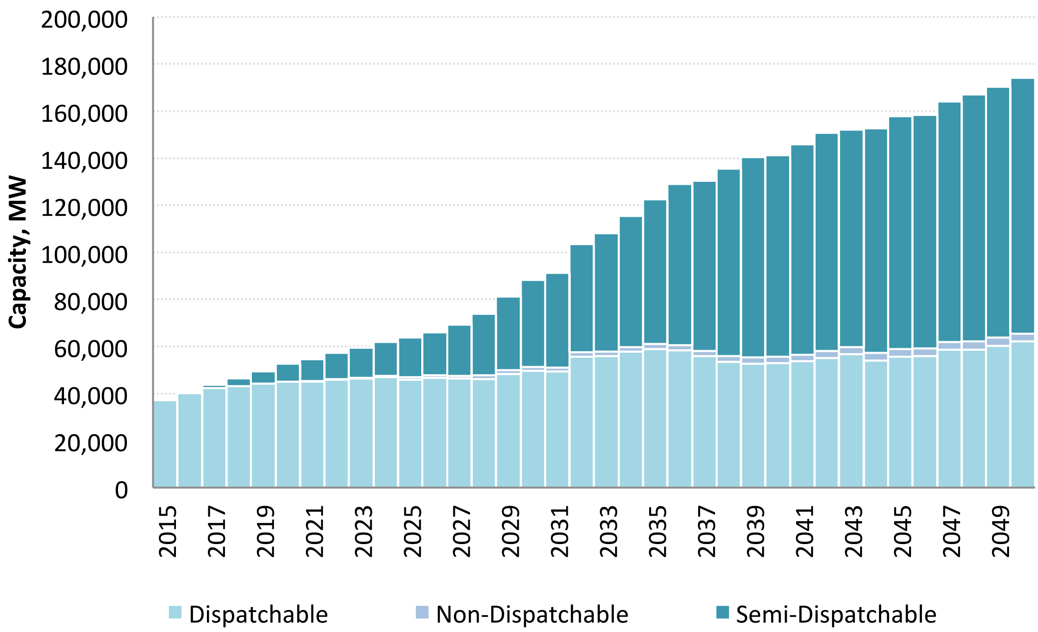


Figure 73 Viet Nam Installed Capacity by Dispatch Status (ASES)



7.7 Reserve Margin and Generation Trends

Figure 74 plots the reserve margin under the SES. Figure 75 and Figure 76 respectively show the installed capacity mix and generation mix for different categories of generation in the power system. The ASES reserve margin trends past 100% as conventional baseload technologies are retired early to meet renewable energy policy target of 100% by 2050.

Conventional reserve margin measures are generally not suited to measuring high renewable energy systems in the same context used for thermal-based systems. Renewable technologies generally have much lower capacity factors and require more capacity to meet the same amount of energy produced from thermal-based technologies.

Figure 74 Viet Nam Reserve Margin (ASES)

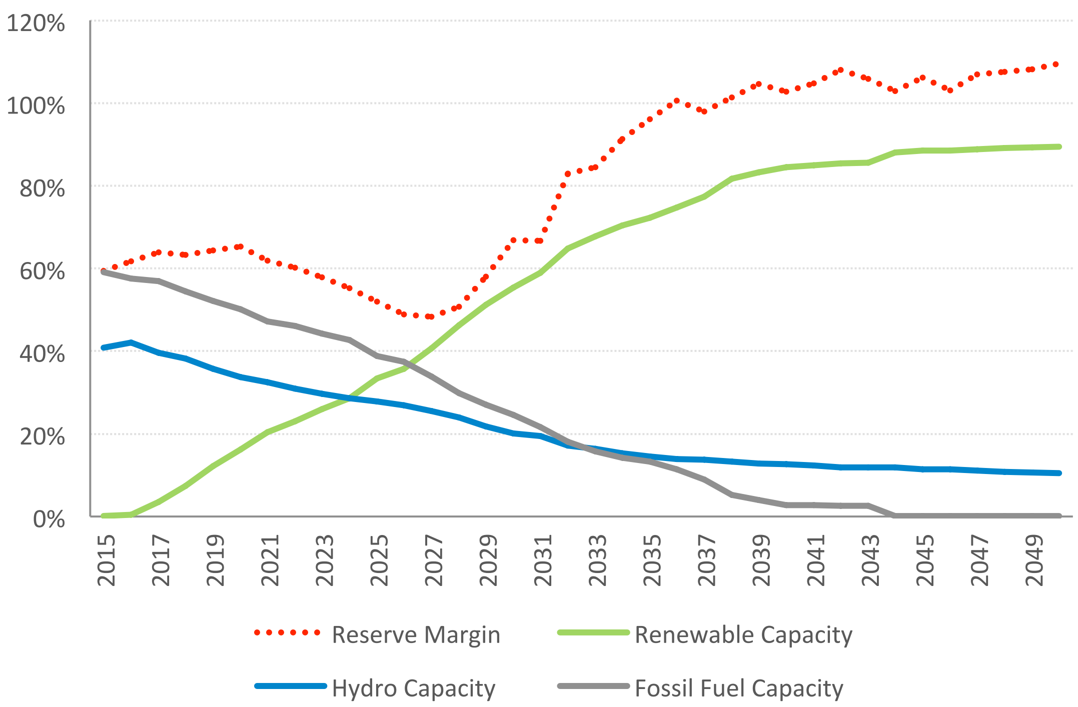


Figure 75 Viet Nam Installed Capacity Shares for ASES by Generation Type

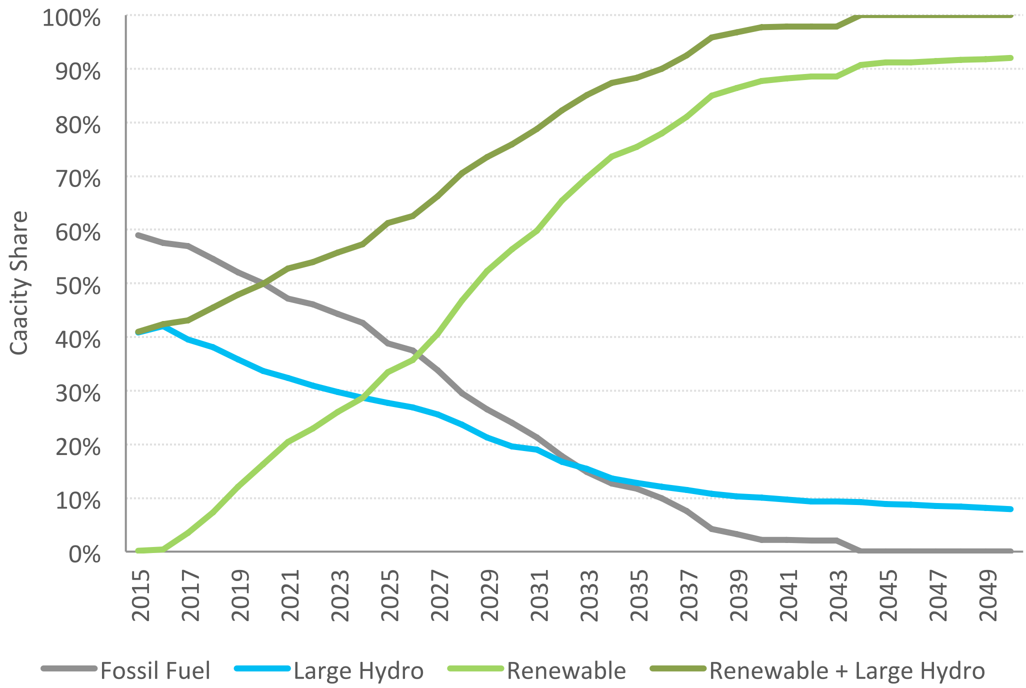
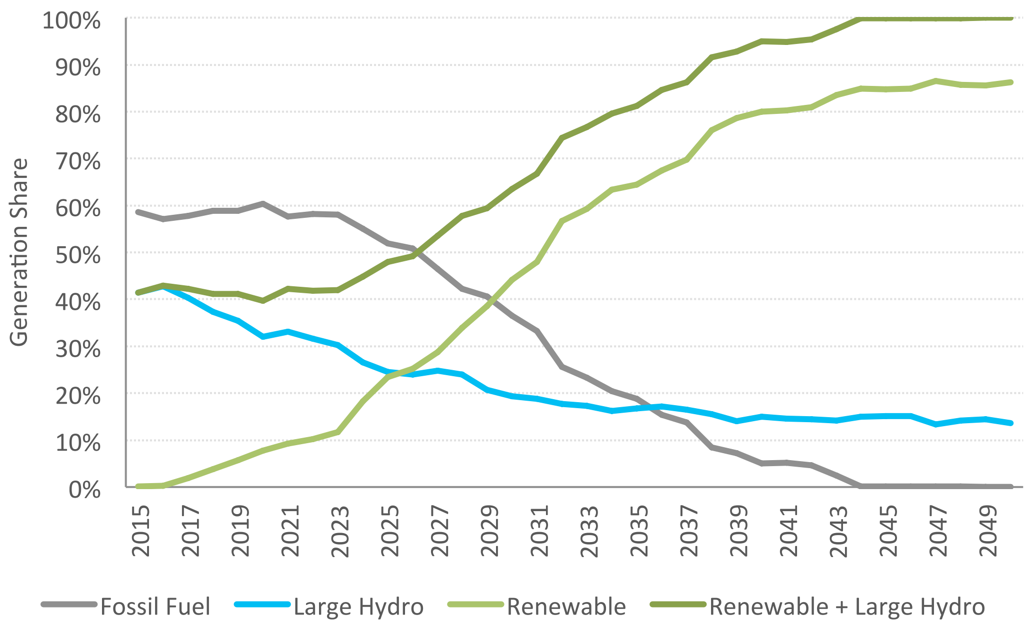


Figure 76 Viet Nam Generation Shares for ASES by Generation Type



7.8 Electrification and Off-Grid

Most of Viet Nam is already grid electrified and as per the BAU and SES, in the ASES we have assumed that the grid remains centrally interconnected into the future.

8 Analysis of Scenarios

Section 5, section 6 and section 7 presented projections of capacity and generation mix for the BAU, SES and ASES scenarios respectively. In order to understand the implications of the SES and ASES over the BAU, we have formulated a set of metrics to assist in their comparison.

These are as follows:

- Overall energy consumption per year;
- Peak electricity demand per year;
- Renewable energy percentage comparisons;
- Carbon emissions measures;
- Hydro power developments;
- Analysis of bioenergy situation;
- A number of simple security of supply measures; and
- Interregional power flows.

8.1 Energy and Peak Demand

Figure 77 compares the total electricity consumption of the BAU, SES and ASES with Figure 78 plotting the percentage reduction in electricity consumption of the SES relative to the BAU and ASES relative to the BAU. As can be seen the energy consumption of the SES is lower than the BAU with the main driver being enhancements in energy efficiency in the SES. There is a similar situation for the ASES noting that electric vehicle uptake was doubled in the ASES. Figure 79 compares peak load and shows the same relativities. This is attributable to improvements in load factor (reaching 80% by 2030 in SES and ASES). On top of this the SES and ASES has contributions from flexible and controllable demand that allows reductions in peak demand consumption included in the scenario as an assumption.

Figure 77 Viet Nam Energy Demand Comparison

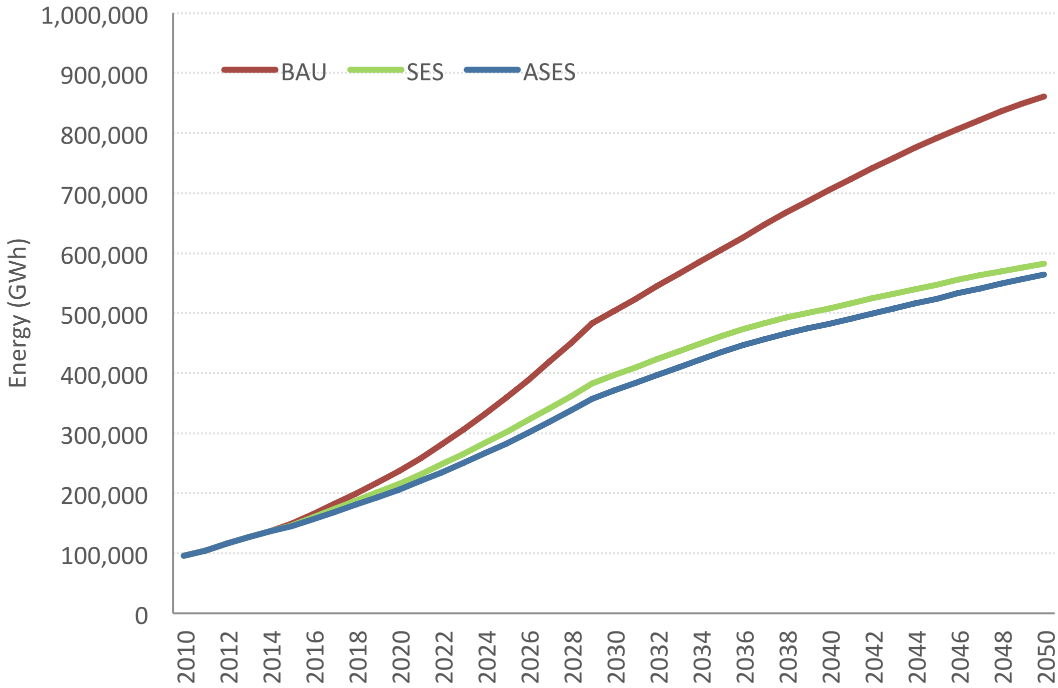


Figure 78 Viet Nam Percentage Reduction in Electricity Demand

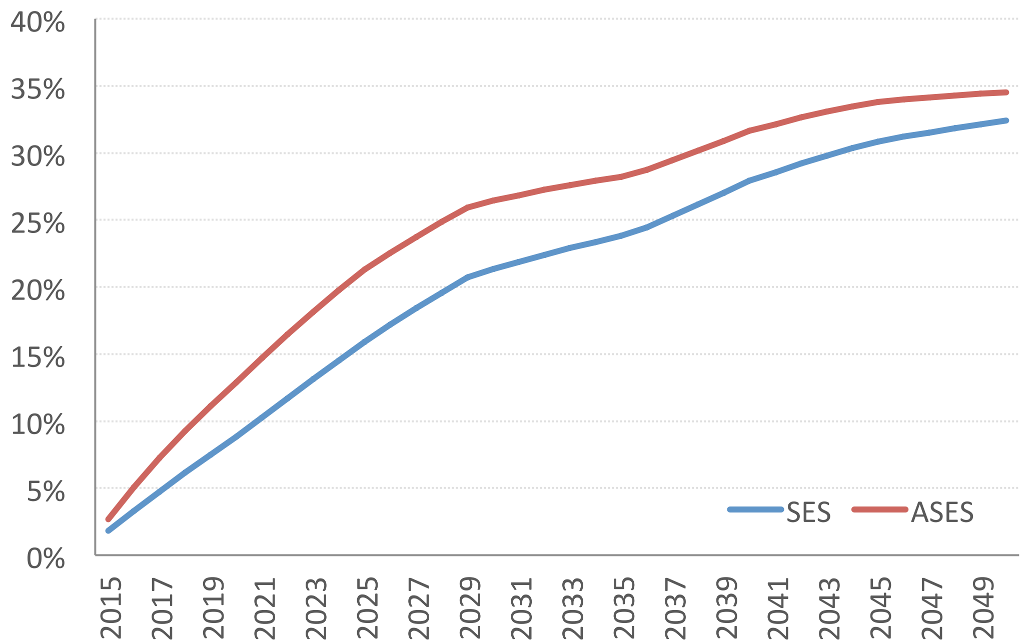
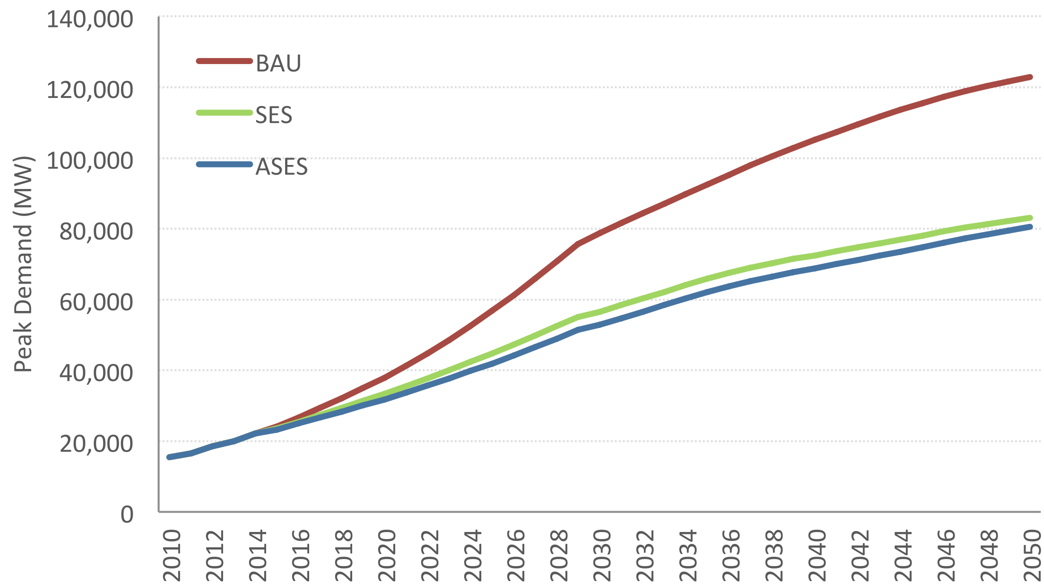


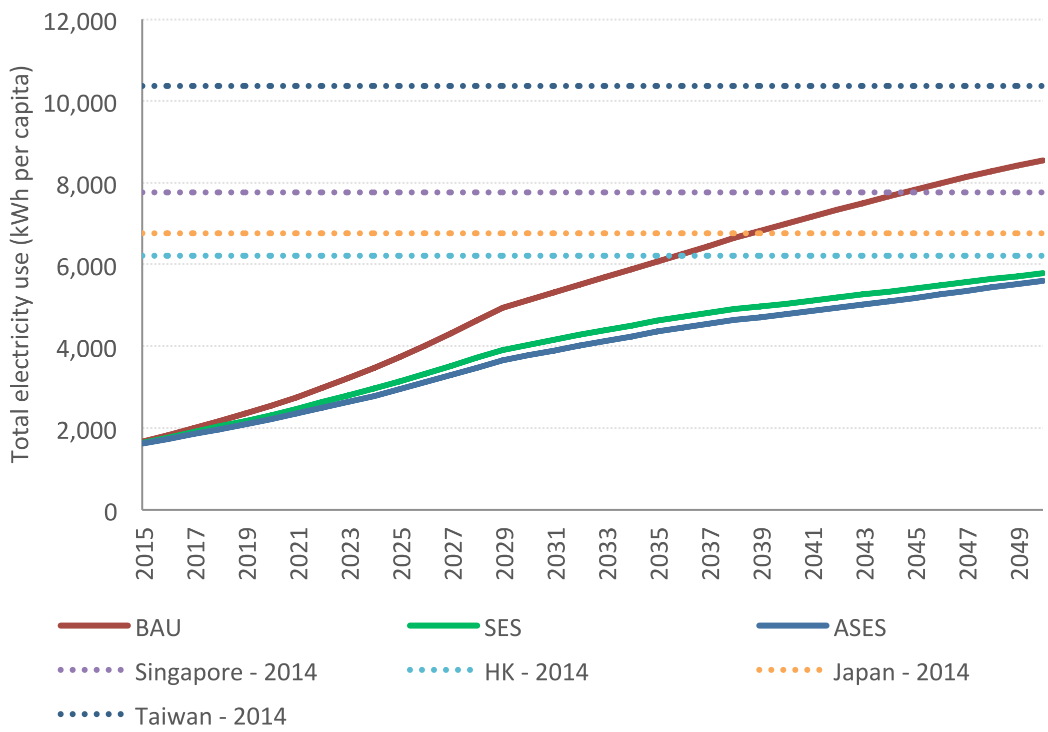
Figure 79 Viet Nam Peak Demand Comparison



8.2 Energy intensity

Figure 80 plots the per capita electricity consumption per annum across the scenarios. Electricity consumption includes all electricity consumption across the country. In the BAU, per capita consumption levels increase at a rate of 4.8% to reach 8,500 kWh pa which is between Singapore and Taiwan's current levels. In the SES, it increases more slowly at 3.7% pa to reach 5,800 kWh pa and the ASES at 5,600 kWh by 2050. The SES and ASES assume higher energy efficiency savings keeping per capita consumption below Hong Kong's current levels. It should be noted that GDP growth assumptions remain constant across all scenarios with the difference in the ASES and SES being measures taken to improve energy efficiency.

Figure 80 Viet Nam Per Capita Consumption Comparison (kWh pa)



8.3 Generation Mix Comparison

Figure 81 and Figure 82 below show the renewable capacity and generation mix between the three scenarios. Renewables (including large-scale hydro) reach 41% in the BAU which is equivalent to a 24% generation mix compared to the capacity reaching 90% in the SES contributing 73%. The ASES has renewables (including large-scale hydro) accounting for 100% of total capacity and generation by 2050.

Figure 81 Viet Nam Renewable Installed Capacity Mix

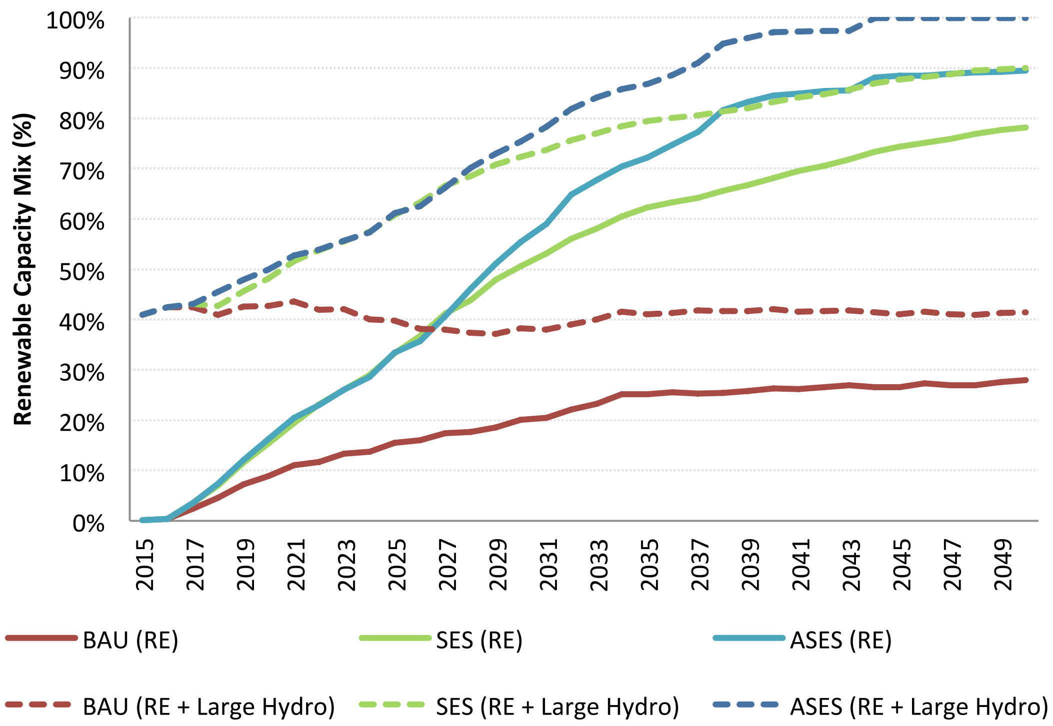
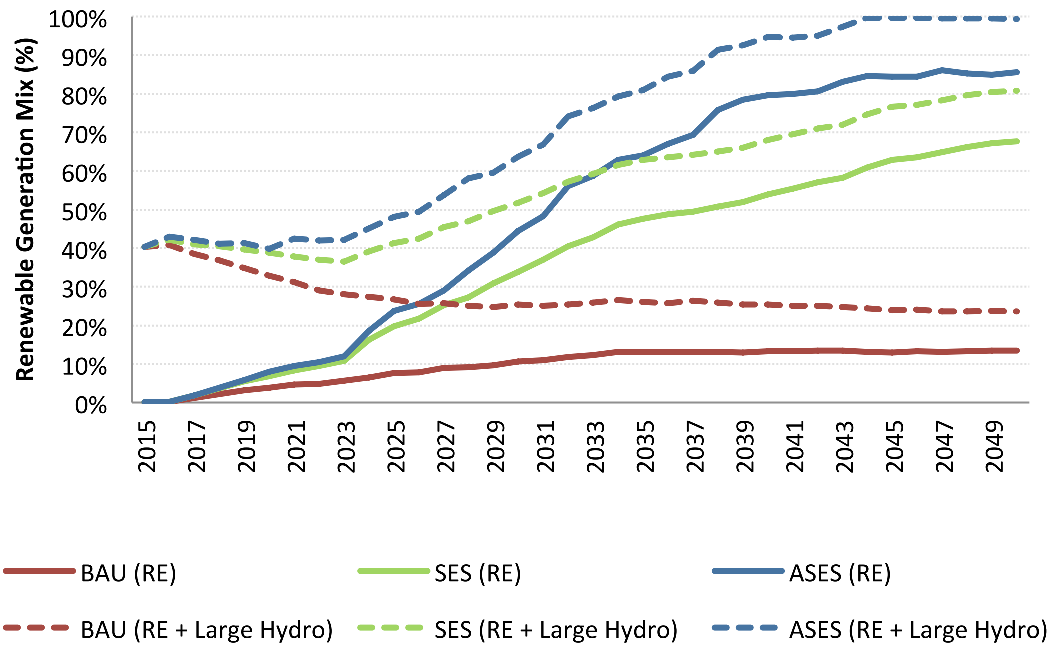


Figure 82 Viet Nam Renewable Generation Mix Comparison



8.4 Carbon Emissions

Figure 83 and Figure 84 show the carbon intensity of Viet Nam's power system and the total per annum carbon emissions respectively. The carbon intensity increases in the early periods as committed coal enters the system. The SES trajectory then trends towards 0.15t-CO2e/MWh and the BAU ranges between 0.5 - 0.6t-CO2e/MWh beyond 2025. In terms of total carbon emissions, the shift towards the SES and ASES saves up to 383 and 461 mt-CO2e, respectively, or the equivalent of 82% and 100% savings respectively against the BAU as a baseline. The BAU emissions level continues to peak as a result of increasing demands and the reliance on coal.

Figure 83 Viet Nam Carbon Intensity Comparison

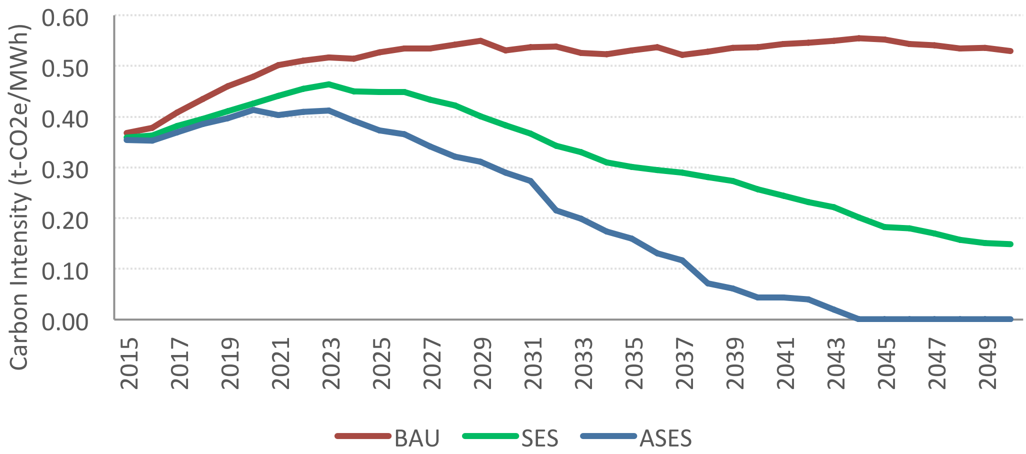
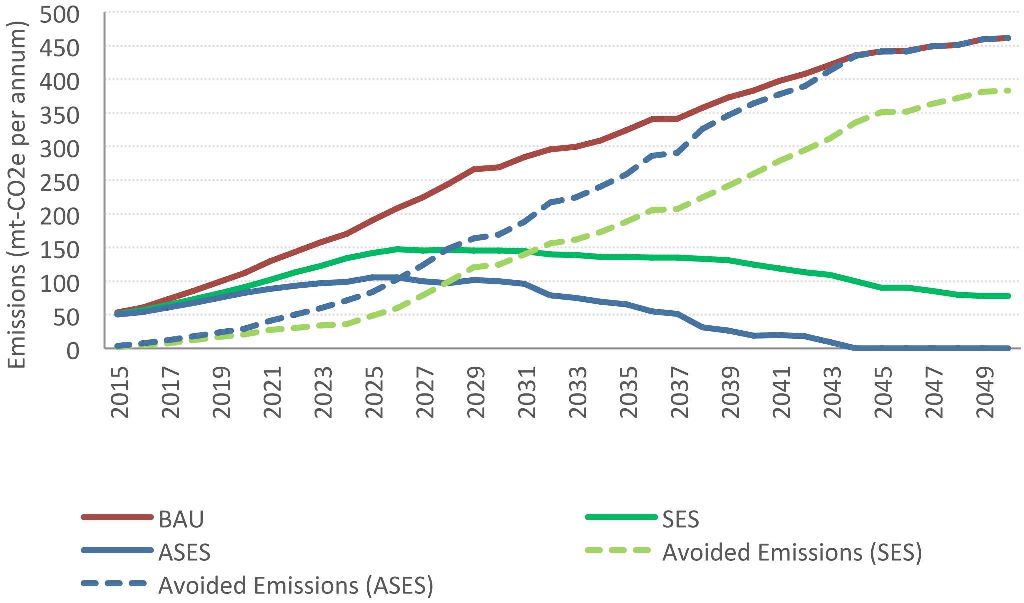


Figure 84 Viet Nam Carbon Emissions Comparison



8.5 Hydro Power Developments

Table 23 lists the hydro generation projects and commissioning year under the 3 scenarios. Hydro projects are assumed to be refurbished as required to maintain operations throughout the modelling horizon. As discussed earlier, projects such as Xekaman 3 located in other countries but dedicated to exports are included as projects in the export markets (with capacities adjusted accordingly) [60].

Table 23 Hydro Power Project Developments in BAU, SES and ASES

Hydro Project	Installed Capacity (MW)	Year Commissioned		
		BAU	SES	ASES
Ngoi Phat	72	2015	2015	2015
Song Bung 4	156	2015	2015	2015
Srepok 4A	64	2015	2015	2015
Ba Thuoc 1	60	2015	2015	2015
Bac Me	45	2015	2015	2015
Dong Nai 5	150	2015	2015	2015
Huoi Quang 1	260	2015	2015	2015
Lai Chau 1-1	400	2015	2015	2015
Nậm Mức	44	2015	2015	2015
Nam Na 2	66	2015	2015	2015

[60] The hydro projects for future construction selected here are example or generic hydro projects only and do not mean that we have a particular preference for those hydro projects compared to others.

Hydro Project	Installed Capacity (MW)	Year Commissioned		
		BAU	SES	ASES
Nậm Na 3	84	2015	2015	2015
Nam Toong	34	2015	2015	2015
Ngoi Hut 2	48	2015	2015	2015
Nhan Hac	45	2015	2015	2015
Nho Que	32	2015	2015	2015
Nho Que 2	48	2015	2015	2015
Xekaman 3	200	2015	2015	2015
Song Bung 2	108	2015	2015	2015
Sông Giang 2	37	2015	2015	2015
Song Tranh 3	62	2015	2015	2015
Dak Mi 2	98	2016	2016	2016
Dak Mi 3	45	2016	2016	2016
Huoi Quang 2	260	2016	2016	2016
Lai Chau 1-2	800	2016	2016	2016
Xekaman 1	232	2016	2016	2016
Song Tranh 4	48	2016	2016	2016
Trung Son	260	2016	2016	2016
Yen Son	70	2016	2016	2016
Chi Khe	41	2017	2017	2017
Da Nhim MR	80	2017	2017	2017
Long Tao	42	2017	2017	2017
Xekaman Xanay	26	2017	2017	2017
Thac Mo MR	75	2017	2017	2017
Tra Khuc	36	2017	2017	2017
A Lin	62	2018	2018	2018
Dak Mi 1	54	2018	2018	2018
Hoi Xuan	102	2018	2018	2018
La Ngau	36	2018	2018	2018
Xekaman 4	64	2018	2018	2018
Song Lo 6	44	2018	2018	2018
Song Mien 4	38	2018	2018	2018
Bao Lam	46	2044	Projects not developed in the SES and ASES	
Pac Ma	140	2024		
Thuong Kon Tum 1-1	220	2044		
Nam Pan 5	35	2024		
My Ly	250	2027		
Ban Mong	60	2028		
Tich Nang Bac Ai 1-1	300	2028		

<table>
<tr><th rowspan="2">Hydro Project</th><th rowspan="2">Installed Capacity (MW)</th><th colspan="3">Year Commissioned</th></tr>
<tr><th>BAU</th><th>SES</th><th>ASES</th></tr>
<tr><td>Tich Nang Bac Ai 1-2</td><td>300</td><td>2029</td><td colspan="2" rowspan="10"></td></tr>
<tr><td>Tich Nang Bac Ai 1-3</td><td>300</td><td>2030</td></tr>
<tr><td>Dong Phu Yen 1-1</td><td>300</td><td>2030</td></tr>
<tr><td>Pa Ma</td><td>80</td><td>2032</td></tr>
<tr><td>Tich Nang Bac Ai 1-4</td><td>300</td><td>2033</td></tr>
<tr><td>Dong Phu Yen 1-2</td><td>300</td><td>2033</td></tr>
<tr><td>Huoi Tao</td><td>180</td><td>2034</td></tr>
<tr><td>Dong Phu Yen 1-3</td><td>300</td><td>2036</td></tr>
<tr><td>Lower Sre Pok 2</td><td>155</td><td>2027</td></tr>
<tr><td>Sambor Dam</td><td>1820</td><td>2037</td></tr>
</table>

8.6 Analysis of Bioenergy

Figure 85shows a projection of the biomass available for the GMS (converted to GWh) and the total biomass generation for each scenario for the GMS. The shaded pink area represents the projected total technical biomass resource availability[61] while the solid lines show the biomass consumption used by each scenario. The projected available biomass was based on forecast growth rates in the agricultural sectors of each country. It was assumed that no more than 75% of the total projected available biomass resource was used. The remainder of the bioenergy requirements for each scenario was then assumed to be satisfied by biogas technologies.

Figure 86 shows a similar chart to Figure 85 for the GMS except for biogas. The green shaded area in this chart represents the amount of biogas available (again in units of GWh) and the corresponding generation from biogas in each scenario. This shows that the SES and ASES are dependent on biogas while the BAU is assumed to not deploy this technology. Based on the projections the biomass and biogas resources available to the region can be seen to be sufficient to support the amount of biomass and biogas generation to 2050.

[61] Projections of biomass availability developed by IES based on baselines established from information on biomass and biogas potential reported in 'Renewable Energy Developments and Potential in the Greater Mekong Subregion', ADB (2015) report.

Figure 85 Projected Biomass Availability and Consumption in the BAU, SES and ASES scenarios for the GMS as a whole

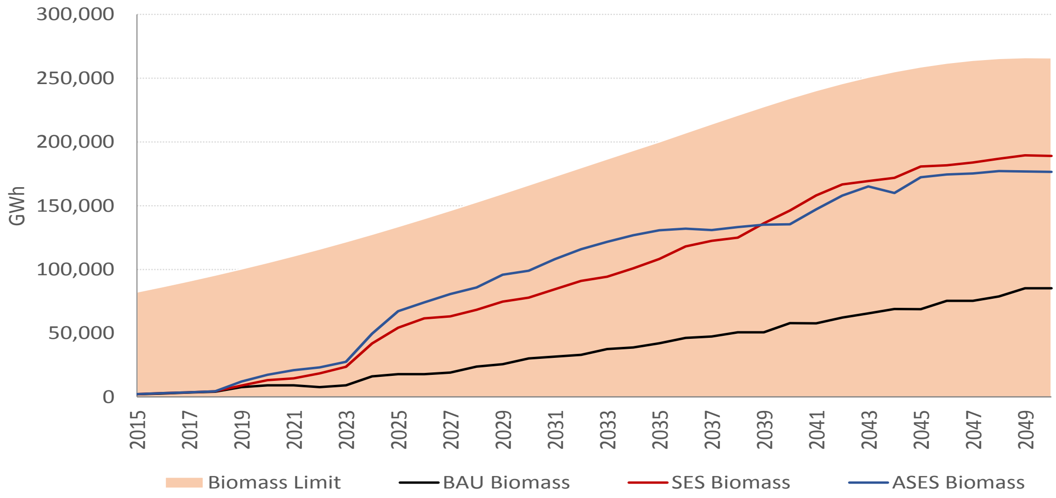
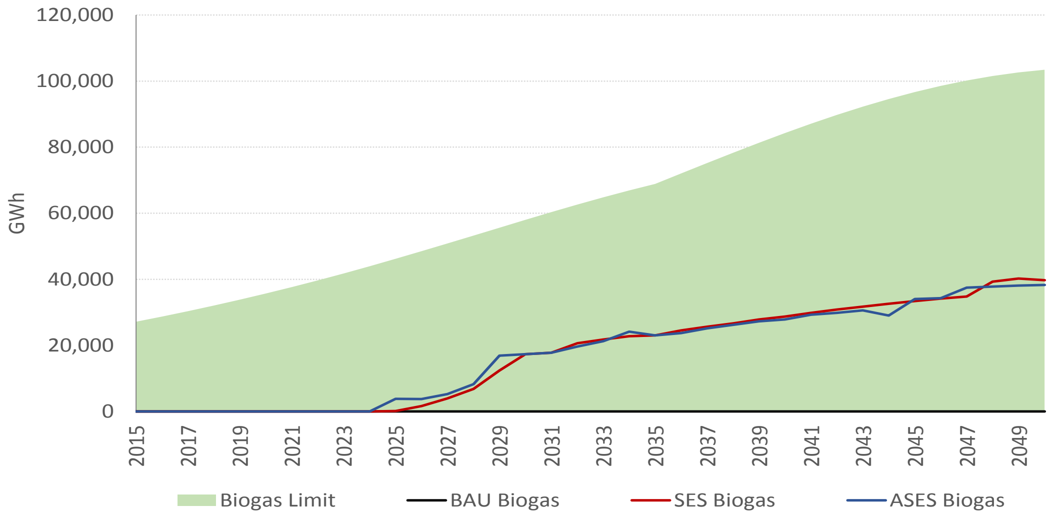


Figure 86 Projected GMS Biogas Requirements



8.7 Security of Supply Indicators

Figure 87 plots the energy reserve margin calculated as the difference between the maximum annual production from all plants accounting for energy limits and the annual electricity demands. For importing countries like Viet Nam, gross import limits have also been included. The figure below shows similar energy reserve margins with the SES and ASES having slightly lower margins around 2030 as gas and coal plants retire. As noted previously, an energy reserve margin is more suited to measuring systems that are renewables-based.

Figure 87 Viet Nam Security of Supply Measure: Energy Reserve

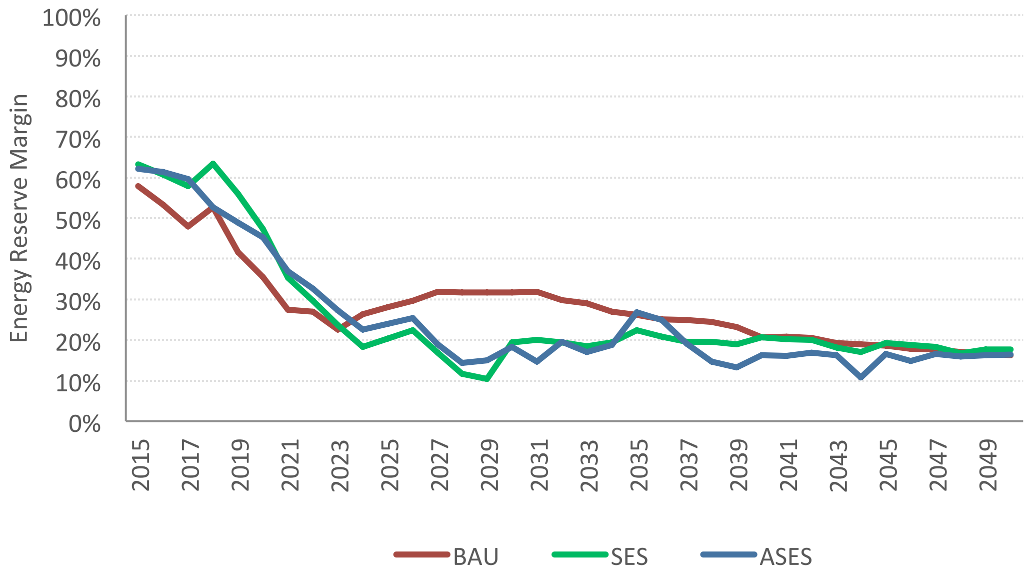


Figure 88 and Figure 89 show two simple security of supply measures.

The percentage generated using domestic fuel sources starts above 95% and declines over time to around 51% by 2050 in the BAU. The decline is driven by the increasing coal and uranium requirements that need to be imported. The security level in the SES and ASES case remains relatively high with the trend declining slightly in the first 15 years due to committed coal projects and settles around 85-90% from 2030 onwards. Although the ASES reaches 100% renewable generation, Viet Nam relies on imported electricity to satisfy up to 15% of its electricity requirements by 2050.

Figure 88 Viet Nam Security of Supply Measure: Percentage of Electricity Generated by Domestic Resources

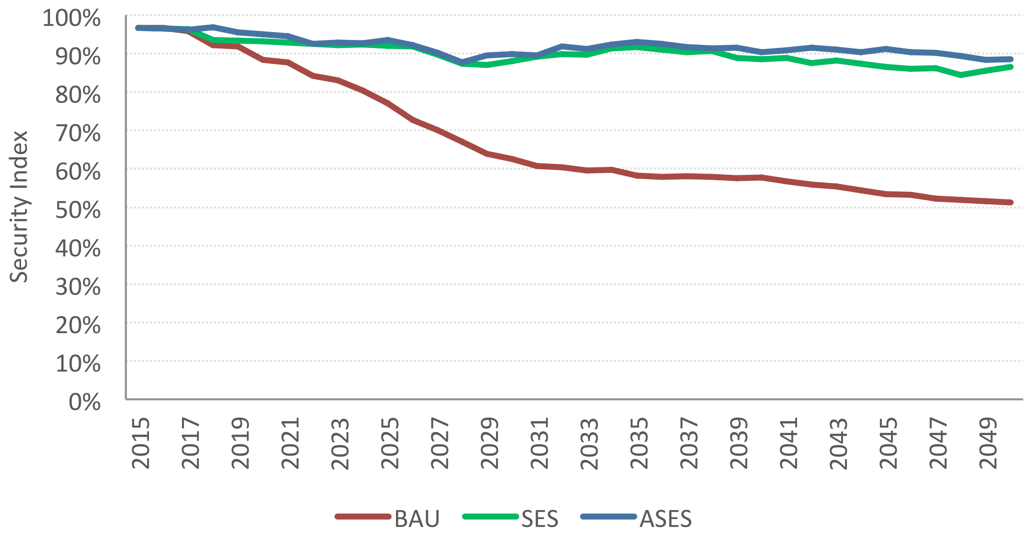


Figure 89 below plots the highest share of generation from a particular fuel source. In the BAU, the dominance is held by large-scale hydro initially then becomes coal-fired focused through the rest of the horizon. In the SES and ASES, it is dominated by hydro then coal in the short-medium term, and then solar PV by the end of 2050.

Figure 89 Viet Nam Security of Supply Measure: Maximum Dominance of a Technology in Generation Mix

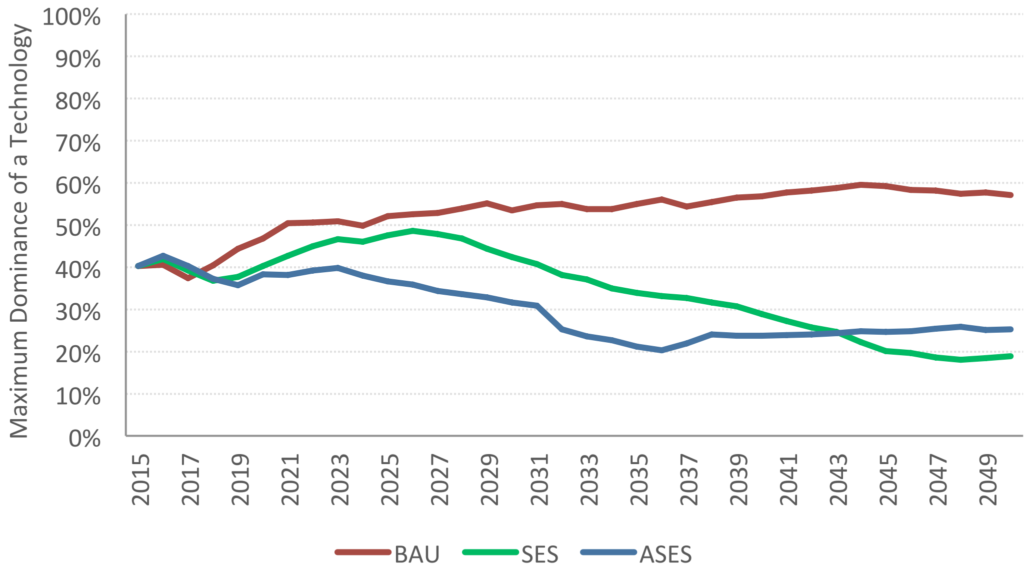
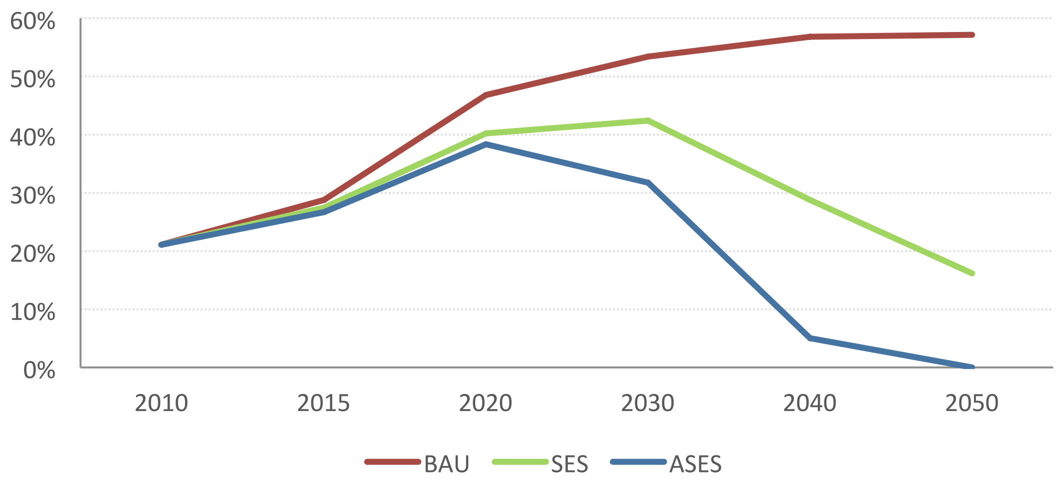


Figure 90 plots the dependence on coal in all scenarios. The coal share increases past 50% under the BAU case indicating higher reliance on imported fuel inputs whereas the SES and ASES decline from 2020 as no further coal projects come online, and older plants are replaced with renewable technologies towards 2050.

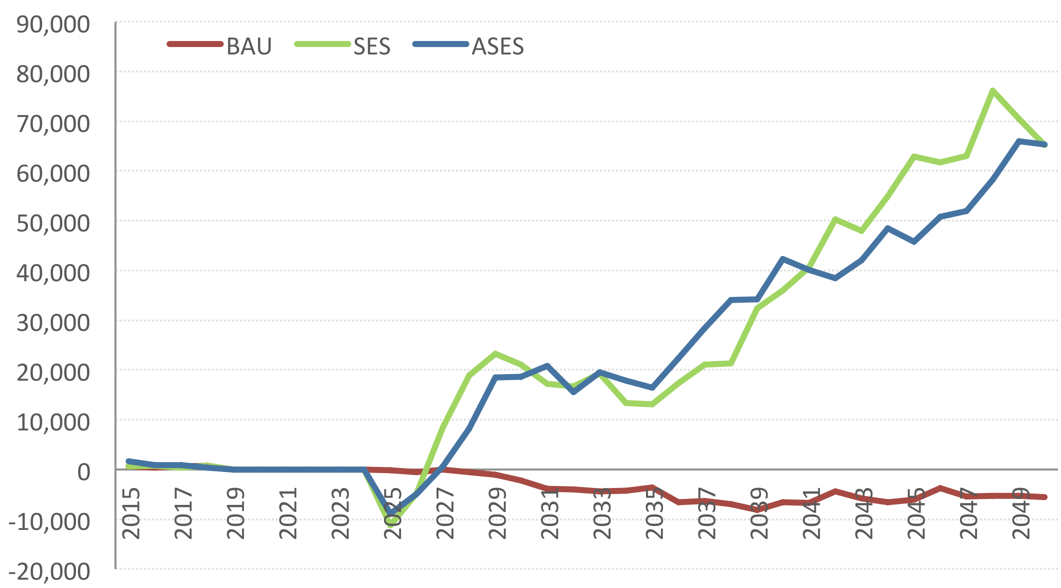
Figure 90 Viet Nam Security of Supply Measure: Coal Share



8.8 Interregional Power Flows

Figure 91 compares the net flows in and out of Viet Nam. The BAU has flows going out into Cambodia and up to 75,000 GWh of net imports in the SES and ASES primarily from Lao PDR to support ongoing demand growth as conventional generation technologies are retired. Imports account for approximately 15% of Viet Nam's total power requirements in the SES and ASES by 2050.

Figure 91 Viet Nam Imports (positive) and Exports (negative) (GWh)



9 Economic Implications

In this section we consider the economic implications of the three scenarios and examine in particular: (1) the levelised cost of electricity (LCOE) generation for the entire system, (2) investment costs, (3) total operating and capital expenditure including the cost of energy efficiency and (4) implications for job creation. It should be noted that the analysis presented in this section is done for the purpose of comparison, and that the prices and costs provided are dependent on the fuel price projections and technology cost assumptions that were used in both scenarios and which have been listed in Appendix A and Appendix B. The analysis in this section is also supported by sensitivity analysis to examine how changes in fuel prices impact the LCOE and to examine how a carbon price would affect electricity costs.

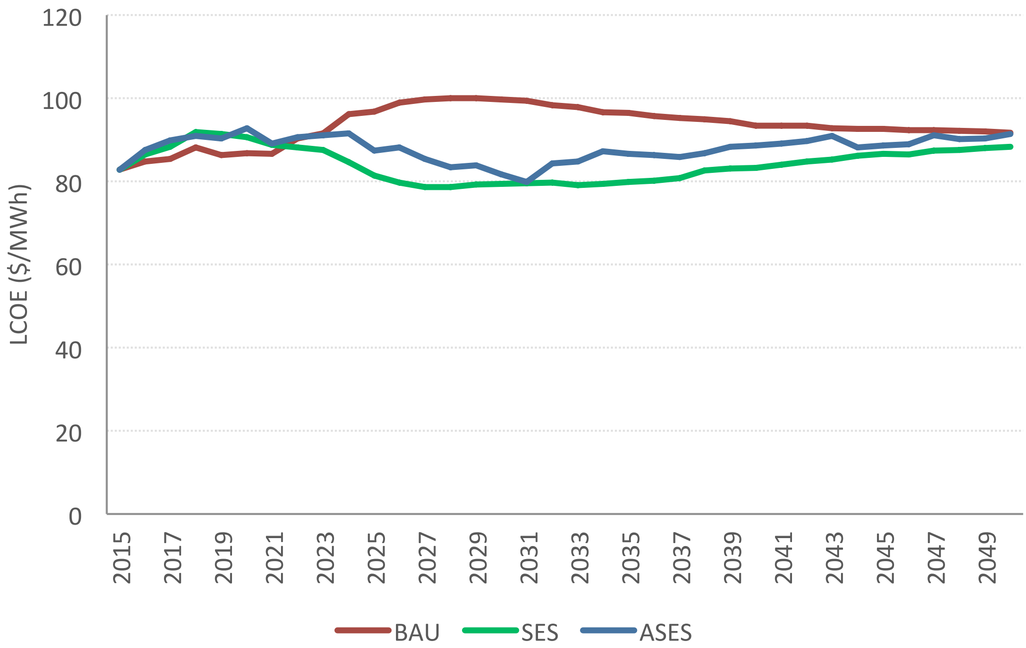
9.1 Overall Levelised Cost of Electricity (LCOE)

The comparison of the LCOE (only includes generation costs) is shown in Figure 92. The LCOE for the BAU starts to increase initially as a result of increasing fuel costs returning to long-term averages then steadily declines to $91/MWh as coal and gas costs stay flat and lower cost renewable generation is added into the capacity mix.

The ASES and SES initially decline then rise from around 2030 onwards driven by more investment in higher cost renewable technologies and battery storage which increases the overall LCOE. The ASES LCOE experiences a step up in costs from 2030 primarily driven by ocean/marine energy developments. By 2050 the SES and ASES reaches $89/MWh and $91/MWh respectively. This LCOE analysis does not include the cost of externalities[62].

[62] A detailed study on the cost of externalities is presented in the following reference: Buonocore, J., Luckow, P., Norris, G., Spengler, J., Biewald, B., Fisher, J., and Levy, J. (2016) 'Health and climate benefits of different energy-efficiency and renewable energy choices', *Nature Climate Change*, 6, pp. 100–105.

Figure 92 Viet Nam LCOE for Generation



9.2 LCOE Composition

High integration levels of renewable energy allow for the avoidance of fuel costs. In order to understand the structure of the LCOE from the previous section we provide decomposed versions of the LCOE in Figure 93 for the BAU, Figure 94 for the SES and Figure 95 for the ASES. This reveals an important trend in the structure of the cost of electricity: a thermal-dominated system has a high portion of its costs as fuel costs while a renewable energy dominated power system is more heavily biased towards capital costs. As is shown in the SES case, the fuel cost component steadily decreases from early in the modelling[63].

The SES and ASES capital costs on a $/MWh basis increases post 2030 due to greater investments in battery storage, biogas and offshore wind in the SES, and ocean energy technologies in the ASES case on top of the SES technologies.

[63] It does not go to zero due to bio generation.

Figure 93 Viet Nam LCOE Composition in BAU

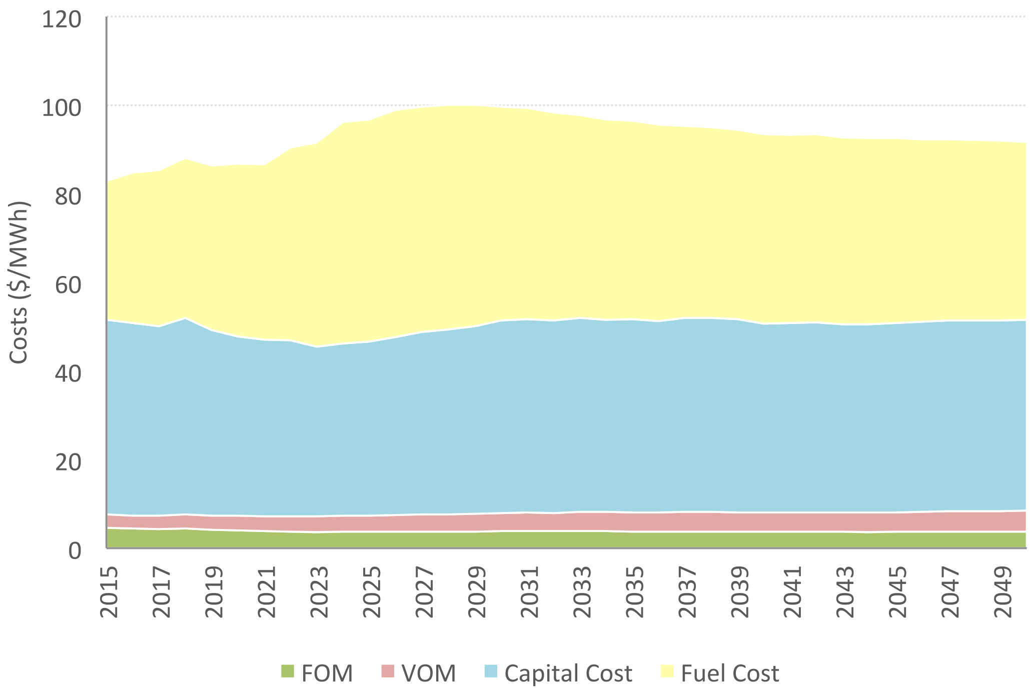


Figure 94 Viet Nam LCOE Composition in SES

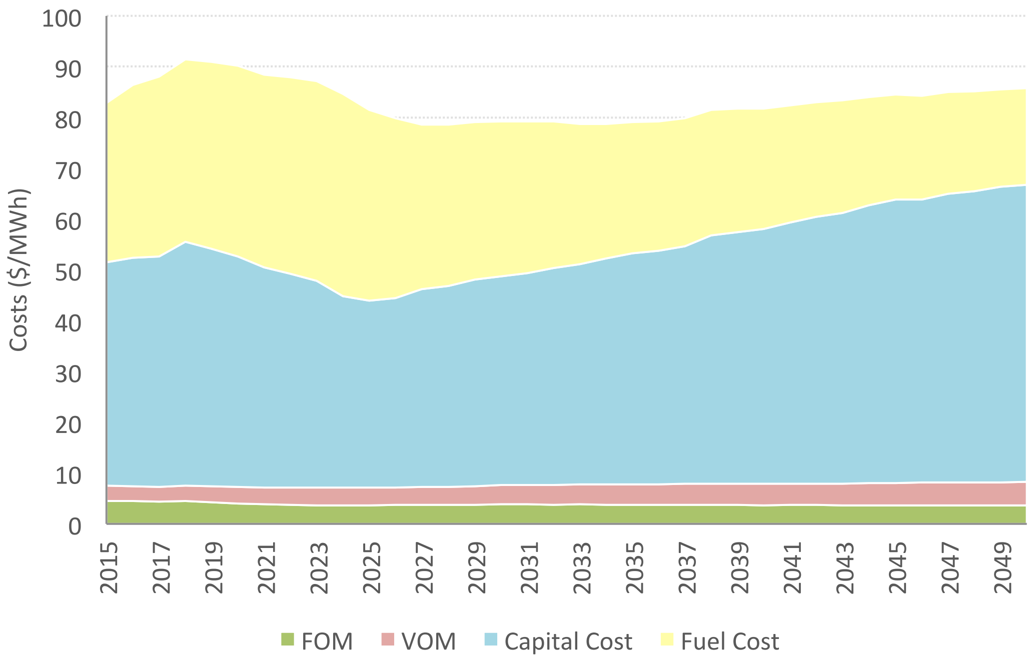
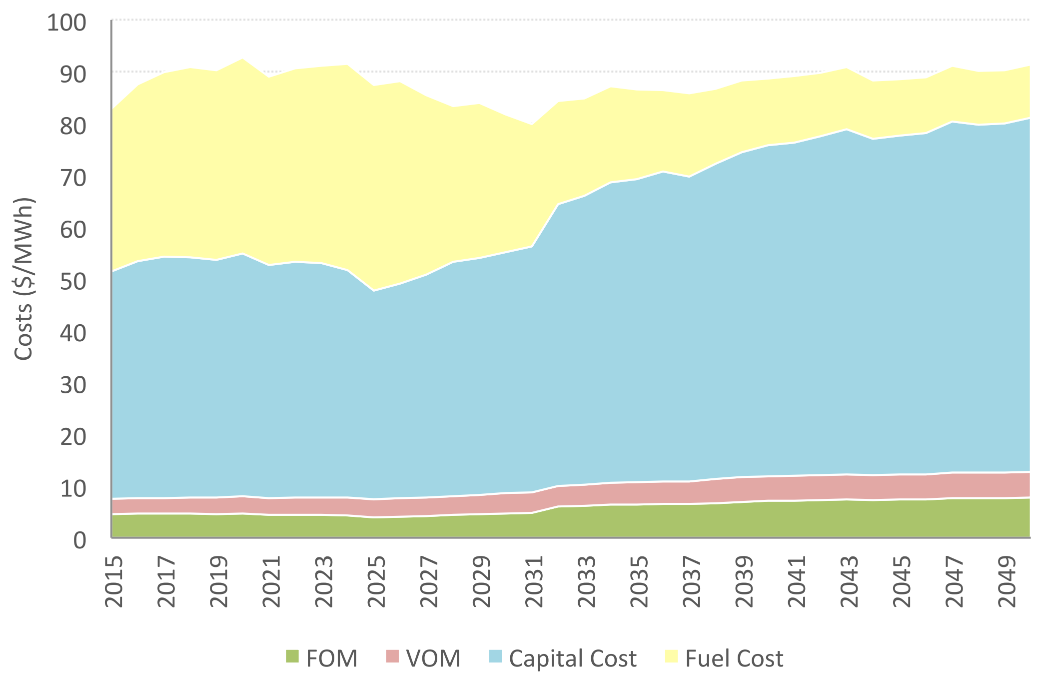


Figure 95 Viet Nam LCOE Composition in ASES



9.3 Cumulative Capital Investment

The following section details the investment costs of meeting demand in Viet Nam and also takes into account import costs (at the LCOE of neighbouring countries). Conversely, the investment costs of net exporting countries will be reduced according to the percentage of power that is exported.

Figure 96 shows the cumulative investment in generation CAPEX and energy efficiency in millions of Real 2014 USD. The earlier observation of the SES having lower demand owing to energy efficiency gains should be recognised. Figure 96 shows the BAU requiring less capital investment by the end of the modelling horizon primarily driven by investment in coal to meet increasing demands. The SES and ASES include investment in energy efficiency measures and greater investments in biogas, offshore wind and wave technologies post-2035. The breakdown costs are presented in Figure 97, Figure 98 and Figure 99. These charts include pro-rated investment costs relating to the dedicated capacity of export units such as Xekaman 4, classified as 'investment for export'.

Figure 96 Viet Nam Cumulative Investment (Real 2014 USD)

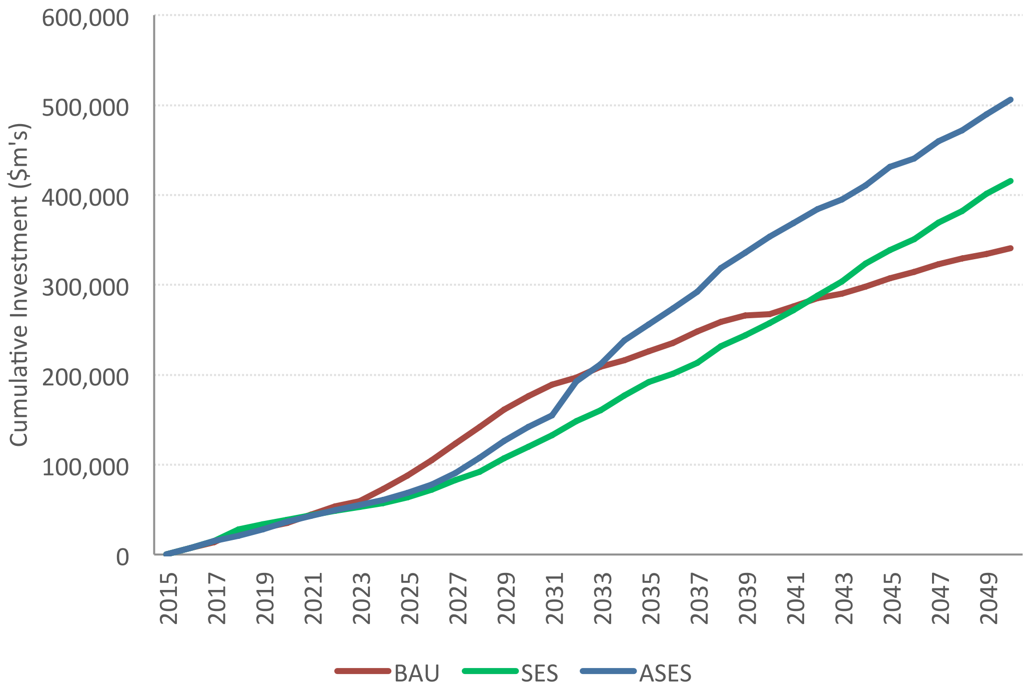


Figure 97 Viet Nam Cumulative Investment by Type (BAU, Real 2014 USD)

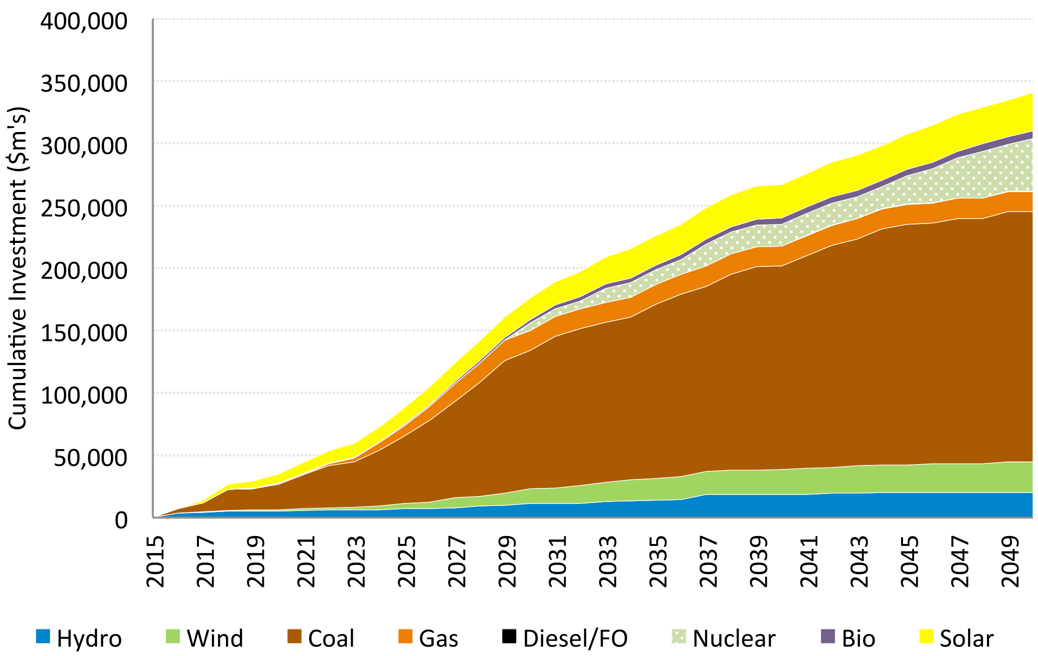


Figure 98 Viet Nam Cumulative Investment by Type (SES, Real 2014 USD)

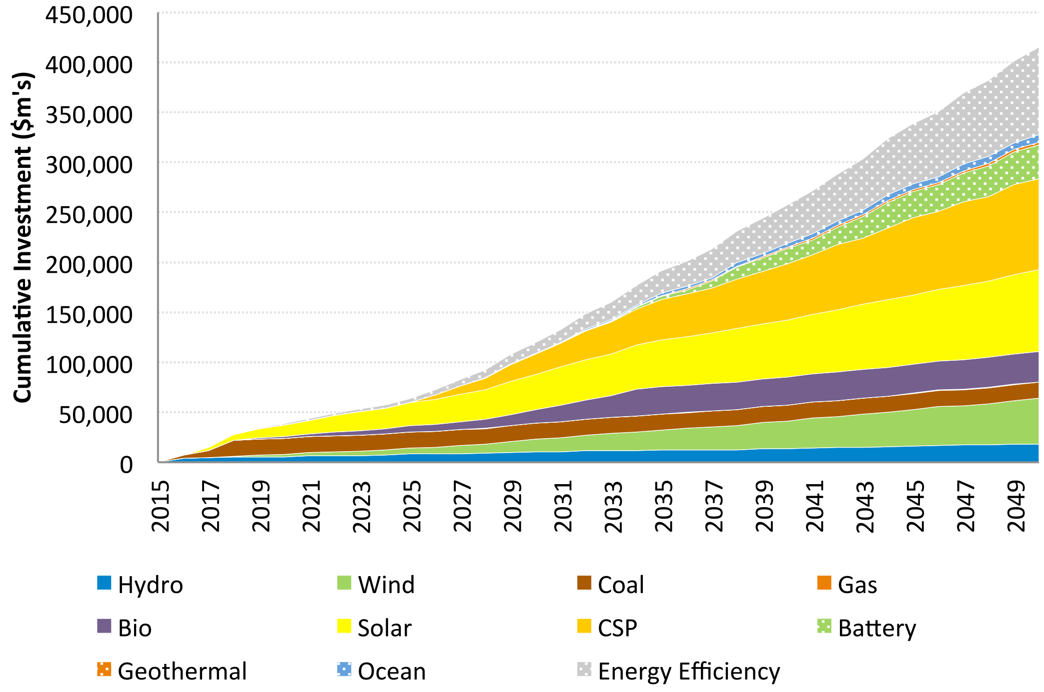


Figure 99 Viet Nam Cumulative Investment by Type (ASES, Real 2014 USD)

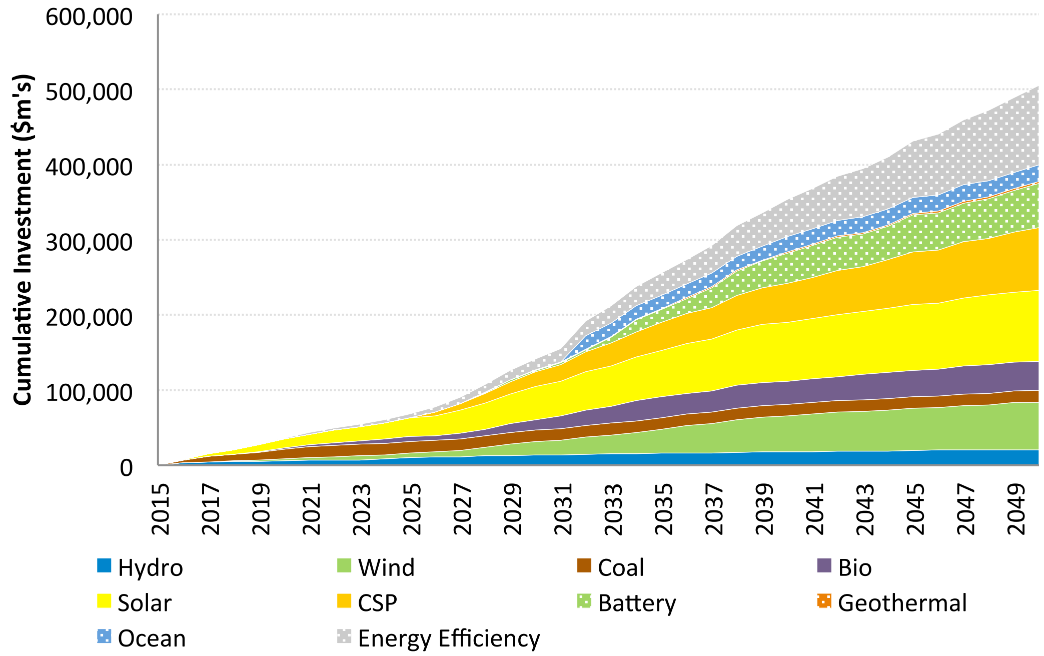


Figure 100, Figure 101, and Figure 102 plot the cumulative investment split for imports and exports. The BAU investment cost is primarily for its own electricity demand with only small amounts of power exported into Cambodia. By 2050, $341 billion is required to develop the BAU generation requirements. In the SES, $368 billion is required to develop generation projects (and energy efficiency) in Viet Nam, with a further $47 billion on projects outside Viet Nam, or $75 billion more than the BAU by 2050. The ASES adds an additional $90 billion bringing the total investment to $506 billion by 2050, or $265 billion more than the BAU at 2050.

Figure 100 Viet Nam Cumulative Investment of BAU (Real 2014 USD)

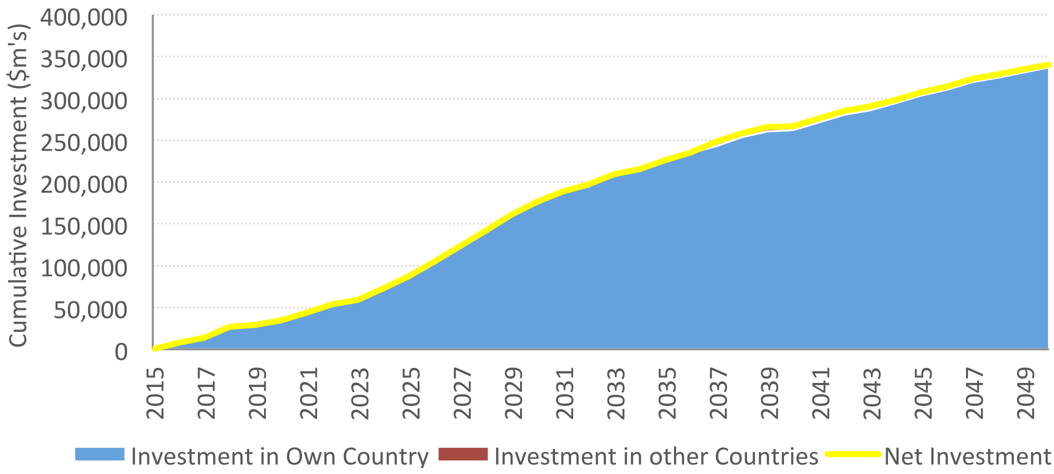


Figure 101 Viet Nam Cumulative Investment of SES (Real 2014 USD)

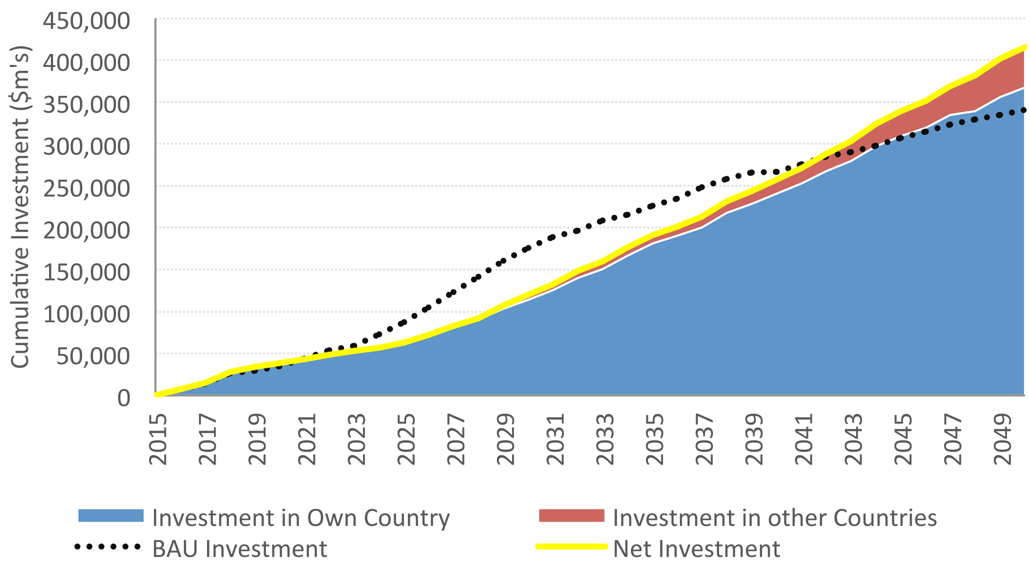
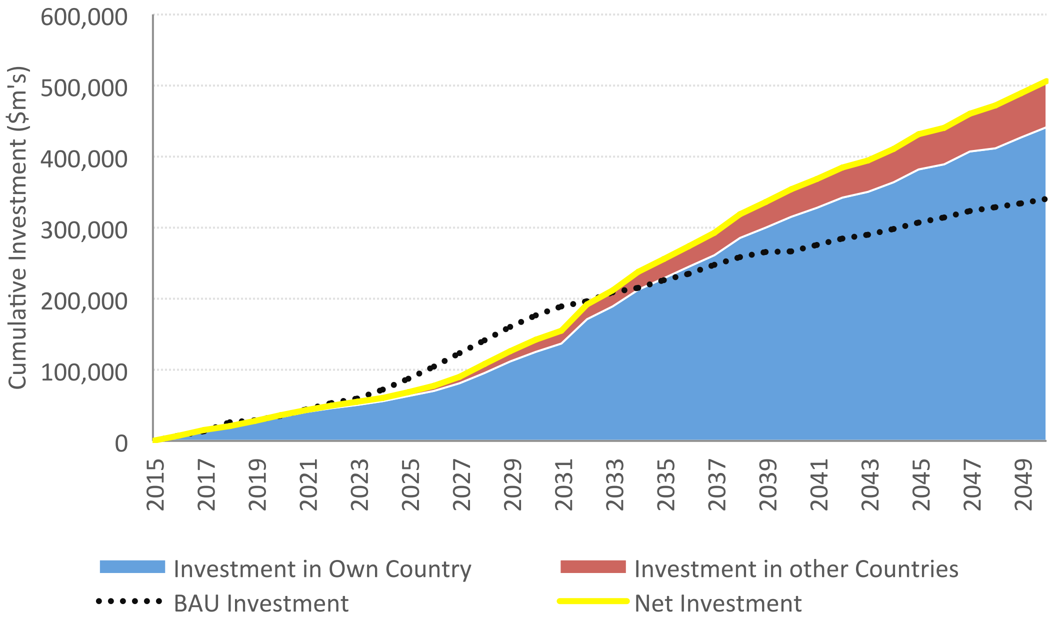


Figure 102 Viet Nam Cumulative Investment of ASES (Real 2014 USD)



9.4 Operating Costs, Amortised Capital Costs and Energy Efficiency Costs

Figure 103 plots the total capex, opex and energy efficiency costs as a proportion of total forecast GDP. Capital expenditure has been amortised over the life of the project to derive annual capex figures. The BAU rises to almost 9.5% of GDP mainly driven by the ramp up in fuel costs before declining as the LCOE drops and GDP continues to increase. The SES and ASES costs trend down towards 5% by 2050. Figure 104, Figure 105, and Figure 106 plots the total annual system cost by component for each of the scenarios.

Figure 103 Total Capex, Opex and Energy Efficiency over GDP

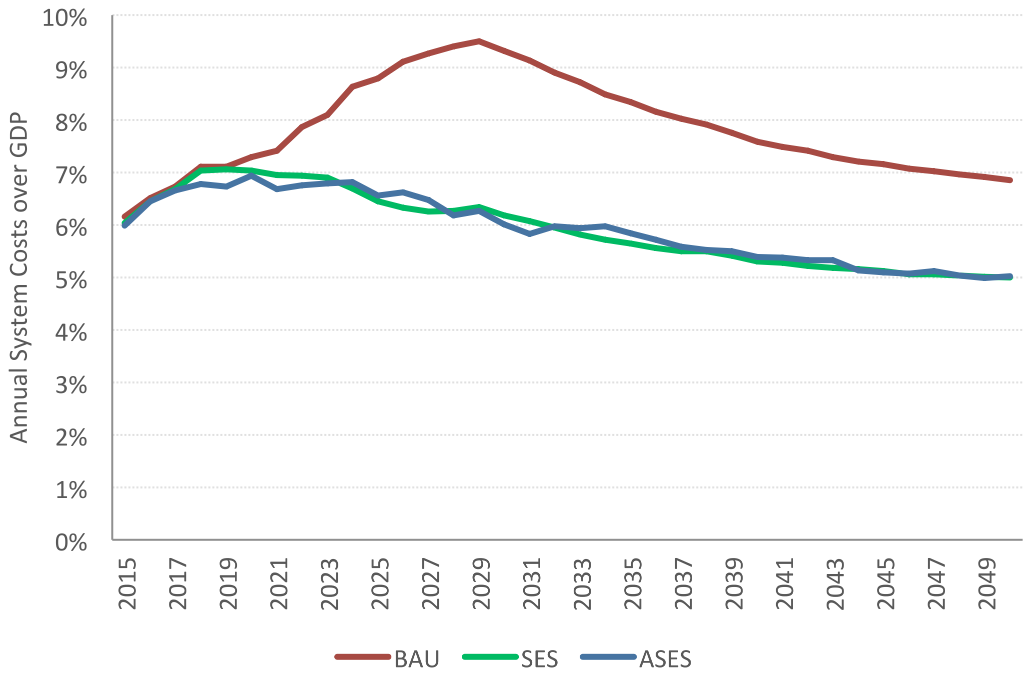


Figure 104 Total System Cost by Type (BAU)

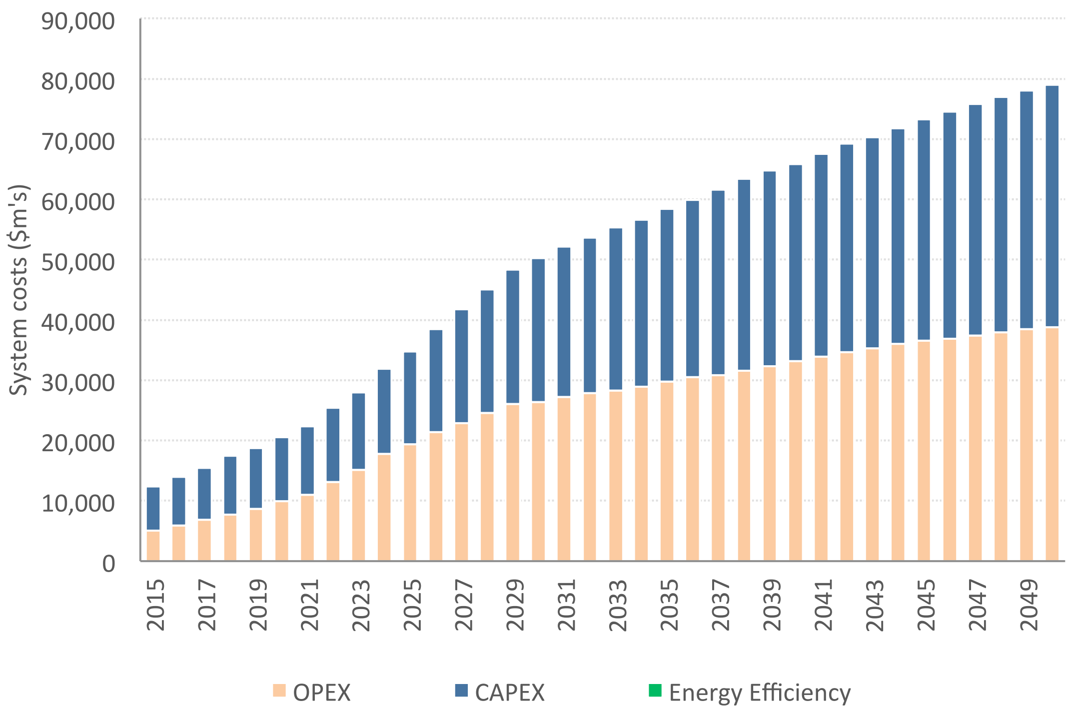


Figure 105 Total System Cost by Type (SES)

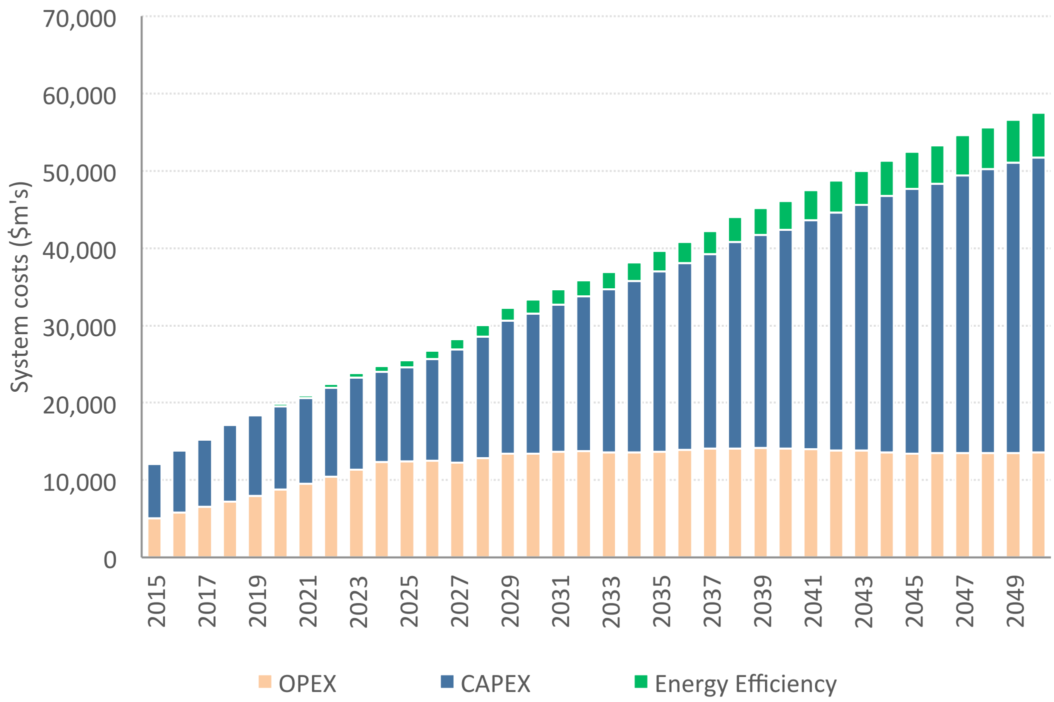


Figure 106 Total System Cost by Type (ASES)

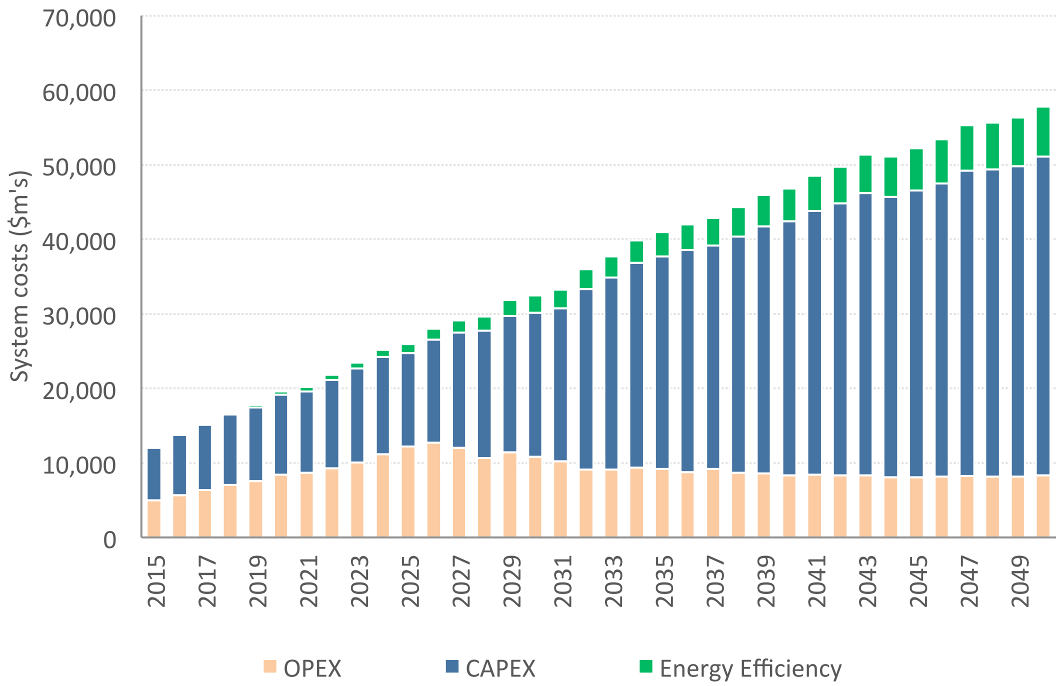


Figure 107 and Figure 108 plot the difference in amortised capex, opex and energy efficiency costs between the SES and BAU, and ASES and BAU respectively. The costs have also been adjusted for exports and imports. Positive amounts represent an additional investment required in either the SES/ASES and negative amounts correspond to cost savings.

For the SES against BAU case, the fuel savings are immediate as renewable developments displace traditional fossil fuels rising past $23 billion a year by 2050 (noting demand differences between the two scenarios). Capex in the short-term is more expensive in the BAU also owing to the demand difference. Energy efficiency is assumed to cost up to $6 billion a year by 2050. Across all three categories, the net result is a cost saving of up to $21 billion a year by 2050.

The ASES follows similar trends to the SES with the noticeable difference of capex savings from 2030 onwards attributable to the replacement of retiring conventional plant with renewable technologies even with the assumed acceleration of capital cost drops. By 2050 the savings amount to $21 billion a year.

Figure 107 Difference in Capex, Opex and Energy Efficiency Costs (SES and BAU)

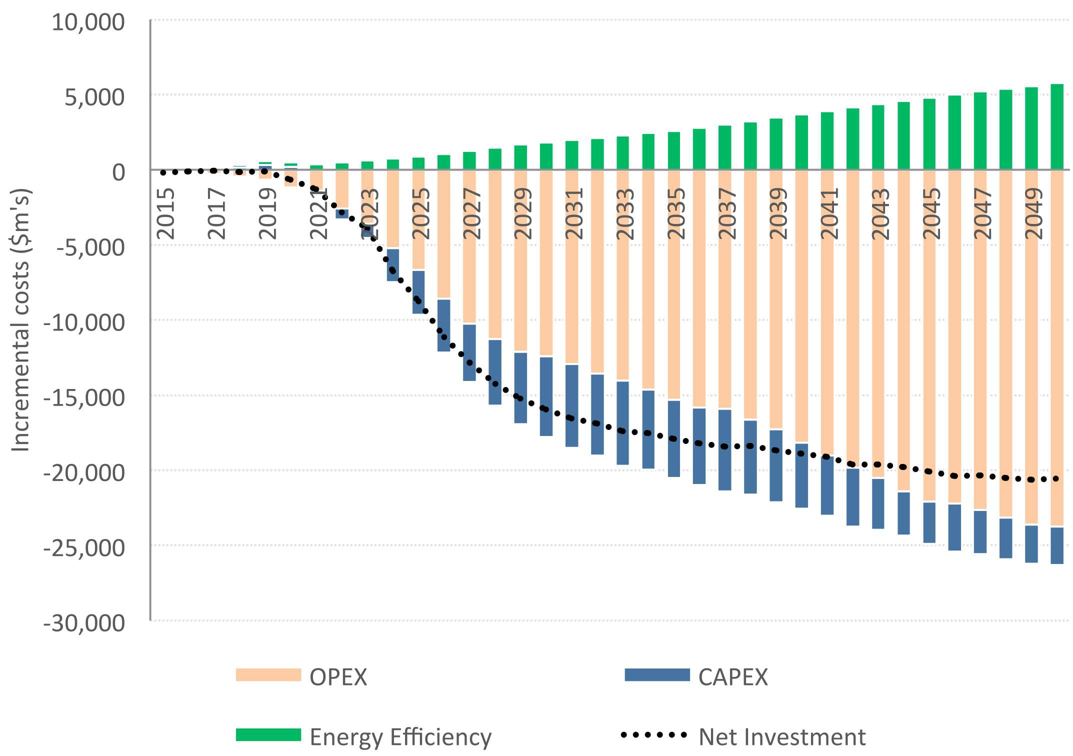


Figure 108 Difference in Capex, Opex and Energy Efficiency Costs (ASES and BAU)

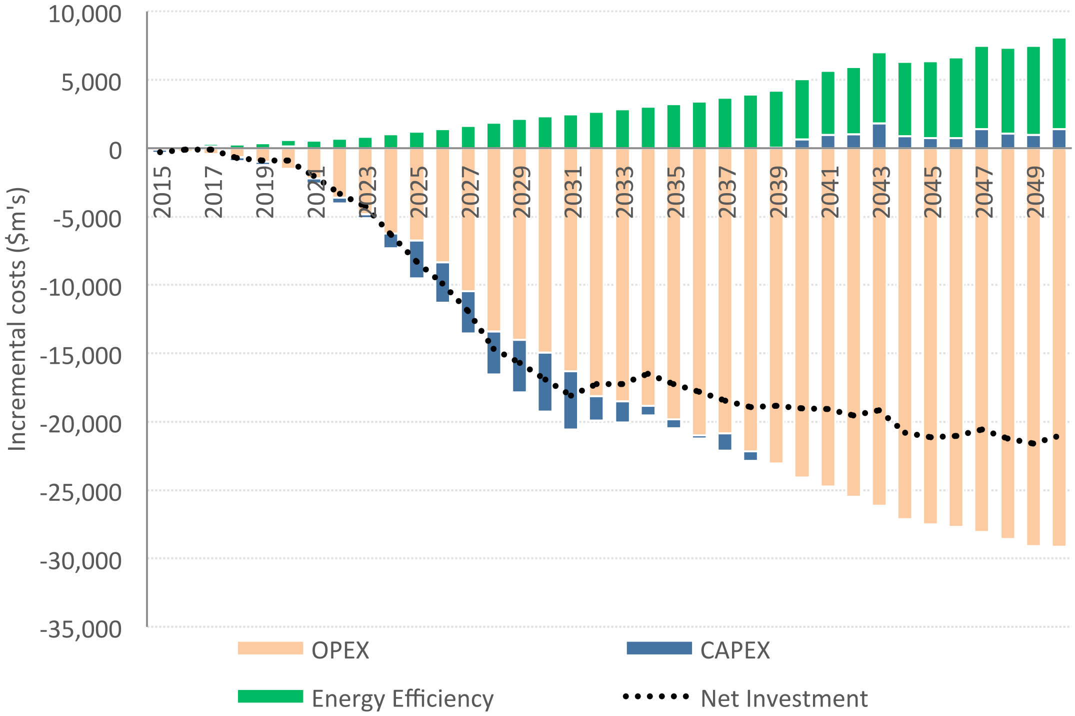


Figure 109 NPV of System Costs over 2015 to 2050 period

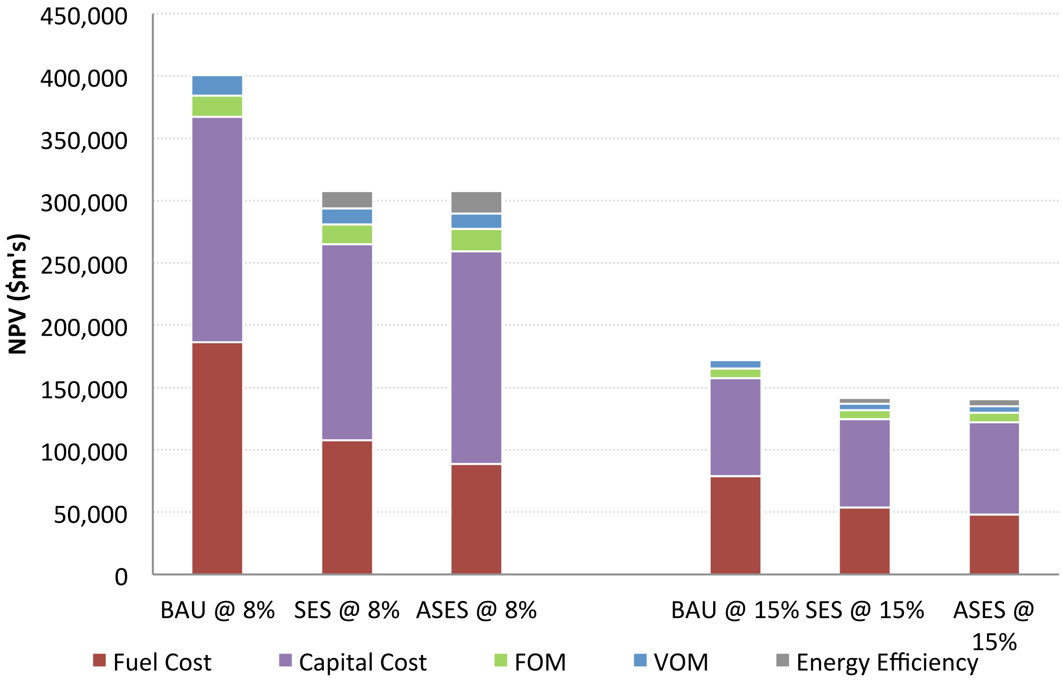


Figure 109 charts the net present value of the power system costs by component using an 8% and 15% discount rate. Figures are tabulated in Table 24. The BAU is comprised of a higher percentage of fuel costs, whereas the ASES has the highest percentage relating to capital costs. The total NPV difference between the BAU and ASES is approximately $93 billion using an 8% discount rate.

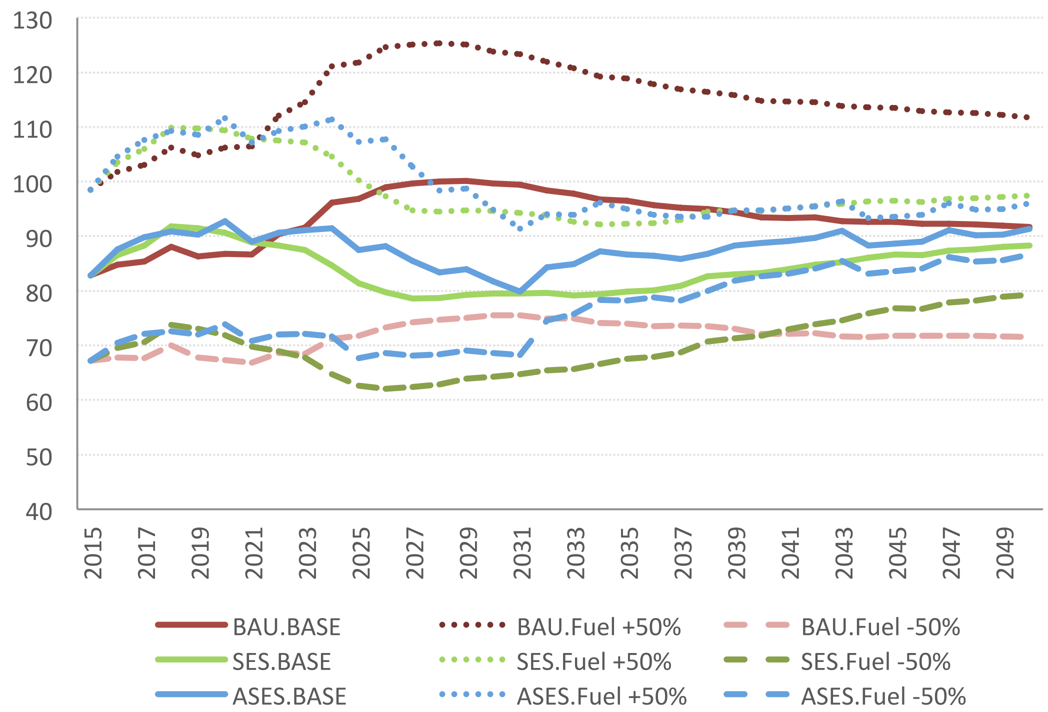
Table 24 NPV of System Costs (Real USD 2014)

NPV ($m's)	BAU @ 8%	SES @ 8%	ASES @ 8%	BAU @ 15%	SES @ 15%	ASES @ 15%
Fuel Cost	186,414	107,667	88,429	78,841	53,804	47,941
Capital Cost	181,061	157,405	171,053	78,751	70,816	74,141
FOM	16,590	15,774	17,781	7,471	7,065	7,529
VOM	16,637	12,781	12,565	6,720	5,513	5,325
Energy Efficiency	0	14,056	17,655	0	4,329	5,644
Total	400,703	307,683	307,484	171,783	141,527	140,581

9.5 Fuel Price Sensitivity

Figure 110 plots the LCOE of the BAU and SES as discussed in section 9.1. In addition, it plots the LCOE for BAU and SES for a 50% increase to the fuel prices, which reflects the difference between IEA's crude oil pricing under the 450 Scenario and the Current Policies Scenario ($95/bbl and $150/bbl respectively). It can be seen that the LCOE of the BAU rises more against a fuel price increase compared with the SES and ASES, as would be anticipated as a direct consequence of having a higher thermal generation share in the BAU compared to renewable energy in the SES and ASES. The SES increases, and the ASES to a smaller extent, as a consequence of bioenergy generation, but as can be seen it is far less sensitive to fuel price shocks than the BAU.

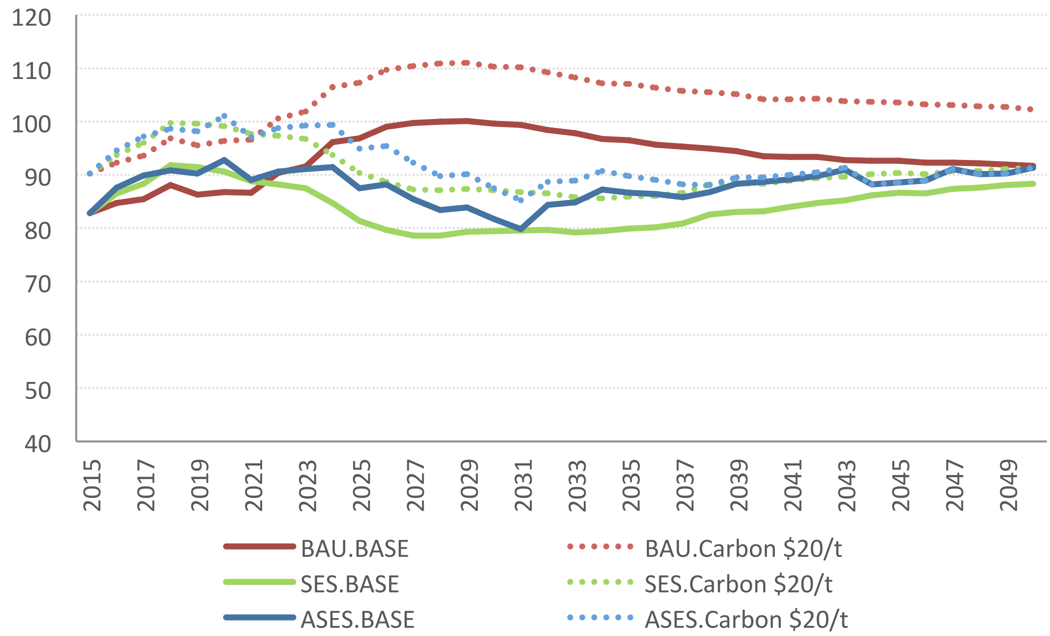
Figure 110 Viet Nam Fuel Price Sensitivity ($/MWh)



9.6 Impact of a Carbon Price

In a similar way to the previous section, Figure 111 plots the LCOE under the ASES, SES and BAU under a carbon price scenario. The carbon scenario puts a $20/t-CO2 impost throughout the entire modelled period. This is intended to show the sensitivity of the BAU and SES to the carbon prices. In a similar way to the previous section, this shows that LCOE in the SES is relatively insensitive ($3/MWh), and the ASES insensitive, to carbon prices by 2050 while for the BAU, it adds an additional $11 Real 2014 USD/MWh to the LCOE.

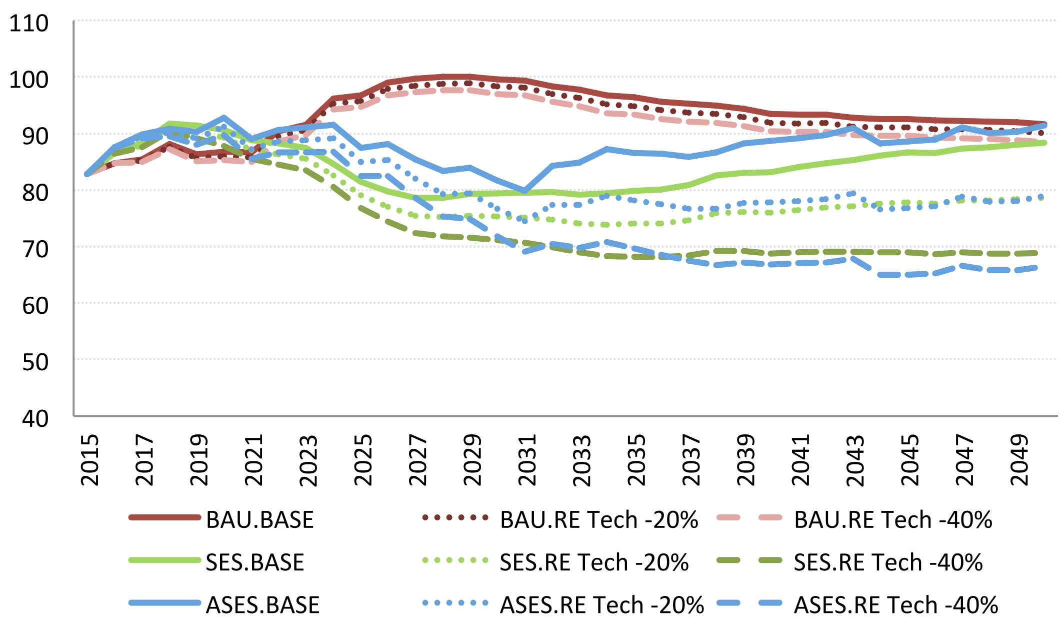
Figure 111 Viet Nam Carbon Sensitivities ($/MWh)



9.7 Renewable Technology Cost Sensitivity

Figure 112 shows the LCOE sensitivity to 20% and 40% decreases in renewable technology costs. As expected the ASES followed by the SES is the most sensitive with potential declines of up to $25/MWh from the base under the highest sensitivity case.

Figure 112 Viet Nam Renewable Technology Cost Sensitivities ($/MWh)



9.8 Jobs Creation

To assess the implications for Job Creation for each scenario we applied the methodology used by the Climate Institute of Australia. The methodology is summarised in Appendix C. The numbers of jobs created for each of the scenarios are shown in Figure 113, Figure 114 and Figure 115. The job categories shown include: manufacturing, construction, operations and maintenance and fuel supply management. Figure 116 provides a comparison of total jobs created for BAU, SES and ASES. The key observations are:

- Across all scenarios, manufacturing and construction account for most of the jobs with a much smaller share attributable to O&M and fuel supply.
- The BAU job creation profile peaks at around 260,000 jobs compared to SES job creation peaking towards 430,000 or almost twice that in the BAU. This is entirely driven by renewable energy developments that require more jobs in the manufacturing and construction phases.
- The ASES job creation peaks at 700,000 jobs, or more than three times that of the BAU driven by even more renewable energy projects required as the region moves towards a 100% renewable generation target by 2050.
- Different skills are required between the scenarios, BAU has people working on conventional coal and hydro, whereas the SES and ASES has people mainly working on solar & battery storage systems.
- Note that the manufacturing and fuel supply jobs shown to be created may not be created within Viet Nam with manufacturing of equipment and fuel management (for imported fuels) occurring in other countries.

Figure 113 Job Creation by Category (BAU)

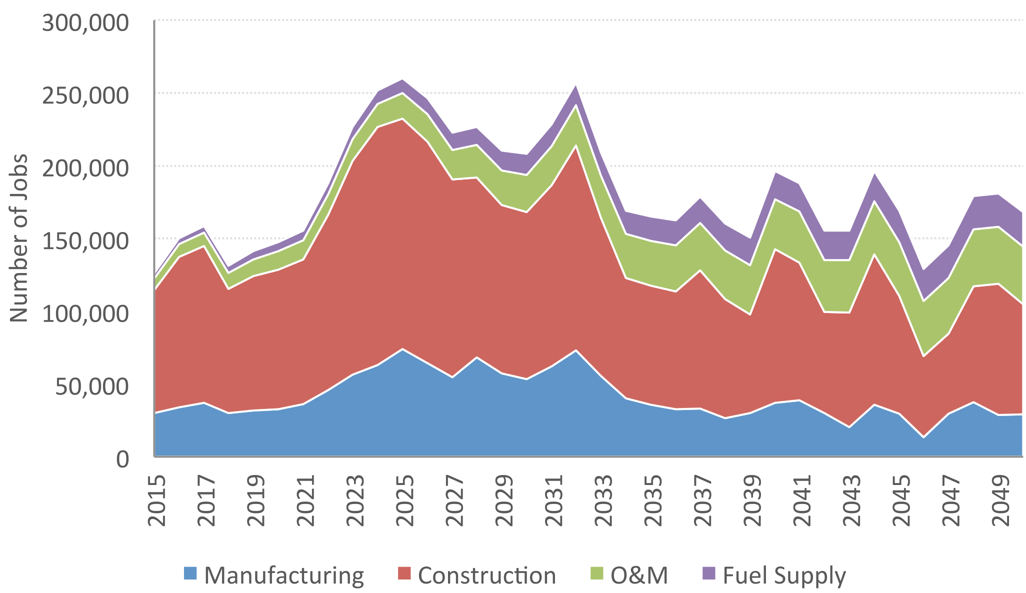


Figure 114 Job Creation by Category (SES)

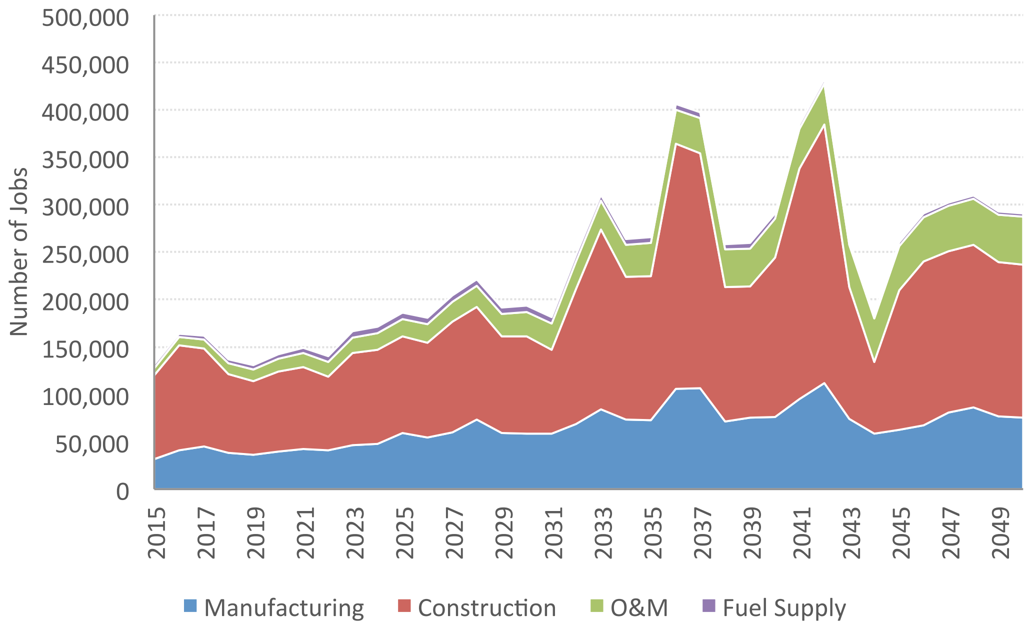


Figure 115 Job Creation by Category (ASES)

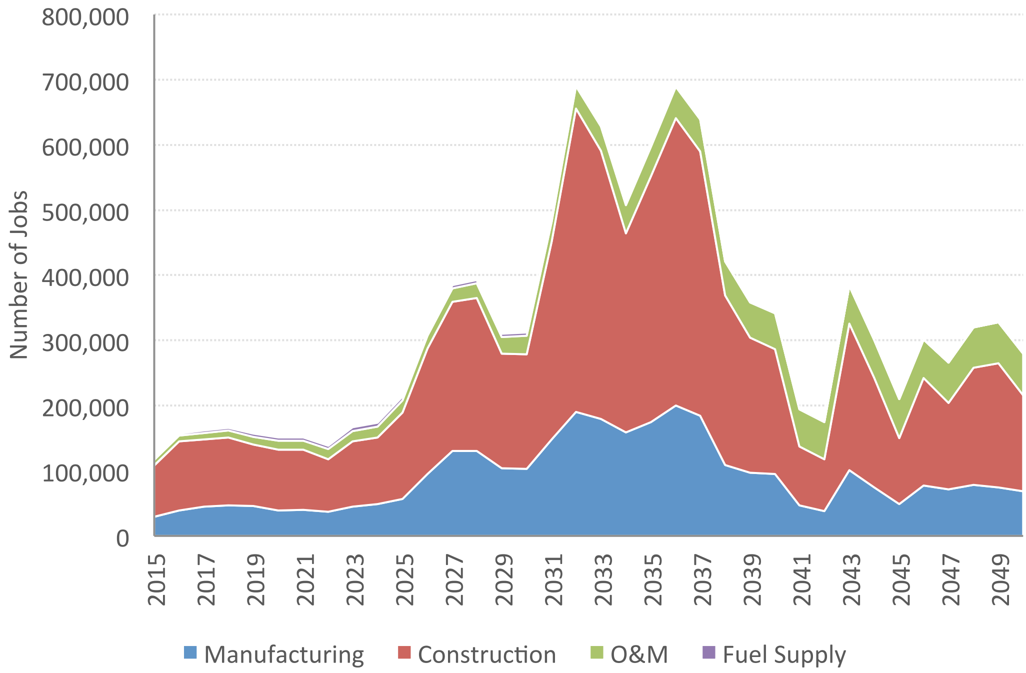
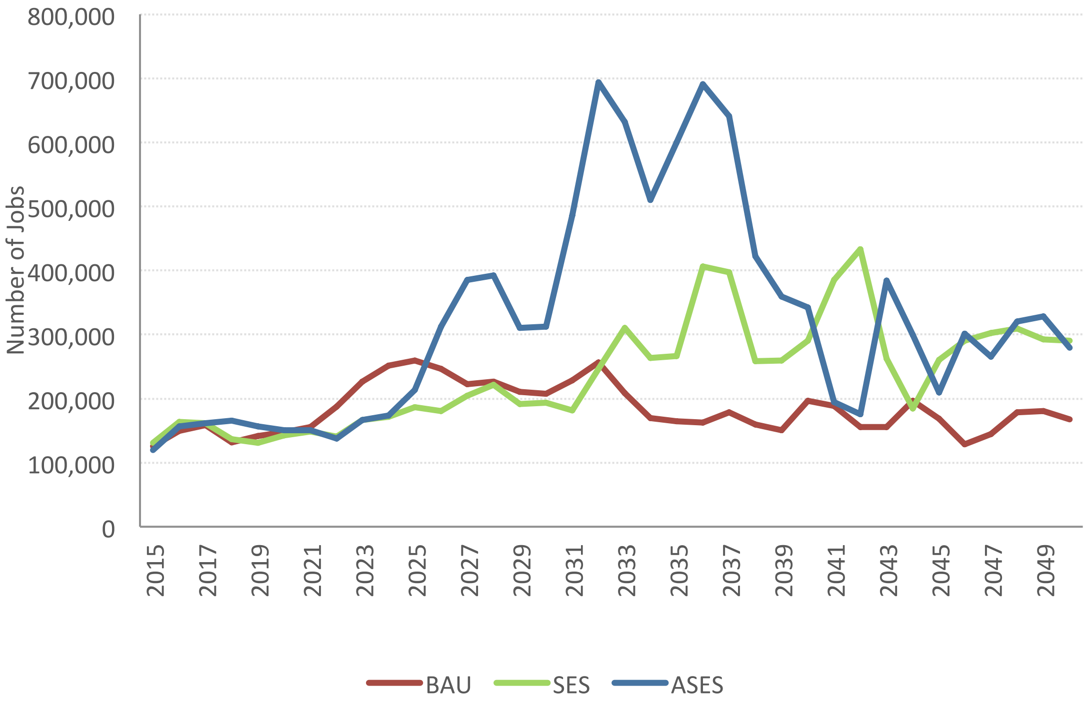


Figure 116 Total Job Creation Comparison BAU, SES and ASES



10 Conclusions

As with a number of other countries in the region Viet Nam's economy has experienced high levels of growth which have been accompanied by very high electricity demand growth rates. Even with a slight softening in the economic outlook for the country in the last year, basic analysis shows that electricity demand growth rates in the country will be relatively high into the near term future. This is more so the case given long-term strategic plans by the Government to focus on transitioning the economy towards one where the industrial sector plays a larger role than at present. Accompanying economic growth has been an increase in the living standards, which has translated into increasing levels of household electricity consumption, particularly in urban areas. These trends have put pressure on the existing infrastructure including distribution networks, transmission networks and generation facilities to ensure a stable and reliable flow of electrical energy is provided to end users.

Viet Nam is endowed with a diverse set of primary energy resources, including domestic coal, offshore natural gas reserves, biomass, biogas, solar, large and small-scale hydro, onshore and offshore wind, geothermal, and marine-based technologies such as tidal and wave. While each of these resources has its own set of challenges, they provide the basis for developing a range of possible development paths for the country's electricity industry. A summary of the main resource development options available to Viet Nam is as follows:

- **Domestic coal**. There are reserves of lignite and sub-bituminous grades of coal with reserves that can support domestic generation projects;
- **Imported coal**. Viet Nam has a coastline that spans some 3260 km which provides a number of sites that would allow for the development of coal import and storage facilities to support coal projects at locations that are convenient given the transmission network structure and location of load centres.
- **Natural gas and LNG**. Viet Nam is estimated to have some 617 Bcm (21.8 Tcf) of proved reserves, or around 52% of the total proved natural gas reserves of the GMS. The country currently produces gas from a number of offshore fields and there are additional offshore gas reserves that could be further exploited. In Viet Nam, there has also been considerable thought put into the development of an LNG terminal to support ongoing gas in Viet Nam, although it presently seems unlikely that an LNG import facilities would be in place before 2020.
- **Nuclear Power.** Viet Nam has in place agreements with Russia and Japan to build nuclear power projects of 2400 MW and 2000 MW respectively[64]; both planned to be constructed in the Ninh Thuan province. Nuclear power

[64] World Nuclear Association, www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Vietnam, October 2015.

features in Viet Nam's power development plans, although the dates of first generation from a nuclear power are uncertain.

- **Large Hydro.** Viet Nam has largely exploited all of the large scale hydro considered to be economically feasible and sustainable; further development beyond what has been exploited to date and what is under construction now is not considered an option.
- **Small, mini, and micro hydro**. Viet Nam has untapped small scale hydro potential and a further 3000 MW is estimated to be developed beyond what has been exploited to date. However, concerns have been raised on small hydro projects in the country based on considerations of the low levels of efficiency achieved from some projects relative to the environmental externalities.
- **Pumped storage hydro**. Viet Nam does not presently have any pumped storage hydro plant in operation. However, feasibility studies have been carried out and show that pumped storage power plant may be feasible with the south and central regions offering the most favourable geographical conditions.
- **Onshore and offshore wind**. Viet Nam is considered to have very good onshore and offshore wind energy potential with coastal areas in the central and south regions among the best locations in Viet Nam as well as a number of locations in the mountainous areas in the central region.
- **Solar Energy**. Viet Nam is considered to have very high potential for the development of solar energy resources both in terms of flatbed solar photovoltaic installations as well as concentrated solar power (CSP) projects, in the central and south regions.
- **Geothermal**. The country is recognised to have a limited amount of geothermal potential with some 300 MW to 400 MW having been identified to date.
- **Ocean.** Viet Nam is considered to have significant ocean/marine energy resources with its high wave resource potential (40-411 kW/m) and long coastline.
- **Bio Generation (Biomass and biogas)**. Viet Nam has potential for power generation from biomass and biogas sources from its agricultural residues and livestock with current production levels equivalent to support 30,000 GWh of electricity production.
- **Power Imports**. Power import projects from neighbouring countries beyond those already in place are possible and being explored in Viet Nam.

In this report we have presented the findings of power system modelling of Viet Nam's power system for Business as Usual (BAU), Sustainable Energy Sector (SES) and Advanced SES (ASES) scenarios. The BAU outlook assumed that future power sector developments would be based on continued large scale hydro development and coal. The SES and ASES have both taken measures to deploy a maximal amount of renewable energy and energy efficiency measures in order to provide some alternative scenarios for the country. The SES and ASES both also assume a more rapid program of cross-border interconnection in the GMS, which allows the region to more fully exploit diversity in demand as well as geographically dispersed areas with high renewable energy potential.

10.1 Comparison of Scenarios

The following are the key conclusions that have been drawn from the analysis presented in this report:

- The SES delivers an energy efficiency gain beyond the BAU case of about 32% compared to the BAU. The ASES delivers efficiency gains of 34% after doubling transport electricity demand;
- The SES is able to achieve a power system that delivers 81% of generation from renewable energy resources (including large-scale hydro) by 2050. In contrast, 24% of the generation in the BAU is provided by renewable energy resources[65];
- By 2050, the SES and ASES avoid around 383 and 461 million tons of greenhouse gas emissions per year compared to the BAU. The SES intensity declines to 0.15 t-CO2/MWh by 2050 vs. 0.53 t-CO2/MWh for the BAU case. The BAU case achieves a higher emissions intensity level because of increased coal generation reliance while the SES delivers a low emissions intensity due to widespread deployment of solar and wind technologies. The ASES reaches 100% renewable generation by 2050.
- Based on some simple measures for energy security:
  - Under the ASES and SES, Viet Nam benefits from a more diverse mix of technologies and is not as dependent on a single source of primary energy as the BAU; for example the BAU is highly dependent on imported coal, while the SES and ASES diversify supply across a range of renewable energy technologies with no generation type accounting for more than 20% and 25% of the generation share.;
  - The ASES and SES have around 88% of their electricity being generated from domestically controlled and managed resources, while the BAU needs to import primary energy resources in the form of gas and coal, which drive down the level of domestic control and management of primary energy resources – by 2050 this level reaches around 51% in the BAU. Under the ASES and SES generation developments are optimised across the region and Viet Nam imports up to 15% of its requirements by 2050; and
  - The ASES and SES achieve a reliable power system through coordination on both the supply and demand side of the industry, with similar energy reserve margins as the BAU. Modelling has shown that the SES is

[65] Large-scale hydro is included

operationally feasible (even with less directly dispatchable resources in the SES compared to the BAU), but stress testing of the SES scenarios against more significant threats to the operation of the power system would help to understand and develop appropriate mitigation measures if required. A key condition for this scenario to be operationally feasible in practice is real-time monitoring and control systems for all elements of the power system, near real-time and automated dispatch operations, and high quality forecasting systems for solar and wind energy.

- The ASES is a more ambitious scenario that contains a more rapid transition towards a power system that is based entirely on renewable energy by 2050. While this is operationally feasible in terms of supply and demand we have not analysed in detail issues such as voltage and dynamic stability. This scenario is more dependent on having in place appropriate real-time monitoring and control systems.

10.2 Economic Implications

10.2.1 Cost of Electricity

Based on the outcomes of modelling the BAU, SES and ASES scenarios, we also examined the following issues in relation to electricity costs: (1) levelised cost of electricity, (2) investment requirements, (3) sensitivity of electricity prices to fuel price shocks, and (4) the implications of a price on carbon equivalent emissions for electricity prices. Based on this analysis we draw the following conclusions:

- The BAU requires lower levels of capital investment than the SES, and in relation to generation costs, the SES and ASES across the modelling period delivers a lower overall short-run marginal cost of electricity and LCOE to Viet Nam;
- Under the SES and ASES significant benefits are gained in the form of avoided fuel costs and this contributes to achieving a lower overall cost of electricity for Viet Nam. The observation is made that the composition of LCOE under the SES and ASES is largely driven by investment costs, hence exposure to fuel shocks is significantly reduce; and
- The LCOE under the SES and ASES is also largely insensitive to a carbon price, as could be reasonably anticipated for a power system that is entirely dominated by renewable energy.

10.2.2 Investment Implications

From 2015 to 2050, the total cumulative investment in BAU, SES and ASES is respectively: $341 billion, $415 billion, and $506 billion (Real 2014 USD). The composition of the investments between BAU and the SES/ASES are quite different:

- 59% of the cumulative investments in the BAU are directed to coal, followed by 12% nuclear, 6% coal, 4% gas and the rest being a combination of renewables;
- In the SES/ASES, investments are more diverse:
  - SES has 28% solar and battery, 22% CSP, 11% wind, 21% energy efficiency and 7% bioenergy; and
  - ASES has 31% solar and battery, 21% energy efficiency, 13% wind, 17% CSP, and 8% bioenergy.

10.2.3 Jobs Creation

The SES and ASES scenarios both result in quite different technology mixes for Viet Nam compared to the BAU. The SES and ASES have different implications for the workforce that would need to be developed to support each scenario. Based on estimates of job creation, we estimate that[66]:

- The BAU from 2015 to 2050 would be accompanied by the creation of some 6.6m jobs years[67] (17% manufacturing, 45% construction, 24% operations and maintenance, and 14% fuel supply);
- The SES would involve the creation of some 8.6 million job years (26% in manufacturing, 55% in construction, 17% in operations and maintenance and 1% in fuel supply); and
- The ASES would involve the creation of 11.6 million job years (25% in manufacturing, 52% in construction, 23% in operations and maintenance and less than 1% in fuel supply).

10.3 Identified Barriers for the SES and ASES

There are numerous barriers to development of renewable energy in Viet Nam[68]:

- Policy and institutional barriers include:
  - absence of clearly defined national strategies and legally bound targets for renewable energy, lack of a uniform legal framework with high level legislations such as a law or a degree to stipulate and mandate strong mechanisms for development of renewable energy;
  - a lack of reliable detailed studies or planning at the national level to assess potential and establish targets for different forms of renewable energy (this is being progressively addressed as national plans for biomass and wind power development should be carried out by the MOIT); and

[66] Based on the employment factors presented in Appendix C.
[67] A job year is one job for one person for one year. We use this measure to make comparisons easier across each scenario as the number of jobs created fluctuates from year to year.
[68] This information in this section is based on various reports including: IE Study on Renewable Energy Development in Viet Nam (2009) and the USAID-sponsored study on Off-Grid Opportunities and Challenges in Viet Nam (2014).

- absence of a state-level focal point organisation dedicated to managing the renewable energy area (currently the RE is overseen by a department within the GDE but there have been suggestions for establishing a national committee for renewable energy[69]).

- Technical barriers:
  - overall knowledge on renewable energy technology in the country is remains limited;
  - absence of training organisations and facility leading to a lack of qualified experts and skilled technicians;
  - Viet Nam does not have trade companies who can supply renewable energy equipment and related services. Most of renewable energy technologies are imported with limited after installation service;
  - absence of adequate and reliable technical data / measurements as regards renewable energy potentials; and
  - lack of design and operational and safety standards.
- Economic and financial barriers:
  - lack of adequate incentive mechanisms for development of renewable energy sources and lack of financial support mechanisms in place for some forms of renewable energy: solar and geothermal for example;
  - high investment costs and high electricity production cost, which is partly due to the limitations in access to appropriate technology and skilled manpower plus the economy of scale factor;
  - difficulty in accessing financial sources for renewables energy projects which are highly capital intensive; and
  - significant subsidies for conventional electricity discouraging investments into renewable energy.
- Barriers for specific renewable energy technologies
  - Small hydro power: for *Off-grid generators:* Cheap and low quality technology imported from China is still dominating in the off-grid remote mountainous areas in Viet Nam. This course of development is regarded unsustainable as the site installations usually lack of proper operator training, lack of manuals translated into Vietnamese and poor commissioning procedures. There is limited spare part availability for replacement and repairs and lack of knowledge on repair and/or spare parts can stop a whole system from working. *Grid-connected plants:* Investors in small hydro power projects have been expressing a concern related to the unpredictable movements in the administered avoided cost tariff prices over the economic life of the project.

[69] http://nangluongvietnam.vn/news/vn/du-bao-kien-nghi/kien-nghi-thanh-lap-uy-ban-quoc-gia-ve-nang-luong-tai-tao-viet-nam.html

- Wind power: issues include: (1) lack of experience and technology that have been tested under Viet Nam's particular conditions (high risk of typhoon, high humidity, etc.), (2) absence of management and business models for successful O&M of a wind farm, even for small wind farms suitable for application to Viet Nam's offshore Islands (where wind-diesel hybrids represent an important option to lower the costs of traditional diesel generation), (3) some of the provinces with good wind potentials such as Binh Tuan and Ninh Thuan are also rich in minerals which creates a conflict in land use (wind parks vs. mines).
- Solar power: (1) a particular policy and legal framework to support solar power installations is yet to be developed in Viet Nam, (2) local producers of solar equipment and appliances have difficulties competing in quality with imported panels and side equipment from Europe and China, and the equipment failure rate is high, and therefore the trust in local equipment is low, (3) there are no standards reported for solar technologies; performance standards, equipment certification and codes of practice for quality control need to be developed and accepted; lack of incentives for the establishment and adherence to such technical standards.
- Biomass: (1) While there exist various proven and highly efficient biomass power technologies in the world for grid-connected power generation, they are still not well known in Viet Nam and not many local companies supplying biomass power technologies. Most of the technologies are imported without consulting and technical services for biomass power technologies, especially maintenance and repair services after installation. (2) Locations of the residues are scattered throughout the country. For example, rice is not always processed in a central, large scale, location so the residues are normally spread over a large area especially in the remote areas. As a result a RE system needs to be developed where residues can be efficiently collected and transported to - at a central power station or processing location. This also makes contracting of the biomass sourcing difficult. Transport from inland or remote areas to the commune or hamlet centre for decentralised production might be a financial barrier for the farmers, and potentially even a logistical barrier (due to the bad roads).
- Biogas: Electricity production from biogas has faced very specific technology barriers, in particular, fragmented and artisan production of spare parts and instruments which means the quality and compatibility of the equipment and spare parts replaced as the technology is not standardised. Due to lack of spare parts to replace, many projects cannot operate efficiently at full capacity.

• Barriers related to energy efficiency include:
  - Information barrier: Energy users remain unaware of potential energy savings and their financial benefit, and how to attain them. Many

consumers, especially in commercial or industrial establishments, actually have little concrete idea of the potential for energy savings in their businesses, and how much money could be saved through improved management or modest investment.

- Expertise barrier: Appropriate expertise to advise clients on energy savings options and conduct energy audits is not readily available locally. Experts with established track records in implementing projects are especially valuable for providing advice derived from actual experience rather than theoretical calculation. Expanding and improving the qualifications of local experts is an area that requires major efforts in Viet Nam.
- Energy Pricing Barrier: Higher and cost reflective energy prices are an exceptionally powerful force to attract attention to energy efficiency and to increase incentives for action. In Viet Nam, prices paid for energy are low relative to those in most other countries. Despite frequent increases, the actual level of electricity tariffs has not risen in real terms over the past decade. Domestic coal prices are well below levels in other countries. Although solid returns on a wide range of energy-efficiency investments still exist, incentives and investment results could be sharply improved if energy prices better reflected international levels.
- Cost-consciousness barrier: Consumers are not always interested in reducing operating costs. In some state-owned enterprises, reducing operating costs, such as energy or water utility costs, may not be a priority to managers, even if quite profitable. In addition, when economic growth is robust, commercial and industrial establishments may naturally place greater emphasis on the expansion or introduction of new products to increase market share, and investments for long-term payoff in operating cost savings may be assigned lower priority for the time being.

- Other factors that impede the development of renewable energy and application of energy efficiency measures in Viet Nam might include:
  - Lack of social acceptance and support for clean energy.
  - Low awareness among customers and in wider communities about the benefits from renewable energy and energy savings, and about environmental damage costs resulted from use of fossil fuels; and
  - Lack of educational and information strategies and plans.

10.4 Recommendations

The following are key recommendations to reduce the barriers and “enable” the SES and ASES:

- Formation of more comprehensive energy policies to create an environment that is appropriate for investment in renewable energy technologies and energy efficiency measures. Investor confidence in renewable energy investment will be enhanced by having a transparent regulatory framework that provides certainty to investors and appropriately considers the ramifications of high levels of renewable energy in the generation mix.

- Formation of electricity pricing policies and mechanisms that encourage efficient behavior and investment in generation technologies, transmission and distribution equipment and end use energy consumption.
- Continue efforts to perform more detailed assessments of renewable energy potential and make the results publicly available to enable prospective investors to understand the potential, identify the best opportunities and subsequently take steps to explore investment and deployment.
- Knowledge transfer and capability building in the renewable energy technologies and energy efficiency for policy makers, staff working in the energy industry, as well as within education institutions to ensure the human capacity is being developed to support a national power system that has a high share of generation from renewable energy. As we have shown the SES and ASES will require a large number of skilled workers to support a technology mix that is centred on renewable energy.
- Investments in ICT systems to enhance real-time power system operations of both supply and demand sides of the industry such as smart-grid technology and integration of renewable energy forecasting systems and tools into present systems for centralized real-time system operations. This will enable efficient real-time dispatch and control of all resources in Viet Nam's national power system and will create an environment more conducive for the management of high levels of renewable energy and flexible (dispatchable) demand.
- Take measures to encourage cross-border power trade in the region, as this works to the advantage of exploiting scattered renewable energy resource potentials and diversity in electricity demand. In particular:
  - Develop an overarching transmission plan that has been informed by detailed assessments and plans to leverage renewable energy potential in the region and diversity in demand and hydrological conditions. In the BAU, Viet Nam's power sector evolves to be almost entirely self-sufficient with only a small dependency on power imports from neighbouring countries. In the SES and ASES, the situation is quite different: power around 10% to 15% of Viet Nam's electricity consumption between 2030 to 2050 is satisfied by power imports and is the result of Viet Nam being more tightly integrated into a regional power network and one that has been developed to leverage scattered and diverse renewable energy potential.
  - Enhance technical standards and transmission codes in each country to allow for better interoperation of national power systems.
  - Establish dispatch protocols to better coordinate real-time dispatch of power systems in the region to make the best use of real-time information and continuously updated demand and renewable generation forecasts.

  - Develop a framework to encourage energy trade in the region, and in particular towards a model that can support multilateral power trading via a regional power market or exchange (for example).
- Take measures to improve power planning in the region to:
  - Explicitly account for project externalities and risks;
  - Evaluate a more diverse range of scenarios including those with high levels of renewable energy;
  - Take into consideration energy efficiency plans;
  - Take into consideration overarching plans to have tighter power system integration within the region; and
  - Carefully evaluate the economics of off-grid against grid connection where this is relevant.

Appendix A Technology Costs

Table 25sets out the technology cost assumptions that were used in the modelling presented in this report for the BAU and SES scenarios. Table 26sets out the technology costs used in the ASES. The technology costs of coal and gas do not include overheads associated with infrastructure to develop facilities for storing / managing fuel supplies. These costs were however accounted for in the modelling.

Figure 117 and Figure 118 presents the levelised cost of new entry generation based on assumed capacity factors. LCOE levels presented in Section 9 are based on weighted average LCOE's and modelled output and will differ from the LCOE's presented here. The LCOE for battery storage is combined with solar PV technology assuming 75% of generation is stored for off-peak generation.

Table 25 Technology Costs Assumptions for BAU and SES Scenarios

	Technology Capital Cost (Unit: Real 2014 USD/kW)			
Technology	**2015**	**2030**	**2040**	**2050**
Generic Coal	2,492	2,474	2,462	2,450
Coal with CCS	5,756	5,180	4,893	4,605
CCGT	942	935	930	926
GT	778	772	768	764
Wind Onshore	1,450	1,305	1,240	1,175
Wind Offshore	2,900	2,610	2,480	2,349
Hydro Large	2,100	2,200	2,275	2,350
Hydro Small	2,300	2,350	2,400	2,450
Pumped Storage	3,340	3,499	3,618	3,738
PV No Tracking	2,243	1,250	1,050	850
PV with Tracking	2,630	1,466	1,231	997
PV Thin Film	1,523	1,175	1,131	1,086
Battery Storage - Small	600	375	338	300
Battery - Utility Scale	500	225	213	200
Solar Thermal with Storage	8,513	5,500	4,750	4,000
Solar Thermal No Storage	5,226	4,170	3,937	3,703
Biomass	1,800	1,765	1,745	1,725
Geothermal	4,216	4,216	4,216	4,216
Ocean	9,887	8,500	7,188	5,875
Biogas (AD)	4,548	4,460	4,409	4,359

*Battery technology quoted on a $/kWh basis

Figure 117 Levelised Cost of New Entry (BAU & SES, $/MWh)

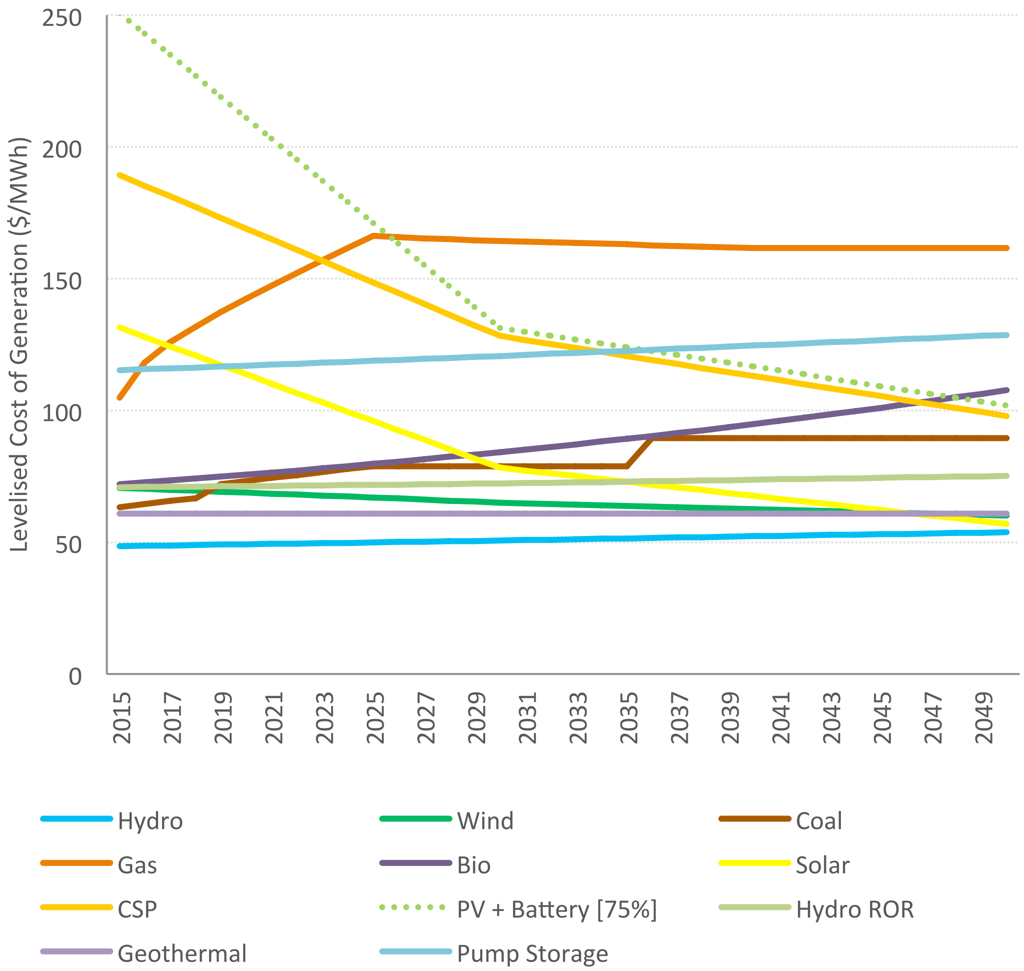
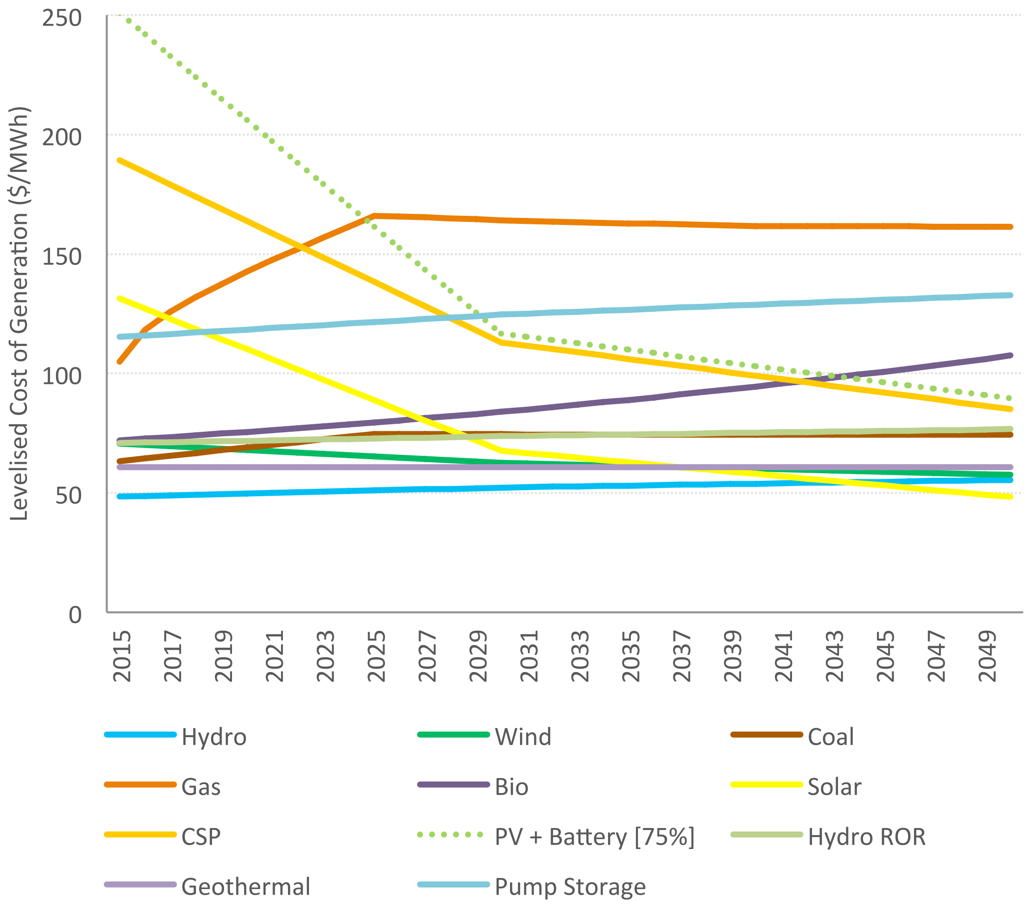


Table 26 Technology Costs Assumptions for ASES Scenarios

	Technology Capital Cost (Unit: Real 2014 USD/kW)			
Technology	**2015**	**2030**	**2040**	**2050**
Generic Coal	2,492	2,462	2,450	2,437
Coal with CCS	5,756	4,893	4,605	4,334
CCGT	942	930	926	921
GT	778	768	764	761
Wind Onshore	1,450	1,240	1,175	1,113
Wind Offshore	2,900	2,480	2,349	2,225
Hydro Large	2,100	2,275	2,350	2,427
Hydro Small	2,300	2,400	2,450	2,501
Pumped Storage	3,340	3,618	3,738	3,861
PV No Tracking	2,243	1,050	850	688
PV with Tracking	2,630	1,231	997	807
PV Thin Film	1,523	1,131	1,086	1,043
Battery Storage - Small	600	338	300	267
Battery - Utility Scale	500	213	200	188
Solar Thermal with Storage	8,513	4,750	4,000	3,368
Solar Thermal No Storage	5,226	3,937	3,703	3,483
Biomass	1,800	1,745	1,725	1,705
Geothermal	4,215	4,215	4,216	4,215
Wave	9,886	7,187	5,875	4,802
Biogas (AD)	4,548	4,358	4,308	4,259

*Battery technology quoted on a $/kWh basis

Figure 118 Levelised Cost of New Entry (ASES, $/MWh)



Appendix B Fuel Prices

Table 27 sets out the Free on board (FOB) fuel price assumptions that were used in the modelling presented in this report. This fuel price set was common to all three scenarios.

Table 27 Fuel Price Assumptions (Real 2014 USD/GJ)

Year	Coal	Gas	Diesel	Uranium	Fuel Oil	Biomass	Biogas
2015	2.39	10.08	13.34	0.72	9.13	2.57	1.00
2016	2.51	11.88	15.24	0.76	10.49	2.62	1.00
2017	2.63	12.91	15.28	0.80	11.68	2.67	1.00
2018	2.74	13.72	16.41	0.80	12.43	2.72	1.00
2019	2.86	14.47	17.53	0.80	13.18	2.78	1.00
2020	2.98	15.16	18.64	0.80	13.93	2.83	1.00
2021	3.10	15.81	19.73	0.80	14.65	2.89	1.00
2022	3.21	16.46	20.80	0.80	15.36	2.95	1.00
2023	3.33	17.10	21.86	0.80	16.06	3.01	1.00
2024	3.45	17.72	22.90	0.80	16.76	3.07	1.00
2025	3.56	18.34	23.93	0.80	17.44	3.13	1.00
2026	3.56	18.29	23.86	0.80	17.39	3.19	1.00
2027	3.56	18.24	23.79	0.80	17.34	3.25	1.00
2028	3.56	18.19	23.72	0.80	17.29	3.32	1.00
2029	3.56	18.14	23.65	0.80	17.24	3.39	1.00
2030	3.56	18.09	23.58	0.80	17.19	3.45	1.00
2031	3.56	18.06	23.53	0.80	17.15	3.52	1.00
2032	3.56	18.02	23.49	0.80	17.12	3.59	1.00
2033	3.56	17.99	23.44	0.80	17.08	3.67	1.00
2034	3.56	17.96	23.40	0.80	17.05	3.74	1.00
2035	3.56	17.92	23.35	0.80	17.02	3.81	1.00
2036	3.56	17.89	23.30	0.80	16.98	3.89	1.00
2037	3.56	17.86	23.26	0.80	16.95	3.97	1.00
2038	3.56	17.83	23.21	0.80	16.92	4.05	1.00
2039	3.56	17.79	23.16	0.80	16.88	4.13	1.00
2040	3.56	17.76	23.12	0.80	16.85	4.21	1.00
2041	3.56	17.76	23.12	0.80	16.85	4.29	1.00
2042	3.56	17.76	23.12	0.80	16.85	4.38	1.00
2043	3.56	17.76	23.12	0.80	16.85	4.47	1.00
2044	3.56	17.76	23.12	0.80	16.85	4.56	1.00
2045	3.56	17.76	23.12	0.80	16.85	4.65	1.00
2046	3.56	17.76	23.12	0.80	16.85	4.74	1.00
2047	3.56	17.76	23.12	0.80	16.85	4.84	1.00
2048	3.56	17.76	23.12	0.80	16.85	4.93	1.00
2049	3.56	17.76	23.12	0.80	16.85	5.03	1.00
2050	3.56	17.76	23.12	0.80	16.85	5.13	1.00

Appendix C Methodology for Jobs Creation

This section briefly summarises the methodology that we adopted for jobs creation. The methodology that we have adopted has been based on an approach developed by the Institute for Sustainable Futures at the University of Technology, Sydney and used by the Climate Institute of Australia[70]. In essence the jobs created in different economic sectors (manufacturing, construction, operations & maintenance and fuel sourcing and management) can be determined by the following with the information based on the numbers provided in Table 28.

Figure 119 Job Creation Calculations

Jobs = manufacturing + construction + operations and maintenance (O&M) + fuel, where:

Manufacturing	=	MW installed per year	x	Manufacturing employment multiplier	x	Annual decline factor (years)	x	% local manufacturing
Construction	=	MW installed per year	x	Construction employment multiplier	x	Annual decline factor years		
O&M	=	Cumulative capacity	x	O&M employment multiplier	x	Annual decline factor years		
Fuel supply (coal)	=	Electricity generation	x	Fuel employment multiplier	x	Annual decline factor years		
Fuel supply (gas)	=	Electricity generation	x	Fuel employment multiplier	x	Annual decline factor years	x	% local fuel supply

We have applied this methodology to the results in each scenario discussed in this report in order to make estimates of the jobs creation impacts and allow comparisons to be made[71].

[70] A description of the methodology can be found in the following reference: The Climate Institute, “Clean Energy Jobs in Regional Australia Methodology”, 2011, available: http://www.climateinstitute.org.au/verve/_resources/cleanenergyjobs_methodology.pdf.

[71] The percentage of local manufacturing and local fuel supply is assumed to be 1 to reflect the total job creation potential in total.

Table 28 Employment Factors for Different Technologies

	Annual decline applied to employment multiplier		Construction time	Construction	Manufacturing	Operations & maintenance	Fuel
Technology	**2010- 20**	**2020-30**	**years**	**per MW**	**per MW**	**per MW**	**per GWh**
Black coal	0.5%	0.5%	5	6.2	1.5	0.2	0.04 (include in O&M)
Brown coal	0.5%	0.5%	5	6.2	1.5	0.4	
Gas	0.5%	0.5%	2	1.4	0.1	0.1	0.04
Hydro	0.2%	0.2%	5	3.0	3.5	0.2	
Wind	0.5%	0.5%	2	2.5	12.5	0.2	
Bioenergy	0.5%	0.5%	2	2.0	0.1	1.0	
Geothermal	1.5%	0.5%	5	3.1	3.3	0.7	
Solar thermal generation	1.5%	1.0%	5	6.0	4.0	0.3	
SWH	1.0%	1.0%	1	10.9	3.0	0.0	
PV	1.0%	1.0%	1	29.0	9.0	0.4	

Appendix D Viet Nam Wind Resource Maps

This section provides a number of charts of Viet Nam's wind resource potential which is provided by IRENA's Global Atlas for Renewable Energy (http://irena.masdar.ac.ae/). These are intended to assist in gaining a better appreciation of the diversity of wind potential across Viet Nam.

D.1 Wind Speed Maps

Figure 120 shows simulated wind speeds for the years 2003-10 at 100m above ground level, measured in m/s, where features of the terrain are estimated and inferences made on wind speeds. Figure 121 shows generalised wind speeds for years 2003-10 at 100m above ground level, where terrain features are left as is. The descriptions of the charts are from IRENA's website respectively are:

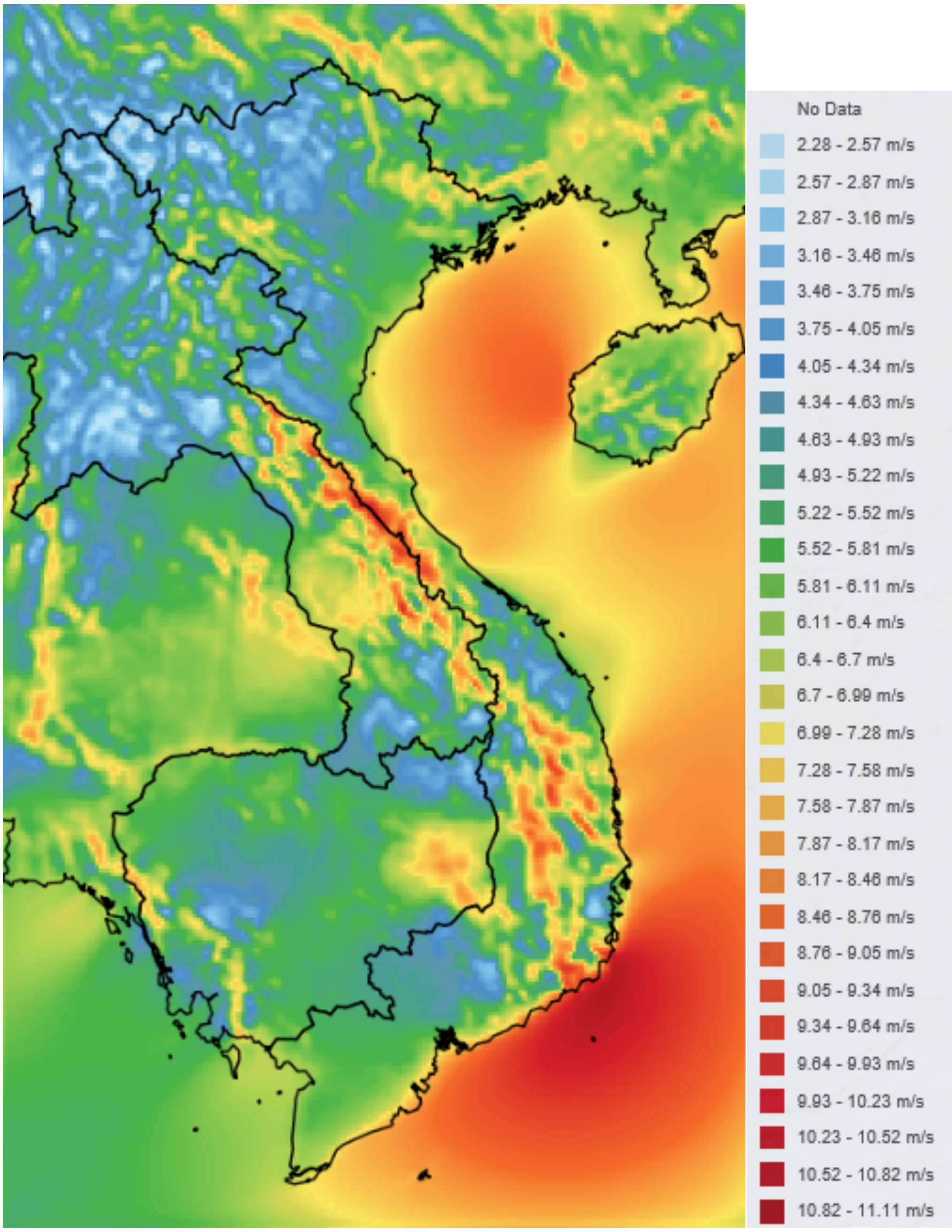
- "Simulated mean wind speed covering the years 2003-2010 at 100 m above ground level (AGL), measured in m per second. Values reflect orography and surface roughness length as they are represented in the model. These data were developed using the Weather, Research, and Forecasting model at a 5km interval. The original modelling work was performed by DTU. The map is an un-validated, satellite-derived estimate. As part of phase II of the WBG initiative, these maps will be validated through the use of ground measurement data, and until the data collection period is finished should be considered for policy use, rather than energy prospecting, following IRENA's classification of renewable energy data."; and
- "Generalized mean wind speed covering the years 2003-2010 at 100 m AGL, measured in m per second. These data introduce flat terrain and uniform roughness length of 10cm across the study area. This generalized model allows for users to plug in their own microscale orography and roughness values in custom simulations. These data were developed using the Weather, Research, and Forecasting model at a 5km interval. The original modelling work was performed by DTU. The map is an un-validated, satellite-derived estimate. As part of phase II of the WBG initiative, these maps will be validated through the use of ground measurement data, and until the data collection period is finished should be considered for policy use, rather than energy prospecting, following IRENA's classification of renewable energy data."

Figure 122 shows the DTU Global Wind Atlas[72] onshore and 30 km offshore wind climate dataset which accounts for high resolution terrain effects for 100 m above ground level. According to the IRENA global atlas description: "this was produced using microscale modelling in the Wind Atlas Analysis and Application Program and capture small scale spatial variability of winds speeds due to high resolution orography (terrain elevation), surface roughness and surface roughness change

[72] See: http://globalwindatlas.com/.

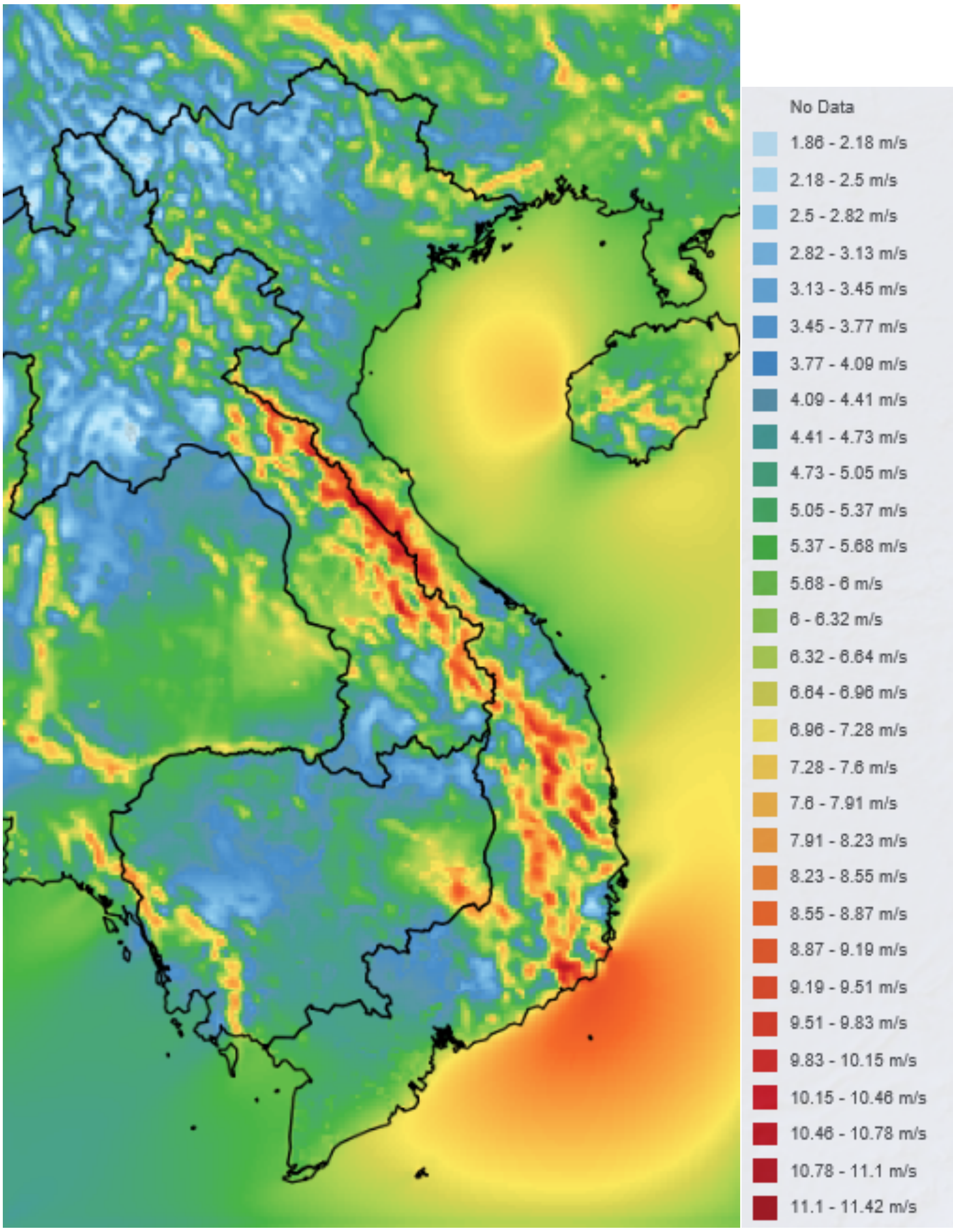
effects. The layers shared through the IRENA Global Atlas are served at 1km spatial resolution. The full Atlas contains data at a higher spatial resolution of 250 m, some of the IRENA Global Atlas tools access this data for aggregated statistics."

Figure 120 Simulated Wind Speed m/s 100m Viet Nam 5km 2003-2010 WBG



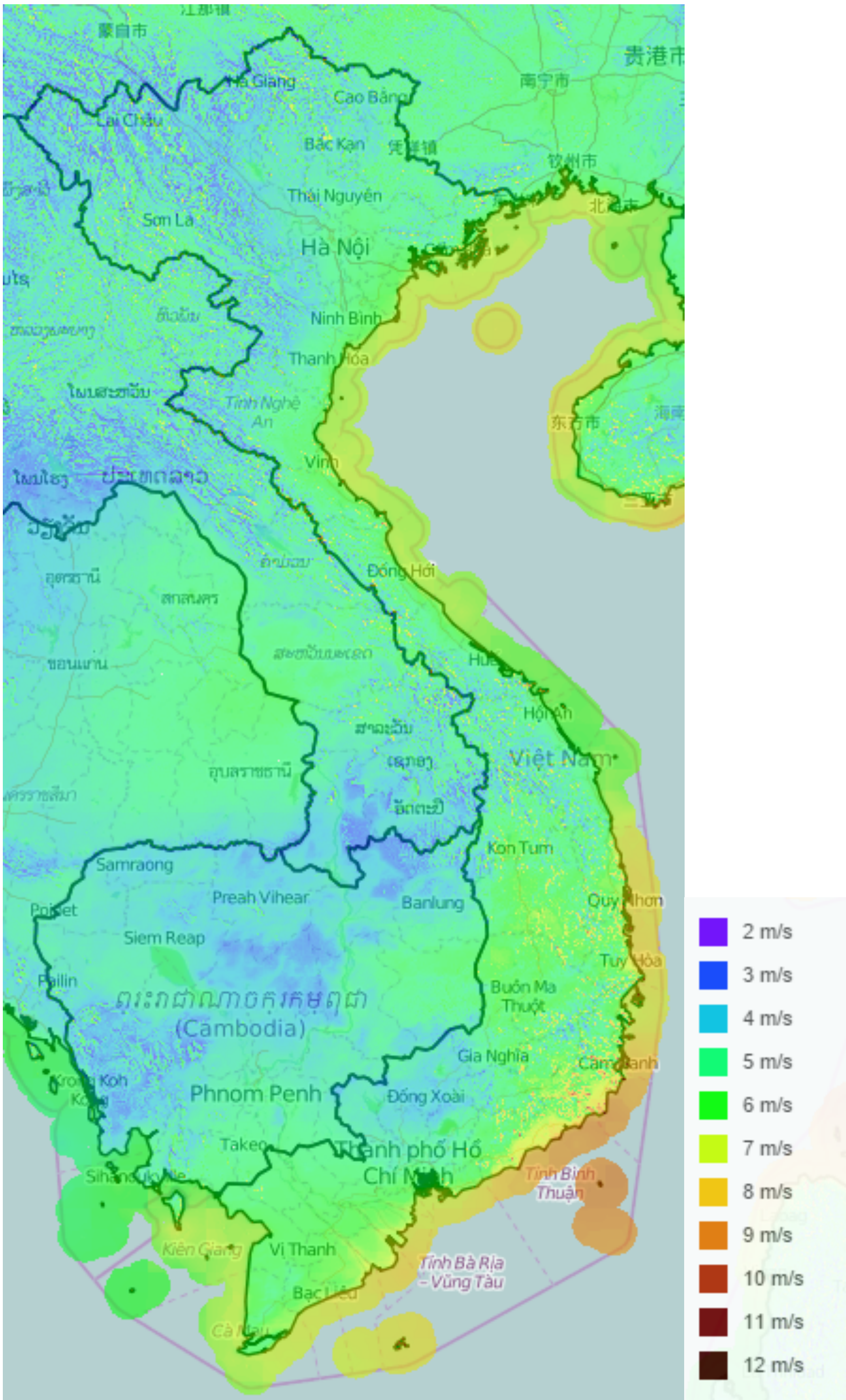
Source: World Bank Group, via IRENA

Figure 121 Generalised Wind Speed m/s 100m Viet Nam 5km 2003-2010 WBG



Source: World Bank Group, via IRENA

Figure 122 Average Wind Speed 1km at 100 m AGL DTU (2015)



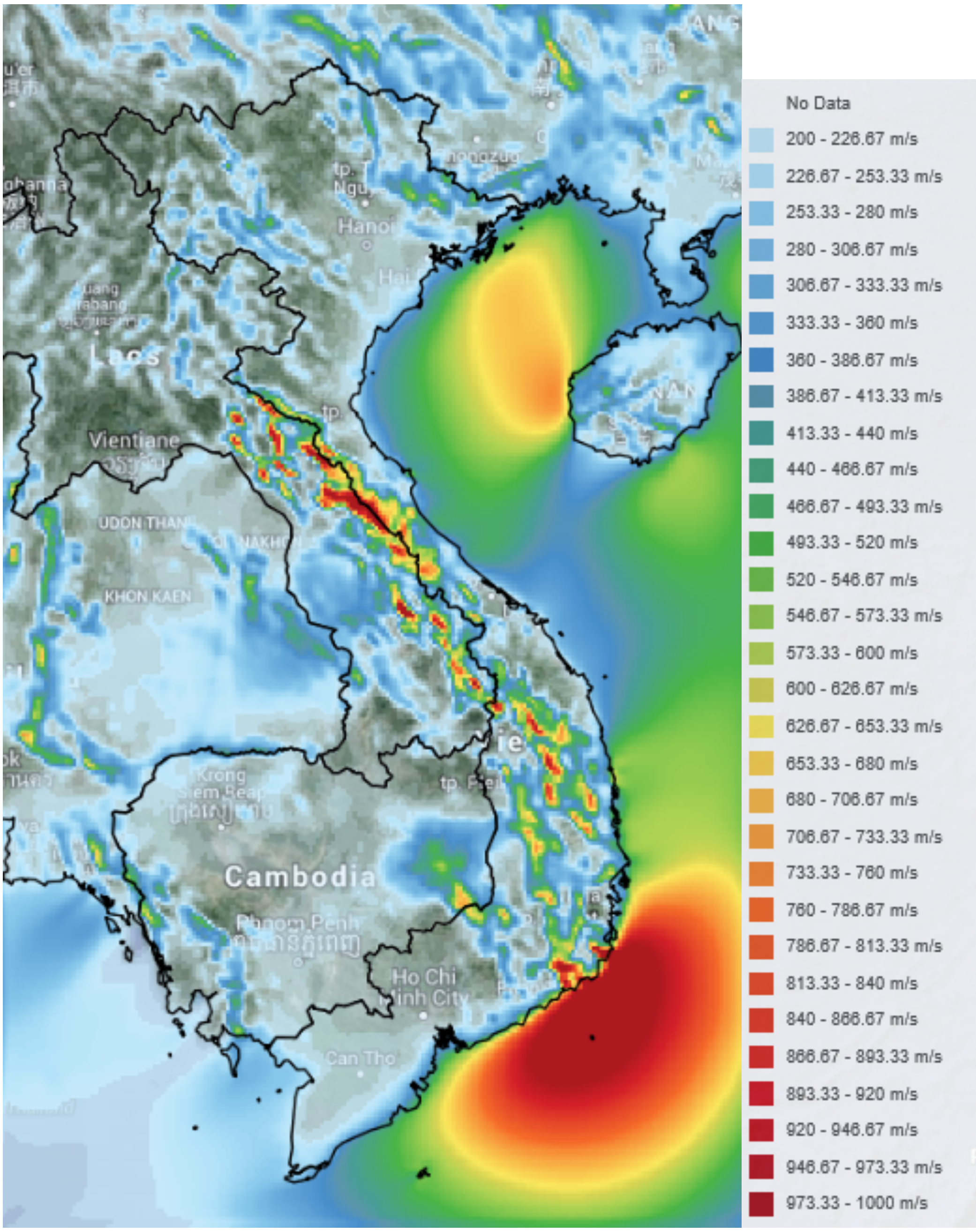
Source: IRENA Global Atlas and Global Wind Atlas (2015)

D.2 Wind Power Density Maps

Figure 123 and Figure 124 respectively show the wind power density in units of W/s based on the wind speed charts presented earlier. The following information on each chart is indicated on IRENA's website:

- "Based on the simulated wind speed data at 100m AGL, power density data measures W per m2. These data introduce flat terrain and uniform roughness length of 10cm across the study area. This generalized model allows for users to plug in their own microscale orography and roughness values in custom simulations. These data were developed using the Weather, Research, and Forecasting model at a 5km interval. The original modelling work was performed by DTU. The map is an un-validated, satellite-derived estimate. As part of phase II of the WBG initiative, these maps will be validated through the use of ground measurement data, and until the data collection period is finished should be considered for policy use, rather than energy prospecting, following IRENA's classification of renewable energy data."; and
- "Based on the simulated wind speed data at 100m AGL, power density data measures W per m2. Values reflect orography and surface roughness length as they are represented in the model. These data were developed using the Weather, Research, and Forecasting model at a 5km interval. The original modelling work was performed by DTU. The map is an un-validated, satellite-derived estimate. As part of phase II of the WBG initiative, these maps will be validated through the use of ground measurement data, and until the data collection period is finished should be considered for policy use, rather than energy prospecting, following IRENA's classification of renewable energy data."

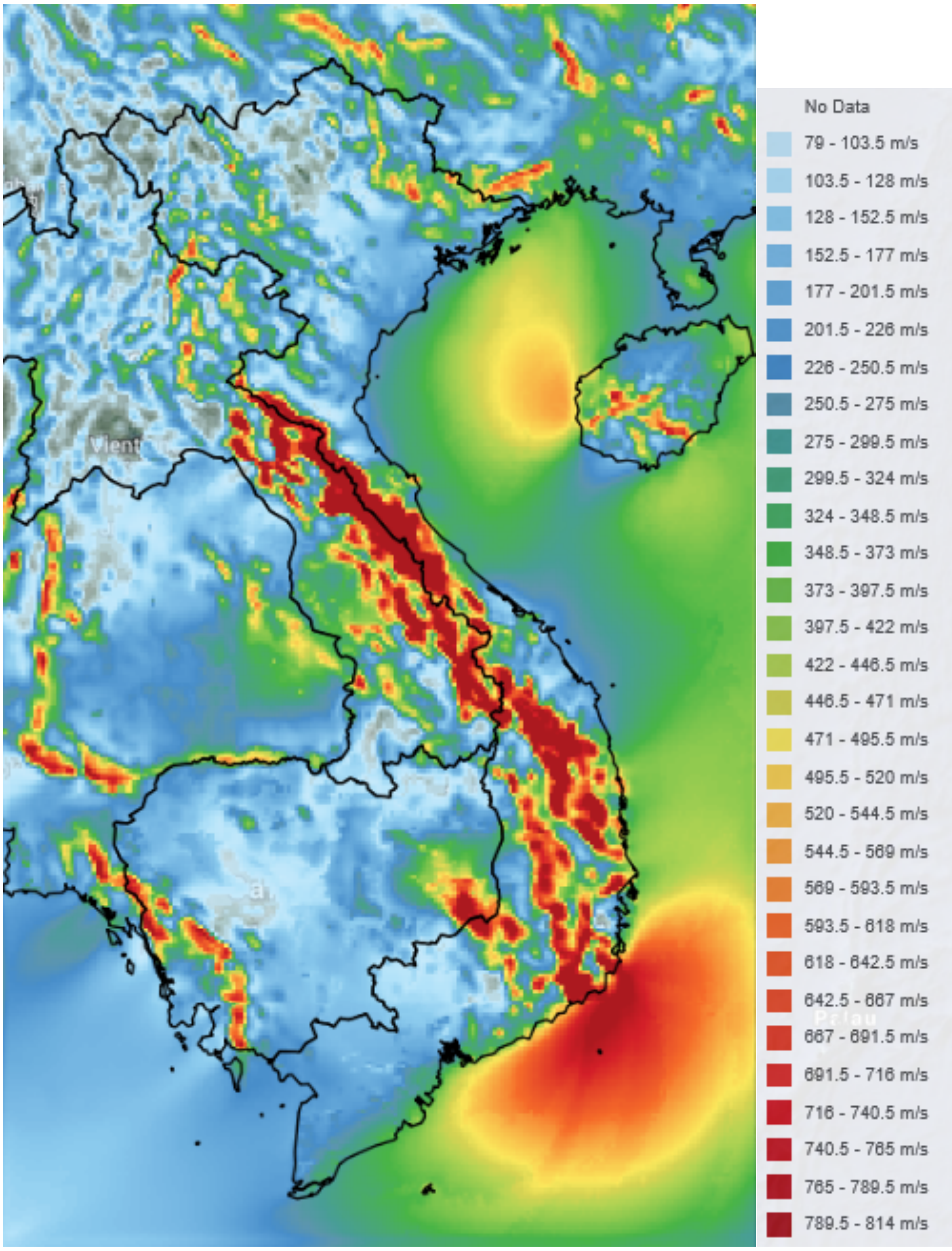
Figure 123 Simulated Wind Power Density 100m 2003-2010 WBG in W/s[73]



Source: World Bank Group, via IRENA

[73] We understand the legend should be "W/s" not "m/s" based on the description of the charts on the IRENA website.

Figure 124 Generalised Wind Power Density 100m 2003-2010 WBG in W/s[74]



Source: World Bank Group, via IRENA

[74] We understand the legend should be "W/s" not "m/s" based on the description of the charts on the IRENA website.

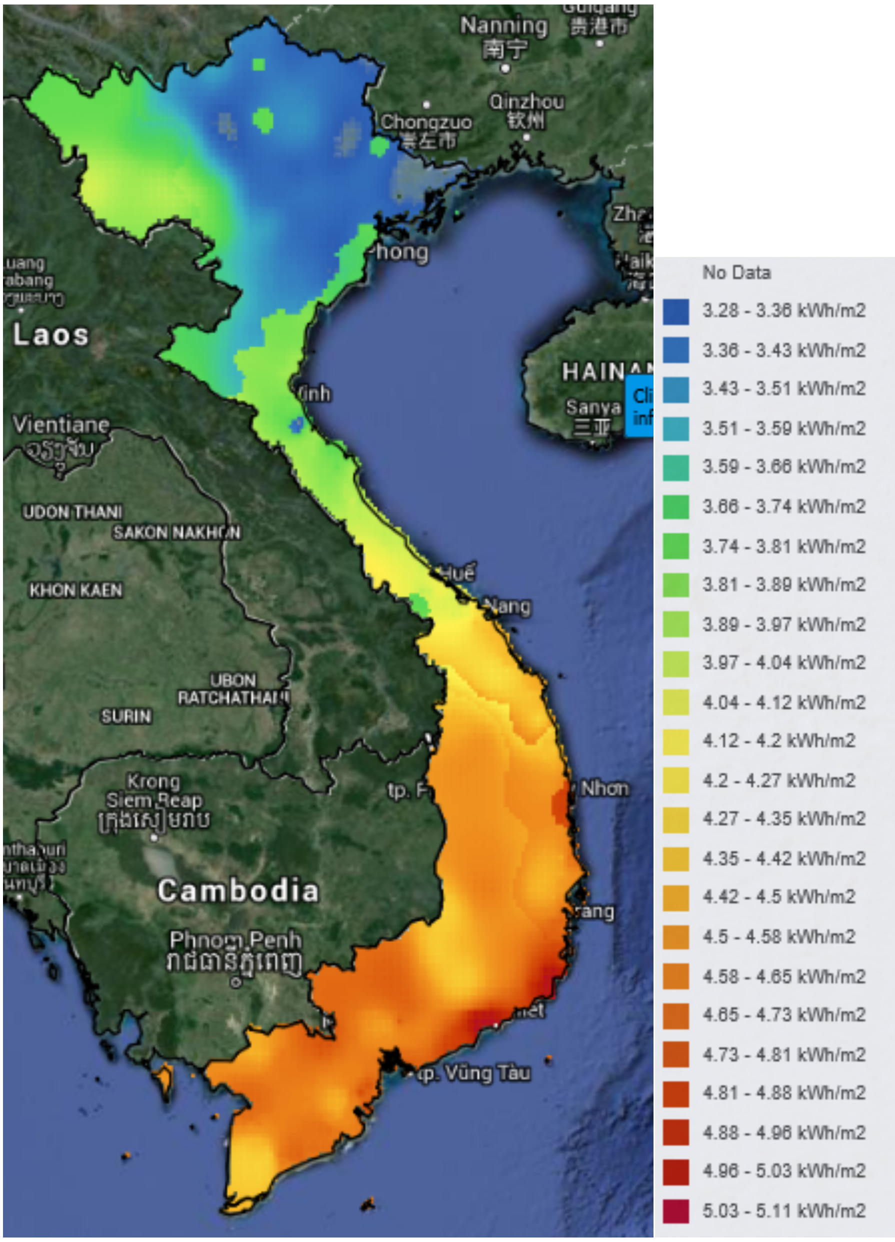
Appendix E Viet Nam Solar Resource Maps

This section provides a number of charts of Viet Nam's solar resource potential, the data and maps of which are accessible by IRENA's Global Atlas for Renewable Energy (http://irena.masdar.ac.ae/). The data themselves are pulled from various sources. The purpose is to illustrate geographical dispersion in solar potential across Viet Nam.

E.1 Global Horizontal Irradiance and Direct Normal Irradiance

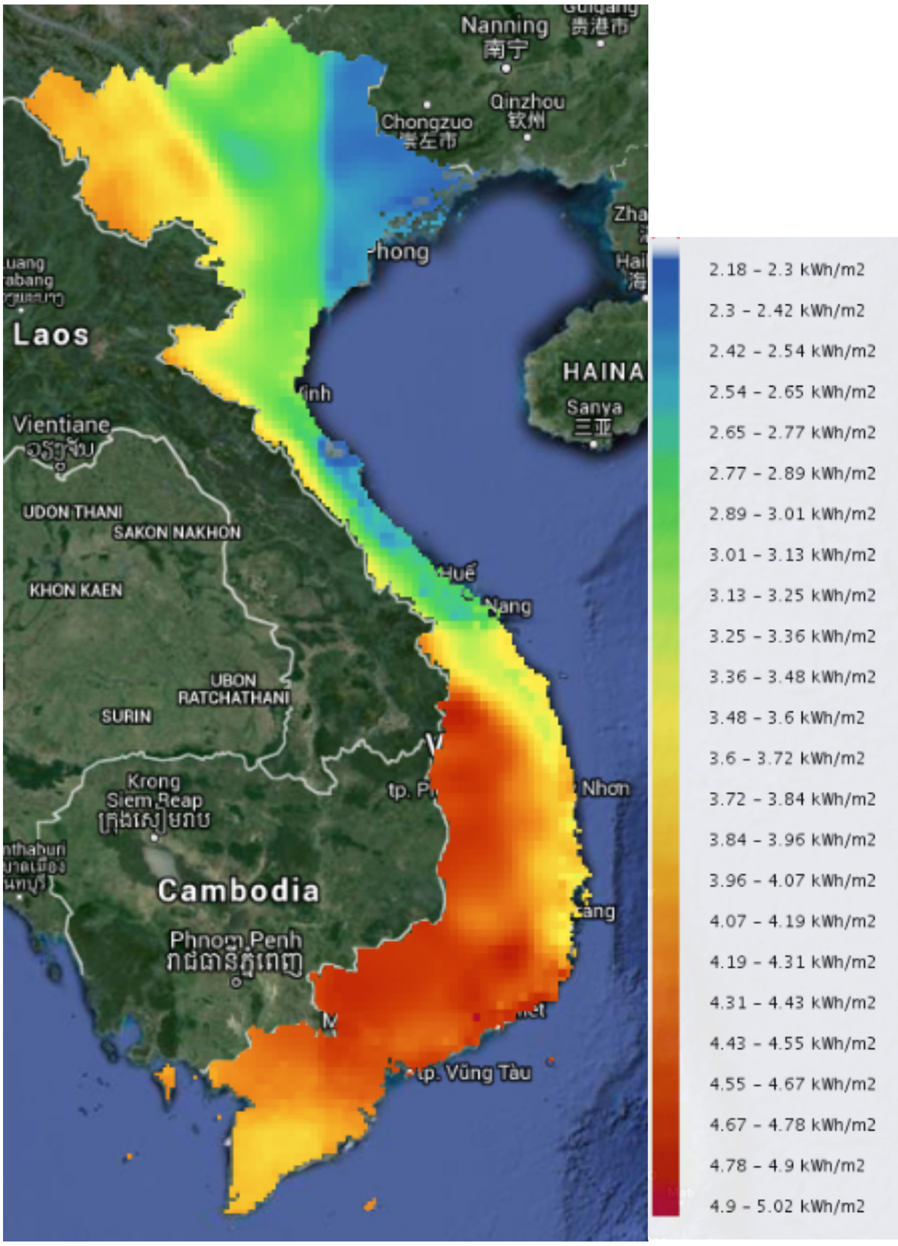
Figure 125 and Figure 126 respectively show annual maps of Global Horizontal Irradiance (GHI) kWh/m2 and Direct Normal Irradiance (DNI) kWh/m2 for 2003-2012 (based on WBG published measurements via the IRENA Atlas).

Figure 125 Global Horizontal Irradiance (GHI) kWh/m2 2003-12 WBG



Source: World Bank Group, via IRENA

Figure 126 Direct Normal Irradiance (DNI) kWh/m2 2003-12 WBG



Source: World Bank Group, via IRENA

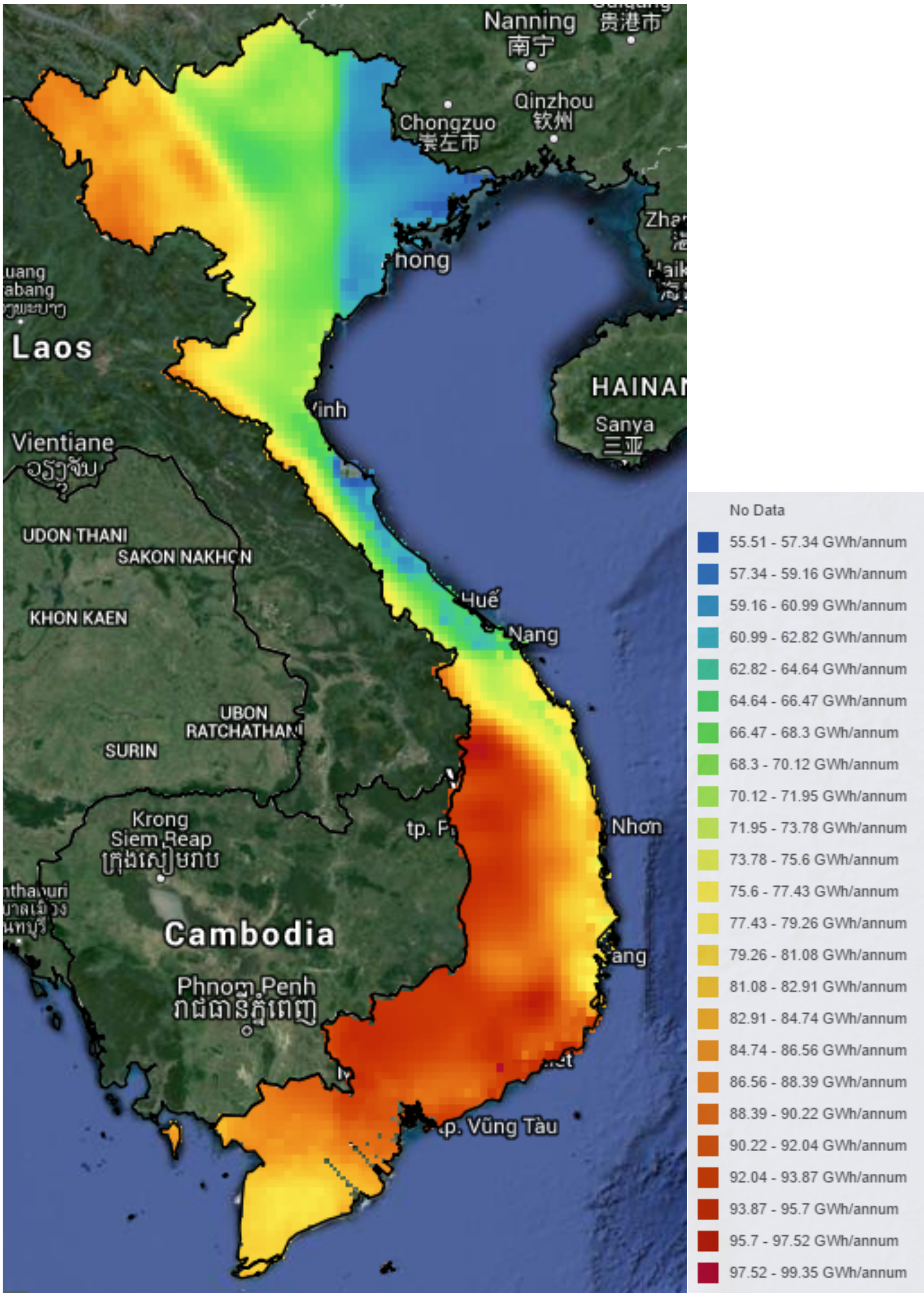
E.2 Concentrating Solar Power (CSP) Potential

Figure 127 and Figure 128 show respectively the theoretical and technical potentials for CSP (GWh/year). The former is based on Solar potential for concentrated solar power through parabolic troughs is estimated based on ANDASOL plant in the south of Spain[75]. The plant is a 50 MWe solar plant with 6 hours of thermal energy storage[76]. The latter combine theoretical potential with technical exclusion areas: slope < 3%, no water, roads, railroads, or protected areas, minimum of 1500 kWh/m/day, and a minimum area of 2 km2 for plan construction.

[75] Source: Dinter and Gonzalez, http://www.peacelink.it/ecologia/docs/4978.pdf.

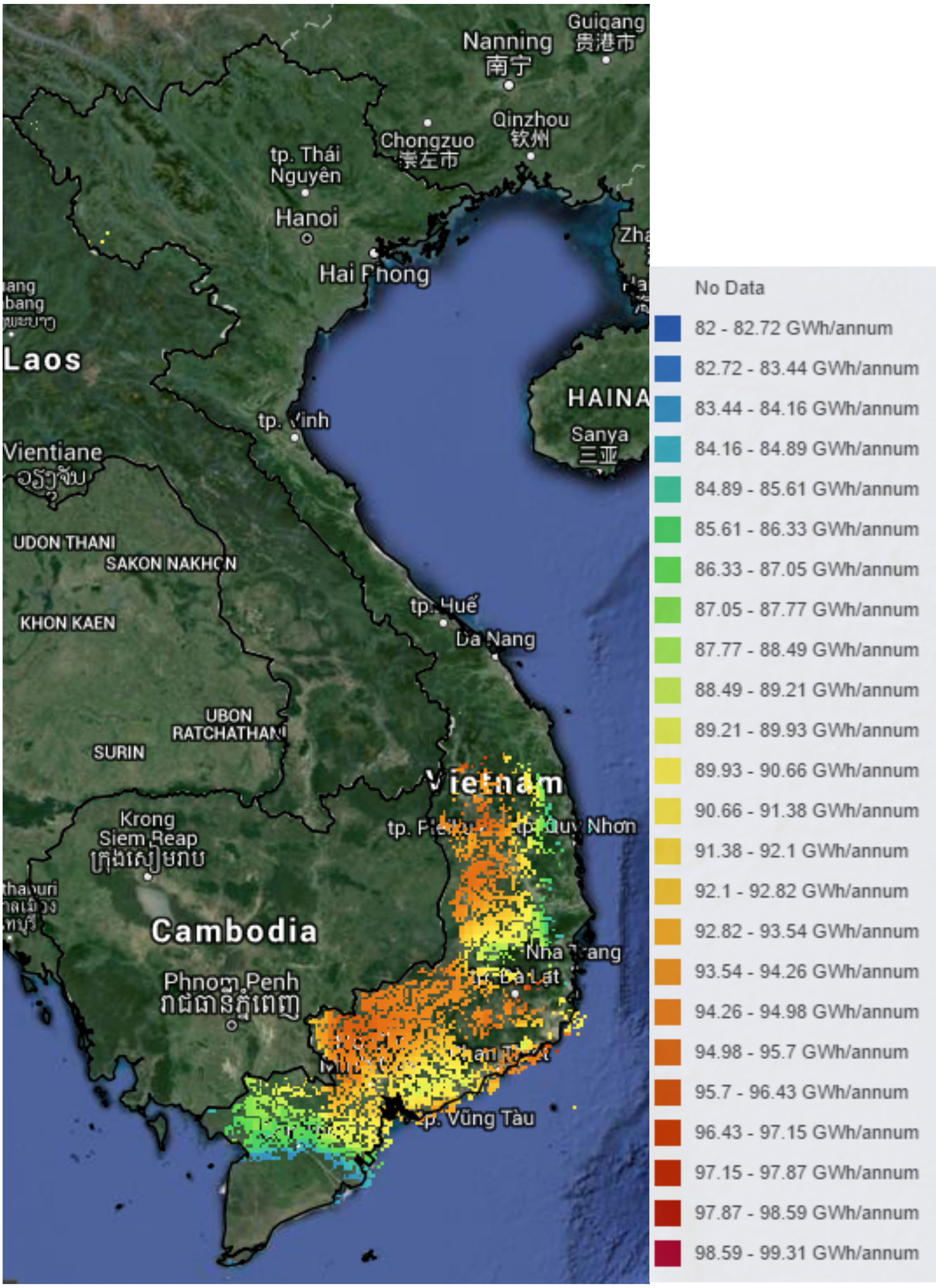
[76] Based on the Spanish Consortium's study briefly discussed in section 3, created by was created by CIEMAT, CENER and IDAE.

Figure 127 Theoretical Potential for CSP 2003-12 (GWh/year)



Source: World Bank Group, via IRENA

Figure 128 Technical Potential for CSP 2003-12 (GWh/year)



Source: World Bank Group, via IRENA