RENEWABLE ENERGY FOR VIET NAM

A proposal for an economically and environmentally sustainable 8th Power Development Plan for the Viet Nam Government

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UTS Institute for Sustainable Futures

ABOUT THE AUTHORS

The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government, and the community to develop sustainable futures through research and consultancy. Our mission is to create change towards establishing sustainable futures that protect and enhance the environment, human well-being, and social equity. We use an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

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ENERGY MODELS

Utility-scale solar photovoltaic and wind power potential mapping was performed with [R]E-SPACE, a mapping tool developed by the Institute for Sustainable Futures of the University of Technology Sydney (ISF-UTS) based on QGIS (open source).
The long-term energy scenario software for the long-term projections and economic parameters is based on the development of the German Aerospace Centre (DLR), Institute for Technical Thermodynamics, (Pfaffenwaldring 38-40, 70569 Stuttgart, Germany) and was applied to over 100 energy scenario simulations for global, regional, and national energy analyses.
Regional *Power Analysis* calculated with [R]E 24/7 was developed by Dr. Sven Teske (PhD), with further developments by ISF-UTS.
Additional cost optimization of the power generation scenarios was performed with OSeMOSYS (open source model).

CITATION

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SUMMARY FOR POLICYMAKERS

The next Power Development Plan 8 is a historical opportunity to chart the way towards a low-carbon power system for Viet Nam, and avoid locking it in a high-carbon social structure.

This report provides a technical and economic analysis of long-term energy and power development plans for Viet Nam, carried out by the Institute for Sustainable Futures at the University of Technology Sydney (ISF-UTS) in cooperation with the Vietnam Initiative for Energy Transition (VIET). To undertake a sensitivity analysis of different energy system scenarios, we used various computer models: a GIS-based mapping tool to assess Viet Nam's potential for utility-scale solar photovoltaic, onshore wind, and offshore wind power generation within the country's space constraints; a long-term energy scenario model to develop mid- and long-term energy pathways for all sectors (power, industry, transport); a computer model that calculates future demands and load curves for the power sector to analyse Viet Nam's power sector, subdivided in eight regions, with 1 hour resolution; and an open-source cost optimization tool to optimize the costs of power generation.

The scenarios examined

The backbone of the analysis is a set of three original narratives for coal scenarios: the "OLD PLAN", "NEW NORMAL", and "FACTOR THREE". The first corresponds to the PDP7 revised (PDP7rev) plan. The second represents possible development under current market forces with regard to the economics of renewable power generation. The third pathway describes what could happen if the government of Viet Nam continues to steer the electricity system into an energy transition, decisively and without imposing high costs upon stakeholders.

- The **OLD PLAN** vision describes PDP7rev, updated to account for actual situational changes that have occurred since it was formulated. Other than coal, all projections for other energy supplies and demand parameters are also based on PDP7. This scenario is called the REFERENCE scenario.
- The **NEW NORMAL** vision is directed towards the power sector policy goal to provide an affordable and secure electricity supply within the next 10 years, under market forces that already prioritize investments in solar and wind generation rather than in fossil fuels.
- The **FACTOR THREE** vision is based on a broader policy goal: to decarbonize Vietnamese society within one generation, while meeting its economic development goals and reducing the energy sector's emissions by a factor of three by the middle of the century.

These three coal pathways were complemented with assumptions about the possible future development of the remaining power generation required—gas power generation, renewable electricity and energy efficiency, to define one reference and two alternative energy-system scenarios:

- REFERENCE combines the coal pathway "OLD PLAN" with the existing plans.
- RENEWABLES 1 (RE1) combines the coal pathway "NEW NORMAL" with a higher level of renewables and energy efficiency.
- RENEWABLES 2 (RE2) has an earlier coal-phase-out horizon, "FACTOR THREE", and therefore increases the introduction of renewable power generation faster than RE1. It assumes the same energy efficiency projections as RE 1. A higher electrification rate, especially for the transport sector, is also assumed.

All three scenarios take into account the same estimated growth in Viet Nam's population and economy until 2030 and 2050.

The overall energy demand in 2030 under both alternative scenarios will be 9% below the energy demand projection of the REFERENCE scenario. In comparison with the REFERENCE scenario, the primary energy demand in 2030 in the RE1 scenario will be reduced by 1,000 PJ/a and by 1,250 PJ/a in the RE2 scenario. Compared with the target of VNEEP III to reduce the cumulative demand by 2,512 PJ between 2015 and 2030, both alternative scenarios will reduce it more strongly: RE1 will reduce the cumulative energy demand by 6,477 PJ between 2020 and 2030, and RE2 by 7,272 PJ during the same period. In terms of sectorial targets, the alternative scenarios will reduce the industrial energy demand by 8.7% across all sub-sectors. For the overall transport sector, the RE1 scenario will reduce the demand by 3% by 2030 compared with the REFERENCE case, and the RE2 scenario will reduce it by 8%. Increased electrification of the transport sector will play a significant role in reducing the energy demand in the RE2 scenario.

To summarize the assumptions, we studied two alternative scenarios in which the development of the electricity supply sector is characterized by a dynamically growing renewable energy market and an increasing share of renewable electricity. These trends more than compensate for the stagnation of new coal power plant installations and, after 2030, the phasing out of fossil-fuel-based power production under both alternative scenarios. By 2030, 38% of the electricity produced in Viet Nam will come from renewable energy sources in the RE1 scenario (2019: 31%), increasing to 75% in 2050. 'New' renewables—mainly onshore wind, solar photovoltaic, and offshore wind—will contribute 19% of the total electricity generation in 2030 and 58% by 2050.

Result 1: Viet Nam has abundant solar and wind resources

Our independent GIS-based study confirms that the conditions for solar photovoltaic power generation are excellent, and assess that the potential for utility-scale photovoltaic power stations—particularly in rural areas—is 48 GW. This is equivalent to Viet Nam's current power plant capacity. This potential is assessed using land within 10 km of the existing power grid, it increases significantly when locations further from the grid are taken into account.

The overall wind resources on land are good compared with those of other mainland South-East Asian countries, and the average annual wind speed is 6–7 m/s in most suitable land areas. Our study mapped Viet Nam's wind potential under four different assumptions based on space constraints. The most conservative approach reveals a 40 GW onshore wind potential, almost as much as solar photovoltaic. Viet Nam also has significant offshore wind potential. This analysis takes into account coastal areas with a maximum water depth of 50 m and a maximum distance to the shore of 70 km. Within these restrictions, Viet Nam has a technical potential of 609 GW, spread over 3000 km of coastline and over 150,000 km^2.

Result 2: Fuel cost savings compensate for additional investment in power generation

In this analysis, we found that fuel cost savings between 2020 and 2030 in the RE1 scenario will equal to the required additional investment costs for renewable power generation. Therefore, RE 1 will be cost neutral compared with the REFERENCE scenario. The more ambitious RE2 scenario will require significantly greater investment in renewables, but investment in new coal power plants will also be reduced. The overall cost savings in fuel will entail a cost benefit of over US 6.5 billion between 2020 and 2030, making the RE2 pathway the most economic propitious.

The significant reductions in the cost of solar photovoltaic, onshore wind, and offshore wind power generation that have occurred in recent years, together with advances in storage technologies, make renewable power generation economically favourable. The construction times for solar photovoltaic and wind power generation facilities are shorter than those for gas- or coal-fuelled power generation facilities. Therefore, power generation can follow demand more easily. Renewable power generation is independent of variations in the fossil fuel price and therefore provides planning security for energy costs.

Electricity generation costs for onshore wind already undercut those for new gas power plants and will be cost competitive with coal within the next 5 years. By 2030, the costs of utility-scale solar photovoltaic, onshore wind, and offshore wind generation will be lower than those for coal generation and thus cost competitive. Therefore, new coal power plant projects will be uneconomic and their establishment will very probably lead to stranded investments.

The role of gas under both alternative scenarios is similar to its role under the REFERENCE scenario until 2025. Thereafter, the RE1 scenario will remain at a total capacity of around 25 GW until 2050, whereas the RE2 scenario will not exceed 15 GW. The annual new renewable power capacities for both scenario aim for stable markets to encourage the sustainable growth of the renewables industry in Viet Nam.

Result 3: The power grid capacity increase in all scenarios

Although both alternative energy pathways will achieve higher accumulated energy savings than the planned VNEEP III, the electricity demand will still increase by around 70% in all regions, which will make an increase in the power grid capacity unavoidable. This increase in the required grid capacity will result from the higher demand, in terms of both the overall energy (in megawatt-hours) and the total loads (in megawatts). This will be independent of the form of energy generation.

The interregional transmission capacity must be expanded, in addition to the increased grid capacity within the region arising from the increase in demand, by 2030 and beyond in all scenarios.

In this analysis, we explored the feasibility of building a national offshore busbar. Undersea high-voltage direct-current cable technology is making rapid progress. In the scenarios to 2050, there is an option to reinforce the national grid by laying a transmission line along the coast, connecting the two deltas with the currently planned systems of offshore wind farms.

Result 4: While the business as usual scenario leads to 5.7 t CO2 per capita emission in 2050, the alternative development scenario divides this number by a factor ten.

RE1 will generate per capita energy-related CO_2 emissions of 3.7 tons by 2030, compared with 4.8 tons in the REF scenario and 3.35 tons under RE2. By 2050, the RE2 scenario will reduce the per capita emissions to under 0.5 tons, whereas RE1 will generate 2.3 tons and REF 5.7 tons.

Policy Discussion: How to implement the alternative scenarios?

The sustainable development question is eternal, but there is urgency now. Year 2020 is a key year for institutional planning in Vietnam, and an opportunity to prepare a general Party directive to orient the socio-economic development towards an ecological society, and adopt a time target goal to stop using fossil fuels. To steer society towards sustainable socio-economic development will require a coherent stream of new policies. This section documents the policy measures we believe necessary in the alternative scenarios presented here, as well as policy measures known to be successful in the international experience. The two alternative scenarios assume that the spirit of the Paris Climate Agreement effectively shape new energy policies in Viet Nam. Measures to support the development of renewable electricity generation include:

- Establish more ambitious targets for onshore- and offshore wind, utility scale solar photovoltaic power plants and roof top systems.
- Establish an offshore plan with the target of 12-15 GW by 2030 including an offshore grid infrastructure program
- Identify the potential for sustainable bio energy and support the implementation of bioenergy application – especially as dispatch and cogeneration power plants – as part of the flexibility initiative (= generation management schemes)
- Maintain the Feed-in Tariff for community owned / operated solar and wind generators and for all renewable power generators / wind farms under 30 MW.
- Establish a tendering system for renewable power generation projects over 30 MW.

The traditional electricity market framework has been developed for central suppliers operating dispatchable and limited dispatchable (‘base load’) thermal power plants. The electricity markets of the future will be dominated by variable generation without marginal/fuel costs. The power system will also require the built-up and economic operation of a combination of dispatch generation, storage, and other system services whose operation will be conditioned by renewable electricity feed-ins. For both reasons, a significantly different market framework is urgently needed, in which the technologies can be operated economically and refinanced. Renewable electricity should be guaranteed priority access to the grid. Access to the exchange capacity available at any given moment should be fully transparent and the transmission of renewable electricity must always have preference. Furthermore, the design of distribution and transmission networks, particularly for interconnections and transformer stations, should be guided by the objective of facilitating the integration of renewables and to achieve a 100% renewable electricity system. High shares of variable renewable power generation requires a flexible power sector, which has:

  - A market for demand side management
  - Incentives to design or retrofit flexible thermal power plants post 2030
  - Hydro power plants with pumped-storage where it is technically feasible
  - Integration of electricity imports and export with Viet Nam’s neighbours

To establish fair and equal market conditions, the ownership of electrical grids should be completely disengaged from the ownership of power-generation and supply companies. To encourage new businesses, relevant grid data must be made available from transmission and distribution system operators. This will require establishing communication standards and data protection guidelines for smart grids. Legislation to support and expand demand-side management is required to create new markets for the flexibility services for renewable electricity integration. Most liberalized power markets worldwide separate generation, transmission and distribution. The measures to do so include:

- Separate transmission and distribution billing
- Formulas for transmission and distribution fees with fair consequences for the various players including the historical monopoly (EVN)
- Use of Power Purchase Agreements (DPPA) for renewable energy projects.

Funding for research and development is required to further develop and implement technologies that allow variable power integration, such as smart grid technology, virtual power stations, low-cost storage solutions, and responsive demand-side management. Finally, a policy framework that supports the electrification and sector coupling of the heating and transport sectors is urgently needed for a successful and cost-efficient transition process.

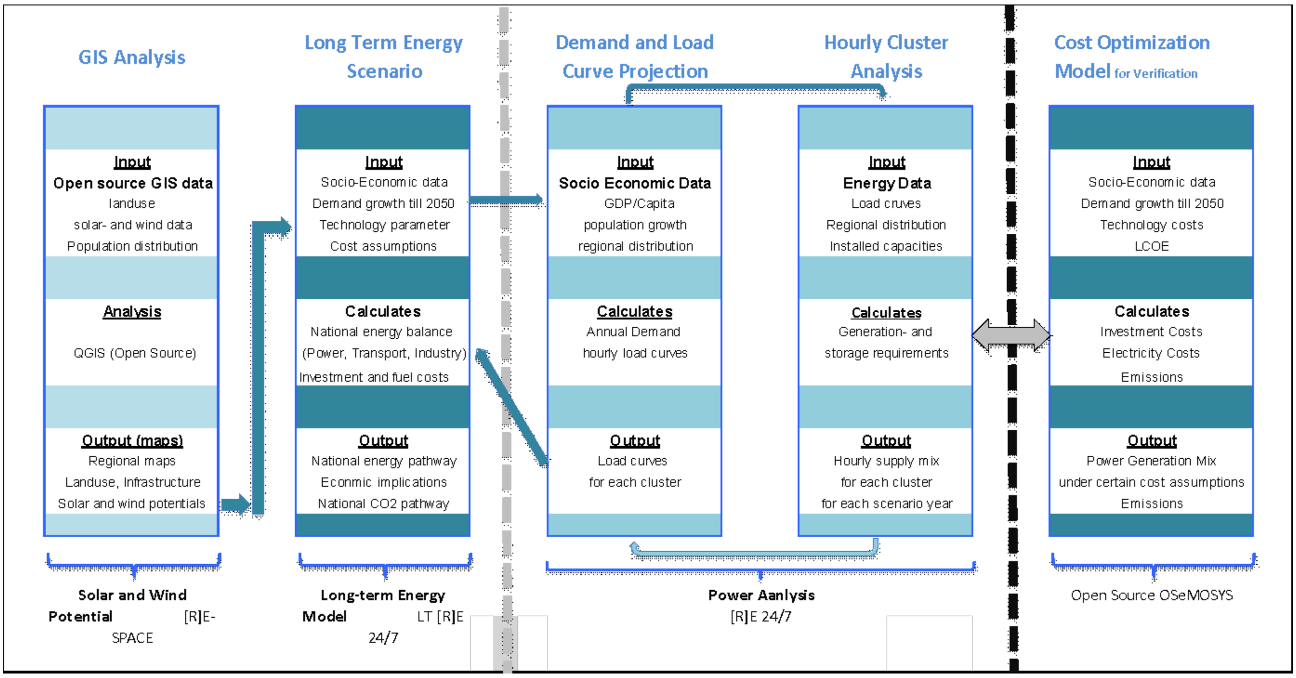
1 TECHNICAL SUMMARY

The research was led by the University of Technology Sydney–Institute for Sustainable Futures (UTS-ISF) and was a collaborative analysis with the Vietnam Initiative for Energy Transition (VIET), a think tank based in Hanoi, UTS-ISF in Sydney, Australia. RENEWABLE ENERGY FOR VIET NAM is a proposal for an economically and environmentally sustainable 8th Power Development Plan for the government of Viet Nam. The government of Viet Nam regularly develops power development plans to ensure a reliable and affordable electricity supply. The 8th iteration was ongoing during the time of writing of this analysis (2019).

Methodology

This report provides a technical and economic analysis of long-term energy and power development plans for Vietnam. The analysis is based on the [R]E24/7 energy access pathway methodology developed by the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) and is based on the long-term energy scenario model of the Institute for Thermodynamics of German Aero Space Centre (DLR), energy models developed for various UTS-ISF surveys, and the [R]E 24/7 model. The entire modelling process is based on five modules, four developed by UTS-ISF and the remaining one an open-source model, OSeMOSYS, which has been used for the cost-related sensitivity analysis. Figure 1 provides an overview to the models used and their interactions.

Figure 1: Overview—Modelling concept



In the mapping analysis, a global information system (GIS) was used for the regional analysis of Viet Nam's population density and distribution, its solar and wind resources and the currently existing energy infrastructure (transmission power lines and power plants with over 100 MW installed capacity). This information has been used to define the cluster breakdown.

The long-term scenario—LT [R]E 24/7—has been used to re-model the existing power development plan (see section 2) and to develop alternative national energy pathways for Viet Nam. This model takes into account all sectors (power, heat, and transport) and includes cost and energy-related CO_2 calculations.

The [R]E 24/7 power sector analysis tool computes the annual demand for up to five different years (here 2020, 2030, 2040, and 2050) and the load curves for a full year (8760 h). The hourly load curves are required for the simulation of the demand and supply for each of the eight regions of Viet Nam. The results are the development of loads, generation mix, and storage demand.

Socio-economic data

Viet Nam has a population density of 291 persons per km^2 [25]. Between 1955 and 1990, the annual population growth rate dropped to the current rate of 1%. Further reductions to 0.9% (2025) and 0.5% (2035) are expected[11]. Based on these estimates, the population will reach 117.6 million in 2040 and will decrease to 115.8 million by 2050 (see Table 11).

Viet Nam has enjoyed remarkable economic development during the past 30 years and has transformed from one of the poorest countries in the world to a lower middle income country (WORLDBANK 2019A)[1]. Its per capita income increased from US$388 in 2000 to US$2,342 in 2017 (WORLDBANK 2019 B)[2], in the world[3], with an annual growth rate of over 5% since 2000[13]. Projections for population and economic growth are important factors in the development of energy scenarios because they affect the size and composition of the energy demand, both directly and through their impact on economic growth and development. The population and GDP data shown in Table 2 are based on projections made by the Viet Nam Government, and were used for Power Development Plan 7 2016 (PDP7 2016)[4].

Table 1: Viet Nam—Population and GDP projections

	t	2015	2020	2025	2030	2035	2040	2045	2050
GDP	[billion $$_{2015}$/a]	193.2	258.5	369.4	527.9	716.5	927.6	1,150	1,333
GDP/Person	[$/capita]	2.065	2.616	3.557	4.836	6.245	7.886	9.780	11.509
Population	[million]	93.5	98.8	103.8	109.1	114.7	117.6	117.6	115.8
			2015–2020	**2020–2025**	**2025–2030**	**2030–2035**	**2035–2040**	**2040–2045**	**2045–2050**
Economic growth	[%/a]		6.7%	8.2%	7.2%	5.9%	4.6%	3.3%	2.0%
Population growth	[%/a]		1.0%	0.9%	0.7%	0.5%	0.4%	0.3%	0.3%

Projected development of electricity demand

The parameter projections for the electricity demand were calculated for the residential and business sectors with the [R]E 24/7 model in a bottom-up process. Additional electricity demand for transport —especially for the two alternative scenarios, which have increased electric mobility—and for the internal electricity demand of power plants ("own consumption") and distribution losses are calculated with the long-term model and added to the calculated projected demand. However, the [R]E 24/7 power analysis only takes into account the additional electricity demand for distribution losses because the power plant consumption does not influence storage or grid requirements.

The analysis of the current and future development of the electricity demand for Viet Nam's households was performed on the basis of the "Overview of the Viet Nam Household Living Standard Surveys 2016", published by the General Statistic Office Viet Nam (GSOV 2016)[5]. The different electrification levels for households according to region have been converted into nine household types. The assumed annual demand in kilowatt-hours per year for each household type is shown Table 12. A significant increase in demand (e.g., from *"Rural Phase 2"* to *"Rural Phase 3"*) is mainly attributable to the use of electric air-conditioning. The average assumed efficiency gain across all appliances is assumed to be 0.75% per year across the entire modelling period (for a comparison with VNEEP III, see below).
The analysis of Viet Nam's economic development is based on the GDP breakdown and assumes that the overall structure of the economy does not change and that all sectors grow at rates equal to that of GDP over the entire modelling period. Table 2 shows the assumed breakdown of GDP by sub-category.

[1] Worldbank (2019) A, last update of website 24 April 2019, https://www.worldbank.org/en/country/vietnam/overview
[2] Worldbank (2019) B, https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=VN
[3] Viet Nam News, December 7th 2018, https://vietnamnews.vn/economy/481550/vn-among-10-fastest-growing-economies.html#4i6dRQKYeJkuQQP8.97
[4] PDP 7 (2016), Viet Nam Energy Outlook Report 2017, Danish Energy Agency, https://ens.dk/sites/ens.dk/files/Globalcooperation/Official_docs/Vietnam/vietnam-energy-outlook-report-2017-eng.pdf
[5] (GSOV 2016) - Overview of the Viet Nam Household Living Standard Surveys 2016" published by the General Statistic Office Viet Nam, http://www.gso.gov.vn/default_en.aspx?tabid=515&idmid=5&ItemID=18977

Table 2: Development of GDP shares by industry sector across all regions of Viet Nam (2015)

Industry	35.6%
Manufacturer	22.9%
Mining	6.3%
Utilities	0.7%
Construction	5.7%
Services	52.5%
Public Administration + Service	48.9%
Transport	3.6%
Agriculture	11.9%
Agriculture	11.9%

The GDP distribution by region is based on 2015 data and is assumed to remain the same for the entire modelling period, until 2050. For the industry sector, an efficiency gain of 0.5% per year has been calculated between 2020 and 2030, and of 0.75% per year between 2031 and 2050. For the service and agricultural sector, an efficiency gain of 0.5% per year until 2030 has been calculated, with a gain of 0.25% for the rest of the modelling period.

Table 3: Development of Viet Nam's GDP shares by region

Region	[%]
North West	2.6%
North East	6.8%
Red River Delta	25.1%
Northern Central Coast	6.0%
Central Highlands	3.5%
South Central Coast	7.7%
South East	35.8%
Mekong River Delta	12.4%

Viet Nam Energy Efficiency Program (VNEEP III) targets in relation to projected energy demands for the alternative scenarios

The overall energy demand in 2030 for both alternative scenarios will be 9% below the energy demand projection for the reference case. In terms of sectorial targets, the alternative scenarios reduce the industrial energy demand by 8.7% across all sub-sectors. For the overall transport sector, the RE1 scenario reduces the energy demand by 3% by 2030 compared with the REF case and the RE2 scenario reduce it by 8%. Increased electrification of the transport sector will play a significant role in the reduced energy demand in the RE2 scenario. In comparison with the REF case, the primary energy demand in 2030 under the RE1 scenario will be reduced by 1,000 PJ/a, and by 1,250 PJ/a under the RE2 scenario. Compared with the targeted cumulative reduction of 2,512 PJ between 2015 and 2030 under VNEEP III, both alternative scenarios will produce greater reductions: RE1 will reduce the cumulative energy demand by 6,477 PJ between 2020 and 2030, and RE2 will reduce it by 7,272 PJ during the same period.

Cost projections

The speed of an energy system transition depends, to some extent, on overcoming the economic barriers. These largely relate to the relationships between the costs of renewable technologies and those of their fossil and nuclear counterparts. The projection of these costs for the various scenarios is vital to ensure that valid comparisons of energy systems are made. However, there have been significant limitations to these projections in the past in terms of investment and fuel costs. Moreover, efficiency measures also generate costs, which are usually difficult to determine, depending on the technical, structural, and economic boundary conditions. During the last decade, fossil fuel prices have seen huge fluctuations. After extremely high oil prices in 2012, we are currently in a low-price phase. Gas prices saw similar fluctuations. Therefore, fossil fuel price projections have also varied considerably and have had a considerable influence on the scenario outcomes ever since, especially those scenarios that are based on cost optimization algorithms.

Most renewable energy technologies provide energy with no fuel costs, so the projections of investment costs become more important than the fuel cost projections, and this limits the impact of errors in the fuel price projections. It is only for biomass-based energy generation that fuel costs are important because the

cost of feedstock remains a crucial economic factor. Today, these costs range from negative costs for waste wood (based on credits when waste disposal costs are avoided), through inexpensive residual materials, to comparatively expensive energy crops.
The cost projections for power generation technologies are taken from the Technology Catalogue for Vietnamese Power, published in May 2019, in order to achieve comparable results with the Viet Nam Energy Outlook 2017 of MOIT and the Danish Energy Agency (DEA), especially its baseline scenario representing the PDP7rev[28] The technology costs (overnight costs and escalation costs arising from interest rates during construction) are given in Table 4. The total investment costs and the resulting levelized cost of electricity are calculated with a 10% discount rate.

Table 4: Investment cost assumptions for the most important power generation plants (in $2015/kW) until 2050

Assumed investment costs for power generation plants						
		2015	**2020**	**2030**	**2040**	**2050**
Coal power plant	$/kW	1 700	1 700	1 700	1 700	1 700
Diesel generator	$/kW	900	900	900	900	900
Gas power plant	$/kW	670	500	500	500	670
Renewables						
Hydro power plant	$/kW	1 590	1 540	1 540	1 540	1 540
Photovoltaic—rooftop	$/kW	1 008	1 008	850	780	700
Photovoltaic—utility scale	$/kW	1119	1110	840	745	650
Wind turbine offshore	$/kW	2360	2323	2250	2090	1930
Wind turbine onshore	$/kW	1 700	1 600	1 310	1 210	1 110

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions on GreenID (2018)[6] and LAZARDS (2018)[7]. Although these price projections are highly speculative, they provide a set of prices consistent with our investment assumptions.

Table 5: Development projections for fossil fuel prices

Development projections for fossil fuel prices							
All Scenarios			**2015**	**2020**	**2030**	**2040**	**2050**
Biomass		$/GJ	0.42	0.42	0.42	0.42	0.42
Oil		$/GJ	13.1	16.5	26.80	26.8	26.8
Gas		$/GJ	12.6	13.64	14.76	14.76	14.76
Coal		$/GJ	3	3.2	3.55	3.55	3.55

Assessment of solar and wind potential

Viet Nam has a largely untapped potential for renewable energy sources, and the only resource significantly in use is biomass. However, hydro power has limited potential for further increase because Viet Nam's utilization rate for hydro power plants is already high. Solar energy is abundant, with excellent potential for utility-scale photovoltaic power stations, particularly in rural areas. Successful policy support schemes, such as the feed-in law established in 2019, have shown very good initial results in the solar photovoltaic market.

Wind resources have been assessed by various organizations and show significant potential for onshore wind, and Viet Nam has one of South-East Asia's largest offshore wind potentials, with average wind speeds of up to 11 m/s, leading to capacity factors of more than 4500 h per year. In this analysis, offshore wind is used as a backbone for renewable power generation in Viet Nam after 2030, because:

6 GreenID (2018), Analysis of Future Generation Capacity Scenarios for Viet Nam, Website: www.greenidvietnam.org !OT: 0243 795 6372 I, Email: info@greenidvietnam.org.vn I Fanpage: GreenID Vietnam,

7 LAZARDS (2018); Lazard's Levelized Cost of Energy Analysis, Version 12.0, November 2018

- offshore wind has by far the largest potential of all renewable energy sources in Viet Nam;
- offshore wind has high capacity factors;
- offshore wind electricity will be more economic than coal electricity in terms of generation costs by 2030.

Currently, the country has 100 MW of near-shore wind power plants installed in the south of Viet Nam. In this analysis, we took into account coastal areas with a maximum water depth of 50 m and a maximum distance from shore of 70 km. Within these restrictions, Viet Nam has a technical potential of 609 GW, spread over a total of 3000 km of coastline and over 150,000 km^2.
Further research is required to locate the exact offshore wind areas, with regard to the distance to shipping lines, fisheries, and protected marine areas, and the access to infrastructure (such as the power grid) and harbour facilities, for their operation and maintenance. The offshore gas sector can benefit from increased offshore wind deployment because workers and parts of the infrastructure can be re-used (e.g., ships, supply equipment). Further research is required to develop the R&D capacity necessary to build up Viet Nam's offshore renewable energy industry.

Table 6: Overview—Viet Nam's utility-scale solar photovoltaic, onshore wind, and offshore wind potentials within 10 km of existing power lines

Cluster	Solar Area in km^2	Solar Potential in GW	Onshore Wind Area in km^2	Onshore Wind Potential in GW	Offshore Wind Area in km^2	Offshore Wind Potential in GW
Central Highlands	361.8	9.05	3119.4	12.47	-	-
Mekong Delta	4.2	0.10	60.8	0.24	64,928.18	259.71
North Central Coast	4.8	0.12	86.9	0.35	28,241.36	112.97
North East	331.8	8.3	1148.6	4.59	16,132.06	64.53
North West	184.7	4.62	691.8	2.76	-	-
Red River Delta	317.8	7.95	376.4	1.50	16,664.05	66.66
South Central Coast	594.5	14.86	4210.8	16.84	19,698.60	78.79
South East	122.5	3.06	818.1	3.27	6,784.19	27.14
Total	**1922.3**	**48.06**	**10513.1**	**42.05**	**152,448.44**	**609.79**

Assumptions for the scenarios

Viet Nam must build up and expand its power generation system to keep pace with its economic development and to ensure a reliable power supply. Building new power plants—no matter what the technology—will require new infrastructure (such as power grids), spatial planning, a stable policy framework, and access to finance. Constantly shifting policy frameworks often lead to high investment risks and therefore to higher project development and installation costs for solar and wind projects relative to those in countries with more stable policy.

The scenario-building process under all scenarios includes assumptions made about policy stability, the role of future energy utilities, centralized fossil-fuel-based power generation, population and GDP, firm capacity, and future costs.

- **Policy stability:** This research assumes that Viet Nam will establish a secure and stable framework for the deployment of renewable power generation. In essence, financing a gas power plant or a wind farm is quite similar. The better the investment certainty, the lower the cost of capital.
- **Strengthened energy efficiency policies:** Existing policy settings—that is the energy efficiency standards for electrical applications, buildings, and vehicles—must be strengthened in order maximize the cost-efficient use of renewable energy and achieve high energy productivity by 2030.
- **Role of future energy utilities:** With 'grid parity' of rooftop solar photovoltaics under most current retail tariffs, this analysis assumes that the energy utilities of the future will take up the challenge of

increased local generation and develop new business models that focus on energy services, rather than merely on selling kilowatt-hours.

- **Population and GDP:** All three scenarios are based on the same population and GDP assumptions, consistent with Viet Nam's Power Development Plan 7, which assumes a long-term average growth rate of around 7% per year until 2030.
- **Cost assumptions:** The same cost assumptions are used across all three scenarios. The cost assumptions are documented in section 5.3.

Narratives for the three coal scenarios

VIET has developed three narratives for coal scenarios: "OLD PLAN", "NEW NORMAL", and "FACTOR THREE". The first corresponds to the PDP7rev plan. The second represents a possible development under the current market forces with regard to the economics of renewable power generation. The third pathway describes what could happen if the government of Viet Nam continues to steer the electricity system towards an energy transition, decisively and without imposing high costs upon stakeholders.

1. **OLD PLAN:** Coal power generation units come online according to the "Expected" date listed in reference 9[8]. The plan to procure a fleet of build–operate–transfer (BOT) projects will proceed with small delays, and foreign investors will be satisfied with the 12% internal rate of return allowed in their power purchase agreements[9]. The government interprets the "No new coal" policy as meaning that projects lacking an investor in 2019 will not be pursued, and no new projects will be registered beyond those existing in PDP7A. Units are decommissioned after 40 years.

2. **NEW NORMAL:** Investors recognize that the economic window for building new coal-based power-generation projects in Viet Nam is closed. Only coal power generation units that are already permitted, with a scheduled completion in or before 2025, will be retained. The government will terminate all other projects on the basis of Circular 43[10], bringing relief to investors who were struggling to obtain financing and the administrative and social licenses to operate. After 2035, it will be recognized that operating coal power plants is losing money, so *Viet Nam Electricity* (EVN) will decommission the plants as soon as the BOT investors transfer them back to the state. Sub-critical units will cease operation after 20 years, and the others after 24 years. The exit from coal will be complete by 2050.

3. **FACTOR THREE:** Pilot renewable energy auctions for solar and wind in 2020 will show that procuring electricity from domestic renewable sources is more competitive than the price given to foreign companies to build and operate plants running on imported coal—the BOT program is not cost-efficient. In the same year, power shortages will emphasize that this program has also been ineffective in providing energy security. Investors who are not yet committed will jump ship, recognizing that coal assets will soon become unprofitable. No new coal plant construction will commence after 2019, and none will be commissioned after the end of 2022. The 13th National Congress in January 2021 will adopt the Asian concept of ecological civilization as a key goal for Vietnamese society, and will direct the country to accelerate its energy transition. The Ministry of Natural Resources and Environment (MONRE) will impose stricter pollution control norms, and MOF will raise fossil fuel taxes and import duties. The National Assembly will vote a 2021 Renewable Energy Law, and also enact the Renewable Portfolio Standards for BOT plants. In application, the Prime Ministers will order the Ministry of Industry and Trade (MOIT) to submit a coal exit plan to be integrated in revision. Coal power plants cannot operate profitably after 2035, and will be decommissioned after 20 years. The coal exit is complete before 2045.

Renewable pathways

Although these three coal pathways are the input to the analysis, based on the current situation in Viet Nam's power sector, the possible future development of the remaining power generation required —gas power generation and renewable electricity—is modelled on various scenarios. The long-term energy scenarios compare the REFERENCE case with two renewable scenarios:

The RENEWABLES 1 scenario (RE1) is designed to meet Viet Nam's energy-related targets and to lead towards a target of 100% renewable electricity in the second half of this century.

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[8] Hoang Quoc Vuong. Progress of implementing some key power source projects in PDP VII revised - Tình hình thực hiện các dự án điện trong Quy hoạch điện VII điều chỉnh. (MOIT, EREA, 2019).

[9] Cao Quoc Hung. Circular 56/2014/TT-BCT on method of determination of electricity generation costs, sequence of inspection of power purchase agreement (PPA). 50 (Ministry of Industry and Trade, 2014).

[10] Trần Tuấn Anh. Circular 43/2016/TT-BCT on Commitments for Project Development and Mechanism of Handling Electrical Factory Projects Not Performing a Practice Progress. 11 (Ministry of Industry and Trade, 2016).

In 2030, the electricity demand will increase significantly and reach a final electricity consumption of around 475 TWh, more than twice that in 2020. Renewable electricity generation will grow at the same pace and achieve a 40% share by 2030. The expansion of renewables is calculated under the constraint that the power plant capacity will increase for another decade—the **“NEW NORMAL” pathway**.

The *RENEWABLES 2 (RE2)* scenario takes a more ambitious approach to transforming Viet Nam’s entire energy system towards a 100% renewable energy supply—including the heating and transport sectors—in the second half of this century. The consumption pathways remain almost the same as in the RE1 scenario, but in this scenario, the introduction of electrification to replace fuel for thermal processes for industrial process heating and transportation is much faster. The latter will require a strong role for storage technologies, including batteries, synthetic fuels, and hydrogen. The expansion of renewables is calculated under the constraint that the coal power plant capacity will remain for another decade—the **“FACTOR THREE” pathway**. The resulting final energy demand for transportation will be lower than under the RE1 scenario, based on the assumptions that future vehicles, and particularly electric vehicles, will be more efficient and that there will be great improvements in the public transport system.

Key results—long-term scenario

In the executive summary, we focus on the key results for the power sector and the primary energy demand. The results for the transport and heating sectors are documented in Chapter 5.

Electricity generation

The development of the electricity supply sector is characterized by a dynamically growing renewable energy market and an increasing proportion of renewable electricity. This trend will more than compensate for the stagnation of new coal power plant installations and, after 2030, the phasing out of fossil-fuel-based power production in both alternative scenarios. By 2030, 38% of the electricity produced in Viet Nam will come from renewable energy sources under the RE1 scenario (2019: 31%), increasing to 75% in 2050. ‘New’ renewables—mainly onshore wind, solar photovoltaic, and offshore wind—will contribute 19% of the total electricity generation in 2030 and 58% by 2050.

Table 7: Projected capacities of renewable electricity generation

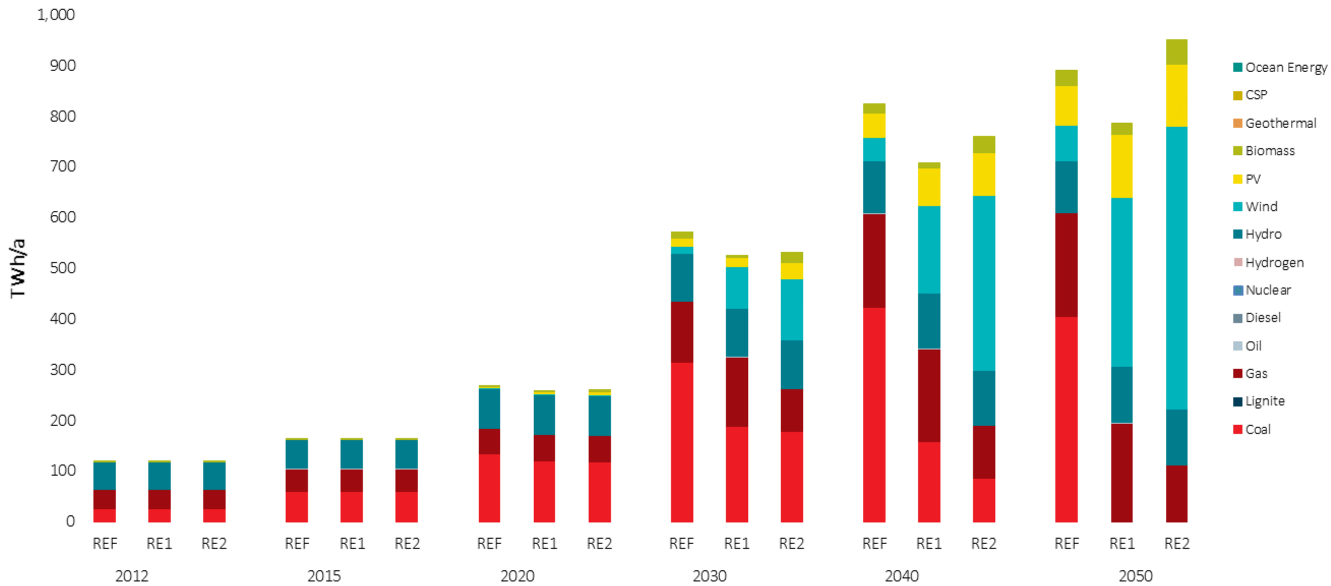
In GW		2015	2020	2030	2040	2050
	REF	13.103	20.632	55.137	56.337	54.093
Coal	RE 1	13.103	20.082	32.915	21.207	0.000
	RE 2	13.103	19.665	23.780	11.548	0.000
	REF	7.543	8.013	24.000	24.789	27.045
Gas	RE 1	7.543	8.174	23.295	24.628	26.476
	RE 2	7.543	8.475	13.142	14.122	15.382
	REF	18.424	21.602	27.800	29.042	29.042
Hydro	RE 1	18.424	20.555	25.303	28.642	29.074
	RE 2	18.424	20.555	25.303	28.642	29.074
Biomass	REF	0.024	0.575	2.100	3.284	5.762
	RE 1	0.024	0.141	0.783	1.831	3.958
	RE 2	0.024	0.582	3.566	5.887	9.338
Onshore Wind	REF	0.149	0.900	6.144	20.835	30.090
	RE 1	0.149	0.922	16.576	32.405	45.663
	RE 2	0.149	0.930	21.560	62.255	85.984
Offshore Wind	REF	0.000	0.100	0.150	1.000	2.139
	RE 1	0.000	0.100	9.485	21.269	5.257
	RE 2	0.000	0.100	20.941	54.307	90.220
Photovoltaic	REF	0.150	1.635	14.665	42.217	68.760
	RE 1	0.150	4 557	14.487	56.433	96.385

	RE 2	0.150	5 287	24.917	63.951	87.739
Total Renewables	REF	18.747	24.812	50.859	96.378	135.783
	RE 1	18.747	26.275	66.634	140.578	227.654
	RE 2	18.747	27.545	96.287	215.042	302.355

The installed capacity for renewables will grow from the current 54 GW to almost 70 GW in 2030 and to 230 GW by 2050. Under the RE2 scenario, renewable electricity generation will achieve a 50% share, which will reach almost 90% in 2050. The renewable capacity will increase to 96 GW by 2030 and to 302 GW in 2050. Table 22 shows the comparative evolution of the different renewable technologies in Viet Nam over time. Until 2040, hydro power will remain the main renewable power source. By 2020, wind and photovoltaics will overtake biomass, which is currently the second largest contributor (after hydro power) in the growing renewable market. After 2020, the continuing growth of onshore wind and photovoltaics will be complemented by electricity from offshore wind. The growth cascade of solar photovoltaics, followed by onshore wind and offshore wind, will reflect the cost competitiveness of these technologies compared with conventional power generation over time.
The RENEWABLES scenarios will lead to a high share of variable power generation sources (photovoltaics and wind) of already 19%–29% by 2030 and 58%–72% by 2050. Therefore, smart grids, demand-side management, energy storage capacities, and other options must be expanded to increase the flexibility of the power system for grid integration, load balancing, and a secure supply of electricity.
The calculated potential for utility-scale solar photovoltaics under all restrictions (see section 3.5) are 48 GW and 242 GW if the mountain areas and areas further than 10 km from transmission lines are taken into account. The most ambitious RE1 scenario can be implemented with 50% utility-scale solar photovoltaics under the most restricted potential, with solar rooftop generation accounting for the remaining capacity.
The RE2 scenario has less solar photovoltaics and more offshore wind because the remaining dispatch capacity—mainly from gas—is lower in RE2 than in RE1.

With regard to onshore wind, both alternative scenarios use the onshore wind potential with the highest restriction (identified in section 3.5.1) until 2030. Thereafter, areas further than 10 km from current transmission lines must be taken into account. The offshore wind potential is almost seven times larger than the most ambitious scenario requires.

Figure 2: Breakdown of electricity generation by technology



100% electricity supply from renewable energy resources in the RENEWABLES 2 scenario will lead to an installed generation capacity of around 300 GW in 2050.

Cost of electricity generation and required investment in power plants

The costs provided in this section include all the construction costs for new power plants, their average standard operation, the maintenance costs for each technology, and fuel costs. Infrastructure costs for the possible additional coal required, liquefied natural gas (LNG) supply capacities, or grid expansion, are not included because it was beyond the scope of this research.

In the REFERENCE scenario, power generation costs remain around US$0.07 over the entire modelling period. By 2030, the average generation costs across all technologies will be US$0.074 and by 2050 US$0.067. The RE1 scenario will lead to slightly lower average generation costs of US$0.069 by 2030 and US$0.052 by 2050. The most favourable scenario results, from RE2, include a high share of solar photovoltaics and wind power, entailing a significantly smaller requirement for fuel and lower capital costs for installation.

Because the uncertainty in the assumed fossil fuel prices increases with time—especially for the REFERENCE case, in which fuel-based power generation has an 83% share—the costs of storage and grid integration are not considered in this calculation. In contrast, under the REFERENCE scenario, the growth in demand and increasing fossil fuel prices result in an increase in the total cost of electricity supply from US$12 billion per year in 2015 to US$42 billion in 2030, compared with US$36 billion in the RE1 scenario and US$30 billion in the RE2 scenario.

Around US$125 billion is required in investment between 2020 and 2030 for the RE1 scenario to become a reality—US$12 billion less than in the REFERENCE case. The RE2 case will require US$157 billion, US$24 billion more than in the REFERENCE scenario. The additional annual investment in RE2 will be US$2.4 billion higher than in the REFERENCE scenario and US$3.2 billion higher than in the RE1 scenario. Under the REFERENCE scenario, the levels of investment in fossil-fuelled power plants will add up to almost 68%, and approximately 32% will be invested in renewable energy until 2050. However, under the RE1 scenario, Viet Nam will shift almost 64% of its entire investment towards renewables and 36% to fossil-fuelled power plants between 2020 and 2030, which is the reverse of the investment shares in the REFERENCE scenario. The RE2 scenario will direct 88% of all new investments into the generation of renewable electricity between 2020 and 2030.

Fuel cost savings

Under the RE1 scenario, the investments saved between 2020 and 2030 are estimated to be US$7.8 billion, and compared with the REFERENCE case, the fuel cost savings will sum to US$7.9 billion. Therefore, the overall savings would add up to over US$15 billion. Even under the assumption that there will be great uncertainties in both future investment costs for power generation equipment and the development of fossil fuel prices, it seems certain that the overall cost balance will be economically favourable for the RE1 scenario. Under the RE2 scenario, the additional investment between 2020 and 2030 is estimated to be around US$2.1 billion compared with the REFERENCE case. However, the fuel cost savings will add up to US$9.4 billion without the transport sector. As in the RE1 scenario, the RE2 scenario will lead to fuel cost savings that will more than refinance the investment cost for renewable power generation.

Primary energy

Under the RE1 scenario, the primary energy demand will increase from the current value of around 4,000 PJ/a to around 6,200 PJ/a in 2030, an increase of 150%. Compared with the REFERENCE scenario, the overall primary energy demand will be reduced by 1,000 PJ by 2030 under the RE1 scenario (REF: 7,250 PJ in 2030). The RE2 scenario will result in a primary energy consumption of around 5,900 PJ in 2030, which will remain at this level because electrification will increase between 2030 and 2050. Therefore, in the RENEWABLES scenarios, renewable primary energy will have an overall share of 16% in 2030 and 43% in 2050 under RE1 and of more than 84% in 2050 under RE2 (including non-energy consumption).

Power sector analysis

The [R]E 24/7 model calculates the demand and supply in eight sub-regions of Viet Nam, which are intended to reflect the main provinces, and it assumes that the interconnections between the sub-regions will increase to 15% of the regional peak load by 2030 and to 20% by 2050. The distribution is based on the regional solar and wind potential and the regional demand, and the model aims to generate electricity where the demand is located. Whereas solar photovoltaic power generation is modular and can be installed close to the consumer or even be integrated into buildings, onshore wind must remain distant from settlements. Thus, onshore wind will have to be clustered into wind farms with double digit megawatt capacities, on average. Offshore wind is not a decentralized renewable energy technology and must be installed in a range of several hundred megawatts to a gigawatt. The distribution of offshore wind farms is based on available wind resources, and the existing infrastructure (harbours, transmission lines), and must be close to centres. Therefore, the largest part of the offshore wind capacity will be located in the Hanoi and Ho Chi Ming City areas in our model calculation.

Table 8: Viet Nam: Load, generation, and residual load development

Viet Nam: Development of load and generation		REF				RE1				RE2			
		Max. Demand	Max. Generation	Max. Residual Load	Peak load increase	Max Demand	Max Generation	Max Residual Load	Peak load increase	Max Demand	Max Generation	Max Residual Load	Peak load increase
Viet Nam		[GW/h]	[GW/h]	[GW/h]	[%]	[GW/h]	[GW/h]	[GW/h]	[%]	[GW/h]	[GW/h]	[GW/h]	[%]
North West	2020	1.1	1.1	0.1	100%	1.0	1.0	0.1	100%	0.9	0.9	0.1	100%
	2030	1.9	1.9	0.1	178%	1.8	1.8	0.1	184%	1.7	1.9	0.1	187%
	2050	3.4	3.4	0.1	323%	3.3	4.9	0.3	345%	4.1	7.2	0.1	445%
North East	2020	3.3	3.3	0.2	100%	3.0	3.0	0.2	100%	2.9	2.7	0.3	100%
	2030	5.5	5.5	0.2	167%	5.1	5.1	0.2	172%	5.0	5.4	0.2	175%
	2050	9.8	9.8	0.2	301%	9.5	14.6	6.8	321%	11.9	21.0	8.9	418%
Red River Delta	2020	9.4	7.6	2.2	100%	8.5	7.6	1.2	100%	8.2	7.6	1.2	100%
	2030	15.8	15.8	0.8	167%	14.6	14.6	0.8	171%	14.2	14.2	3.2	173%
	2050	30.4	30.4	7.0	322%	28.9	36.4	17.6	339%	34.0	50.1	25.1	416%
North Central Coast	2020	3.5	3.5	0.3	100%	3.2	3.2	0.3	100%	3.1	3.0	0.4	100%
	2030	6.0	6.0	0.3	170%	5.6	5.6	0.3	175%	5.5	7.4	0.3	179%
	2050	11.5	11.5	1.4	326%	11.3	19.4	8.5	352%	14.3	30.3	11.1	460%
Central Highlands	2020	1.7	1.7	0.1	100%	1.6	1.6	0.1	100%	1.5	1.4	0.2	100%
	2030	3.2	3.2	0.1	183%	3.0	3.0	0.1	191%	2.9	2.9	0.1	196%
	2050	5.9	5.9	0.1	344%	5.8	5.9	0.5	374%	7.4	8.0	1.4	496%
South Central Coast	2020	3.2	3.2	0.3	100%	2.9	2.9	0.3	100%	2.8	2.6	0.5	100%
	2030	5.7	5.7	0.3	178%	5.3	5.3	0.3	184%	5.2	5.4	0.3	188%
	2050	10.6	10.6	1.7	331%	10.3	15.0	5.4	355%	12.7	21.5	7.5	459%
South East	2020	9.1	8.3	1.2	100%	8.2	7.6	0.7	100%	7.7	7.2	1.2	100%
	2030	16.8	16.8	0.5	184%	15.3	15.3	0.5	187%	14.7	14.7	3.3	190%
	2050	32.5	32.5	11.1	356%	30.0	27.7	14.2	367%	32.9	32.9	20.1	426%
Mekong Delta	2020	4.5	4.5	0.0	100%	3.9	3.9	0.0	100%	3.7	3.5	0.3	100%
	2030	11.2	11.2	0.0	248%	10.5	10.5	0.0	267%	10.3	14.3	1.0	278%
	2050	21.5	21.5	1.5	477%	21.0	37.9	11.6	533%	25.8	57.6	19.0	693%
Viet Nam	2020	35.9	33.2	3.0	100%	32.3	30.8	3.0	100%	30.8	28.8	4.2	100%
	2030	66.0	66.0	2.3	191%	61.2	61.2	2.3	191%	59.6	66.1	8.6	196%
	2050	125.7	125.7	64.8	373%	120.2	161.8	64.8	373%	143.1	228.6	93.1	477%

Important technical conditions: Power grid capacities must increase proportionally to the increase in load.
Both RENEWABLES scenarios aim for an even distribution of variable power plant capacities across all regions of Viet Nam by distributing solar photovoltaic and onshore wind utilities accordingly. However, coastal regions will have a significantly higher share of variable offshore wind utilities than land-locked regions. By 2030, variable power generation will reach 15%–20% in most regions, whereas the shares of dispatchable renewables—bioenergy and hydro power—will vary significantly, from 87% in the Central Highlands to only 1% in the Mekong Delta.

The significant regional differences in power system shares—the ratio between dispatchable and non-dispatchable (variable) power generation—require for their resolution a combination of increased interconnection, storage facilities, and demand-side management incentives. Over time, the variable power generation shares will increase in all scenarios. The regions with large offshore wind capacities will have the highest shares of variable generation in the grid, and will require greater interconnection with neighbouring regions than those with lower variable electricity shares.

Table 8 shows that Viet Nam's load is predicted to double or triple in all eight sub-regions between 2020 and 2030 under all scenarios. The REFERENCE and RE1 scenarios have almost identical load development until the end of the modelling period in 2050. The RE2 case will lead to higher loads after 2030 because of increased electric mobility. This will make it necessary to expand the capacity of Viet Nam's power grid infrastructure until 2030, independent of the form of power generation. Increased electric mobility will require an additional increase in the capacity of the power grid with the higher charging loads for vehicles. However, the locations of transmission grids will depend on the form of power generation involved because the locations of power generation facilities and the demand centres may differ for decentralized and centralized power generation. The REFERENCE scenario will lead to a significant concentration of generation capacity in the north, around Hanoi, and in the south, near Ho Chi Minh City, because coal power depends on fuel supplied via harbours and rail lines, and gas power depends on gas pipelines or LNG terminals for imported gas.

Development of an interregional exchange capacity
The increasing electricity load in all regions, shown in Table 33, will require increases in the transmission and distribution networks of Viet Nam. This analysis assumes that those network upgrades will be implemented as the demand increases. As a technical requirement, Viet Nam will have to increase its grid capacities proportionally to the increase in demand. If this technical condition is not met, the probability of blackouts will increase significantly. This technical requirement to expand the grid capacity will be largely independent of the type of power generated.

The interregional exchange of capacity is a function of the load development and the generation capacity in all eight regions. The [R]E 24/7 model distributes the generation capacity according to the regional load and the conditions for power generation. The locations of coal and gas power plants are given and the installation of new capacities will depend on the possibility of fuel supply. Renewable power generation is more modular and can be distributed according to the load in the first place. However, with increasing renewable electricity shares, the space available for utility-scale solar and onshore wind facilities and the availability and quality of local resources, such as solar radiation and/or wind speed, may cause power generation to move further from the point of consumption. This will require more transmission capacity to allow the exchange of generation capacities between the eight regions of Viet Nam analysed here. In our analysis, an increase in the required interregional exchange of capacity, in addition to the increase in the grid capacity within the regions as the demand increases, will start between 2030 and 2040. A significant increase in transmission capacity will be especially required in those regions with low demand but high generation potential, such as in the North West (hydro power) and locations with offshore wind.

The current real interconnection capacities between the eight calculated regions were not available for this analysis, so the modelling results are based on the assumptions documented in this report. The net transfer capacity in the REREFERENCE scenario for 2050 follows the same pattern as the two alternative scenarios, whereas the 2040 values differ. The modelling results indicate that interconnections must be built earlier in the alternative pathways. However, the large offshore wind capacities along coastal regions will require transmission capacities into the hinterland.

Table 9 Calculated maximum import and export capacities, additional to the increase in grid capacity expansion required as load increases, under the three scenarios

Calculated maximum import and export capacity by region		REF	RE1	RE2	REF	RE1	RE2	REF	RE1	RE2
			2030			2040			2050	
North West	IMPORT	0	0	0	0	0	0	0	0	0
	Export	0	0	2,736	1,579	6,669	5,977	4,757	10,579	8,288
North East	IMPORT	0	0	0	0	0	−764	0	−4,767	−5,383
	Export	0	0	443	278	3,452	3,098	5,570	1,969	3,847
Red River Delta	IMPORT	0	0	−1,533	0	−4,222	−8,015	−4,557	−9,442	−14,709
	Export	0	0	0	0	0	538	2,512	2,401	2,134
North Central Coast	IMPORT	0	0	0	0	−1,842	−3,163	−476	−3,204	−3,737
	Export	0	0	0	0	85	4,754	2,017	2,690	10,832
Central Highlands	IMPORT	0	0	0	0	0	0	0	0	-127
	Export	0	0	0	0	695	5,361	1,062	7,423	9,412
South Central Coast	IMPORT	0	0	0	0	−684	−1,733	−836	−3,204	−3,352
	Export	0	0	0	0	0	1,160	0	1,439	1,161
South East	IMPORT	0	0	−1,647	−1,857	-3,110	−4,714	−8,544	−6,276	−7,040
	Export	0	0	0	0	0	0	0	0	0

The metropolitan areas of the two main cities, Hanoi and Ho Chi Minh City, are currently responsible for approximately one third of Viet Nam's total peak load each (about 10 GW), whereas the remaining 10 GW is distributed across all other provinces. In this analysis, this will not change, whereas the overall load will increase by a factor of three.

Peak load and peak generation events do not appear at the same time, so the values cannot be summed. The peak loads across all regions can also vary and appear at different times. Therefore, to add all regional peak loads will only provide an indication of the peak load for the whole country. To guarantee security of supply, the residual load of a region must be supplied with the following options:

- imports via interconnections with other regions;
- charged storage facilities providing additional load;
- availability of back-up capacities, such as gas peaking plants;
- load and demand-side management.

In practice, security of supply will be achieved with a mixture of several measures and will require an in-depth analysis of regional technical possibilities, e.g., whether a cable connection is possible.

Both RENEWABLES scenarios involve significant amounts of decentralized small-to-medium-scale generation—solar photovoltaics and onshore wind—(RE1:20%/RE2:28%), which can generate power close to the demand. The North Central Coast and South Central Coast regions have relatively low loads, and the combination of regional onshore wind and utility-scale solar photovoltaic potential is well above the calculated load for 2050. Therefore, both regions can develop as net exporters of electricity, although they are currently energy importers. Both RENEWABLES scenarios have offshore wind generation shares of around 55% compared with the total installed capacity. Offshore wind is a centralized renewable power source and requires that specific transmission lines transport electricity exclusively from sea to land. UTS-ISF suggests a specific transmission corridor, which is described in the following section.

Hanoi to Ho Chi Minh offshore wind link

Viet Nam has significant offshore wind potential and a very favourable geography, which should allow the use of this electricity in all provinces, except in the North Eastern region and the Central Highlands, which have no access to a coastline. UTS-ISF suggests that a sea cable parallel to the coastline be used to collect the electricity generated from offshore wind—an offshore wind busbar. This *Hanoi-Ho Chi Minh*

Power Link will transports the power to the two load centres in the north and south and, with lower capacity, will interconnect the other coastal provinces in between. These links can work both ways:

a. supplying those coastal regions that have a lower generation capacity with electricity;
b. transporting surplus power to the load centres (the South Central Coast has significant solar potential).

The suggested position of this offshore wind cable follows the coastline for around 10 km and is interconnected by six currently existing grid knots to each of the six coastal regions. The total length of this cable would be 1775 km, including the land connections. The maximum load calculated for Hanoi/Red River Delta in 2050 under the RE2 scenario is 34 GW, whereas the estimated load for Ho Chi Minh/South East will reach 32.9 GW. The total maximum load for Viet Nam is expected to reach around 110–120 GW by 2050. The installed offshore wind capacity in the RE2 scenario will be 90 GW.

Storage requirements

The quantity of storage demanded will largely depend on storage costs, grid expansion possibilities, and the mix of power generation utilities used. In terms of grid expansion, the geographic situation will greatly influence the construction costs; crossing mountains or river swamps is significantly more expensive than crossing flat lands (Wendong 2016)[11]. Furthermore, the length of the permitting process and whether people will be displaced by grid expansion may confer economic advantages on storage over grid expansion, even though current transmission costs are lower per megawatt-hour than storage costs. Cebulla et al. (2018)[12] have shown that “in general terms, PV-dominated grids directly correlate to high storage requirements, in both power capacity and energy capacity. Conversely, wind-dominated scenarios require significantly lower storage power and energy capacities, if grid expansion is unlimited or cheap”. Cebulla et al. have also demonstrated in an analysis of 400 scenarios for Europe and the United States that once the share of variable renewables exceeds 40% of the total generation, the increase in electrical energy storage capacity is about 1–2 GW for each percentage of variable renewable power generation in wind-dominated scenarios and 4–9 GW in solar-photovoltaic-dominated scenarios. In the RE1 scenario, the share of variable generation will exceed 40% between 2040 and 2045, whereas the RE2 scenario will arrive there 10 years earlier.

The results of the Viet Nam analysis are similar to the findings of Cebulla et al., with 55 GW storage required by 2050 in RE1 and 97 GW in RE2. However, there is no “hard number” for the storage requirement because it is dependent on the available dispatch capacity, e.g., from (bio-)gas power plants, possibility of demand-side management. Furthermore, the economically optimal storage capacity, in terms of both the overall storage volume and the installed capacity, is as function of the storage costs, wind- and solar-power-generation costs, and power system requirements. The majority of storage facilities will be required in the Mekong Delta because this regions has Viet Nam’s greatest demand and a significant proportion of offshore wind generation is concentrated here. For the whole of Viet Nam, the simulation of renewable power generation in scenarios RE1 and RE2 leads to storage needs of 9.3 TWh/a and 33.4 TWh/year, respectively, with installed in/output capacities of 10 GW (RE1) and 35 GW (RE2 Utility-scale storage will be required between 2030 and 2050. The storage demand will vary significantly and will be a function of the regional distribution of variable power generation and the extent to which regions can exchange load via interconnections. However, the expansion of the electricity network with increasing demand is unavoidable under all scenarios. The optimization of the storage demand and interconnections requires further research and is beyond the scope of this analysis.

Summary: Power sector analysis for Viet Nam

Both RENEWABLES scenarios prioritize the use of Viet Nam’s renewable energy resources to reduce the dependence on energy imports and to utilize local resources. The power demand in Viet Nam will increase significantly under each power generation scenario. Therefore, power grids must expand, and power generation must increase according to the load increase, both under a conventional power generation pathway and a renewable-power-dominated pathway.

However, renewable-energy-dominated power generation requires a different infrastructural design than a fossil- and nuclear-power-dominated future. To harvest Viet Nam’s offshore wind and solar resources, the power grid must be able to transport large loads from the coast further north and inland, and decentralized power will shoulder a significant part of the residential sector. Offshore wind will require transmission lines extending to the load centres of Viet Nam. UTS-ISF suggests that an offshore wind link along the coastline

[11] Wendong (2016), Wei, Wendong et al. Regional study on investment for transmission infrastructure in China based on the state grid data,10.1007/s11707-016-0581-4, Frontiers of Earth Science, June 2016

[12] Cebulla et al. (2018), How much electrical energy storage do we need? A synthesis for the U.S., Europe, and Germany, Journal of Cleaner Production, February 2018, https://www.researchgate.net/publication/322911171 How much electrical energy storage do we need A synthesis for the US, Europe and Germany/link/5a782bb50f7e9b41dbd26c20/download

of Viet Nam be designed that would also function in long-distance transmission from and towards the load centres at the northern and southern ends of the country.

In 2050, the majority of dispatch power will come from gas power, which may derive from hydrogen and/or synthetic fuels after 2040. Viet Nam has abundant renewable energy resources, which together with the currently available technologies could supply all the renewable electricity required to produce fuels, and may even allow the export of renewable fuels. However, more research is required to assess how existing gas pipelines in Viet Nam can be converted to renewable fuel pipelines and to identify the best locations at which to produce renewable fuels.

Projected employment in the energy sector of Viet Nam.

Employment growth has been calculated based on the methodology described and the results of the long-term energy scenario documented in Chapter 4. The figures represent quantitative estimates and are compared with the current workforces in Viet Nam for which information was available.

Under the REFERENCE scenario, there will be an increase of about 100,000 jobs in the coal sector, whereas employment in the renewables sector will decrease. The total number of jobs in the energy sector will increase from around 250,000 to almost 380,000 jobs.

Jobs in the energy sector under the REF scenario will increase by 150% and remain at this level throughout 2030, with a slight decline by 2050. However, both alternative energy pathways lead to strong growth in the renewables sector, which will significantly more than compensate for the losses in the coal industry. The RE1 scenario will double the overall employment in the energy sector from 250,000 today to 520,000 by 2025, with a further increase of 130,000 jobs by 2030. Only 14% of these jobs in 2030 will be in the fossil fuel industry, and the remaining 86% will be in the renewables industry.

Our analysis shows similar developments in the RE2 scenario: the overall number of jobs in 2025 and 2030 will be 100,000 above those in the RE1 scenario. Because the RE2 scenario accelerates the development of renewables, the construction rates will decrease after 2030, so that by 2050, there will be around 75,000 fewer jobs in the construction industry than under the RE 1 scenario, but still approximately 200,000 more than under the REF scenario.

Conclusion

The next Power Development Plan 8 is a historical opportunity to chart the way towards a low-carbon power system, and to avoid locking Vietnam into a high-carbon social structure.

The cost development of solar photovoltaic, onshore wind, and offshore wind power generation, and the necessary storage technologies, will makes renewable power generation economically preferable to fossil-fuel-based generation. The construction times for solar photovoltaic and wind power facilities are shorter than those for gas- and coal-fuelled power generation facilities, so power generation can follow demand more easily. Renewable power generation is independent of variations in the fossil fuel price and therefore provides planning security for energy costs.

The electricity generation costs for onshore wind already undercut those for new gas power plants, and will be cost competitive with coal within the next 5 years. By 2030, utility-scale solar photovoltaic, onshore wind, and offshore wind generation costs will be lower than those for coal generation, and will therefore be cost competitive. Consequently, new coal power plant projects will be uneconomic and the probability of stranded investments will be high.

The role of gas in both alternative scenarios is similar to its role in the REF scenario until 2025. Thereafter, the RE1 scenario will maintain a total capacity of around 25 GW until 2050, whereas the RE2 scenario will not exceed 15 GW. The annual new renewables capacities for both scenarios aim for stable markets to encourage the sustainable growth of Viet Nam's renewables industry.

Our analysis indicates that fuel cost savings between 2020 and 2030 under the RE1 scenario will be equal to the additional investment costs required for renewable power generation. Therefore, RE1 will be cost neutral compared with the REF scenario. The more ambitious RE2 scenario will require significantly greater investment in renewables, but will also reduce the investment in new coal power plants. The overall fuel cost savings will generate a cost benefit of over US$6.5 billion between 2020 and 2030, making the RE2 pathway the most economic.

Viet Nam has significant potential for utility-scale solar photovoltaic power generation and onshore wind potential within a 10 km range of existing power lines. These will allow the projected generation capacities for these technologies to be achieved by 2040 under the RE1 scenario and by 2030 under the RE2 scenario. In additional areas, further from existing power lines, these will be achieved later. The potential for offshore wind power generation in the coastal waters of Viet Nam exceeds the countries demand by an order of magnitude.

While both alternative energy pathways will achieve higher accumulated energy savings than the planned VNEEP III, the electricity demand will still increase by around 70% in all regions, which makes an increase in the power grid capacities unavoidable. This necessary increase in grid capacity will result from the higher demand, in terms of both the overall energy (in megawatt-hours) and the total load (in megawatts). This is independent of the type of power generation.

With the increase in energy demand from 2030 onwards under all scenarios, the interregional transmission capacity must be expanded, together with an increase in the grid capacity within each region, independent of the power generation technology in use. However, the geographic locations of grid enforcement will differ. In this analysis, we explored the feasibility of building a national offshore busbar. Undersea high-voltage direct-current cable technology is advancing rapidly. In the projections to 2050, there is an option to reinforce the national grid by laying a transmission line along the coast, connecting the two deltas with the currently planned system of offshore wind farms.

The RE1 scenario predicts per capita energy-related CO_2 emissions of 3.7 tons by 2030, compared with 4.8 tons under the REF scenario and 3.35 tons under RE2. By 2050, the RE2 scenario will reduce the per capita emissions to under 0.5 tones, RE1 to 2.3 tons, and REF to 5.7 tons.

2 METHODOLOGY AND ASSUMPTIONS

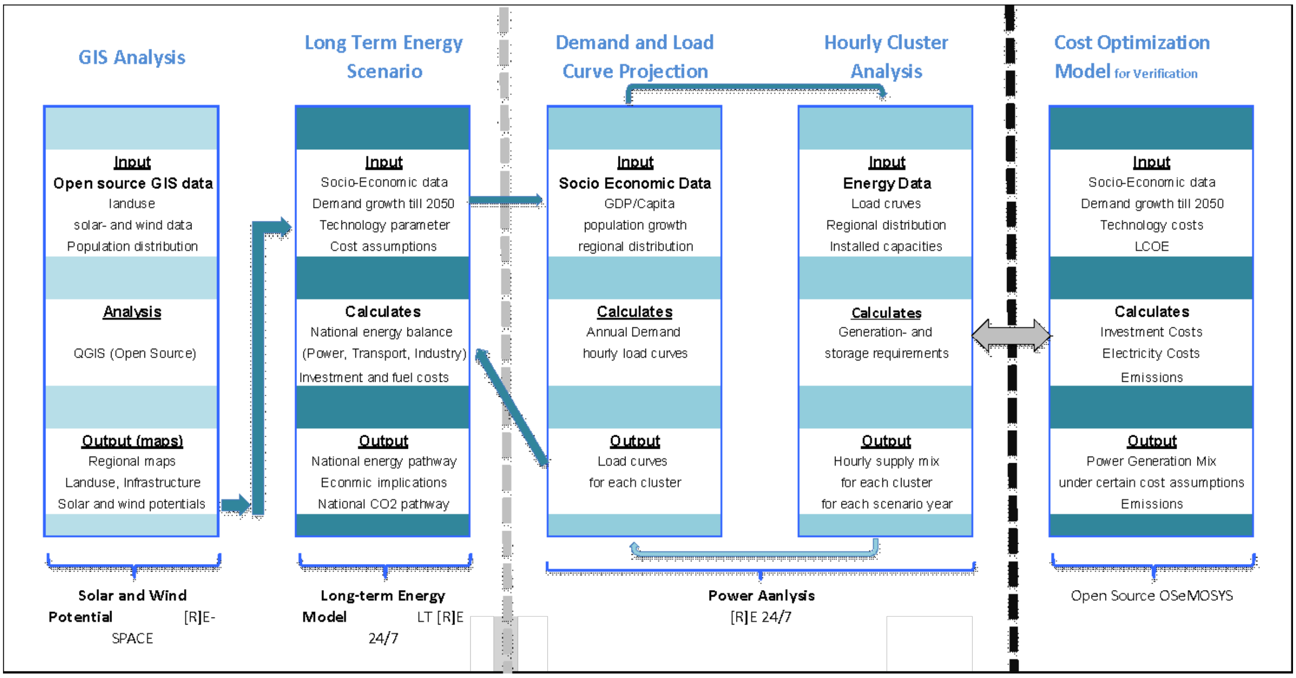
This report provides a technical and economic analysis of the long-term energy and power development plans for Vietnam. The analysis is based on the [R]E 24/7 energy access pathway methodology developed by the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) and on the long-term energy scenario model of the Institute for Thermodynamics of German Aero Space Centre (DLR), energy models developed for various UTS-ISF surveys, and the [R]E 24/7 model. The following section explains the methodology and provides an overview of the required input parameters, basic functions, and calculated outputs. The entire modelling process is based on five modules, four developed by UTS-ISF and the remaining one the open source model OSeMOSYS, which we have used for the cost-related sensitivity analysis. The models are described below in their order of use.

For the mapping analysis, a global information system (GIS) was used for a regional analysis of Viet Nam's population density and distribution, its solar and wind resources, and the currently existing energy infrastructure (transmission power lines and power plants with over 100 MW of installed capacity). This information has been used to define the cluster breakdown.

The long-term scenario LT [R]E 24/7 has been used to re-model the existing power-development plan and to develop alternative national energy pathways for Viet Nam. This model takes all sectors into account (power, heat, and transport) and includes cost and energy-related CO_2 calculations.

The [R]E 24/7 power sector analysis tool computes the annual demand for up to five different years (here: 2020, 2030, 2040, and 2050) and the load curves for a full year (8760 h). The hourly load curves are required to simulate the demand and supply for each of the eight regions of Viet Nam. The results are the development of loads, the generation mix, and the storage demand.

Figure 3: Overview—Modelling concept



2.1 [R]E 24/7—GIS MAPPING TOOL

The primary purpose of GIS mapping is to ascertain the renewable energy resources (primarily solar and wind) available in Viet Nam. It also contributes to the regional analysis of geographic and demographic parameters and the available infrastructure that can be leveraged in developing the scenarios.
In this project, mapping was performed with the computer software 'QGIS', which analyses and edits spatial information and constructs and exports graphical maps. It has been used to allocate solar and wind resources and for demand projections for each calculated region. Population density, access to electricity, and the distribution of wealth, or the economic development projections, are key input parameters in the region-specific analysis of Viet Nam's future energy situation.

Open-source data and maps from various sources are used to visualize the country and its regions and districts. Further demographic data related to population and poverty, as well as transmission networks and power plants, are also plotted on the maps. The main data sources and assumptions made for this mapping are summarized in the table below.

Table 10: [R]E 24/7—GIS-mapping—data sources

Data	Assumptions	Source
Regions	The Vietnamese Government groups the various provinces into eight regions: North West, North East, Red River Delta, North Central Coast, South Central Coast, Central Highlands, South East, and Mekong River Delta.	Pacific Disaster Center (PDC)
Land use/land cover	Land cover types of bare soil, annual cropland, perennial cropland, and grassland are included in the wind analysis. Only land cover types of bare soil, perennial cropland, and open bush land are included in the solar analysis.	World Bank: ESMAP
Elevation	For both wind and solar analyses, any land with a slope of more than 30% was ignored.	Open DEM
Bathymetry	Offshore water bodies (ocean) within 70 km of the coast and with a depth of no more than 50 m below sea level were included in the offshore wind analysis.	GEBCO
Population density	Estimates of numbers of people per pixel (ppp), with national totals adjusted to match UN population division estimates.	WorldPop
Poverty	Based on the GSO-WB poverty headcount in percentage terms for each province.	WorldBank
Power plants	The Global Power Plant Database is a comprehensive, open-source database of power plants around the world.	GIZ Vietnam, Global power plant database, World Resource Institute
Solar irradiance	The average yearly direct normal insolation/irradiation (DNI) values range from 1 to 5 MWh/m^2 per year.	Solar GIS
Transmission lines and network	Only those sites within 10 km of an existing transmission line were included in the analysis.	EnergyData.info
Wind speed	Wind speeds above 6 m/s were considered at a height of 80 m	Global wind atlas

The areas of land available for potential solar and wind power generation were calculated at both national and regional levels (eight regions of Viet Nam—see section 3.4) using the ellipsoidal area tool in the *QGIS* processing toolbox. Intersects were created between the transmission level layers and the solar/wind utility vector layers to break down the total land area available clusterwise. A correction was put in place for sites that intersected the cluster boundaries and were part of the two transmission levels. This input was fed into the calculations for the [R]E 24/7 model, as described below.

2.2 LONG-TERM SCENARIO MODELLING

Historically, heating, electricity, and mobility have been separated in terms of their energy sources, requiring different infrastructures and therefore different planning: electricity for stationary power, petrol and diesel for mobility, and onsite heat for buildings and industrial processes. This will almost certainly change, with increasing use of electricity for heating and mobility, such as in electric vehicles. This emerging *sector coupling* must be taken into account and requires an integrated approach across heat, mobility, and electricity/stationary power when developing future energy system scenarios, as is done in this model.

Three scenarios have been developed, a reference case and two alternative energy pathways. The assumptions for those scenarios are documented in section 3.7. The long-term (LT) modelling approach used in this research is based on the development of target-orientated scenarios. In this approach, a target is set and technical scenarios are developed to meet this target, and then compared with a reference case. The set target can be in terms of annual emissions and/or renewable energy shares. For Viet Nam, an exogenous target for the development of the installed coal capacity over the next 30 has been developed (see section 3.7.1).

The scenarios are based on detailed input datasets that consider defined targets, renewable and fossil fuel energy potentials, and specific parameters for power, heat, and fuel generation in the energy systems. The datasets are then fed into the LT-[R]E 247, which is based on a DLR model that uses the MESAP/PlaNet software, an accounting framework for the calculation of the complete energy system balance to 2050.

The LT-[R]E 24/7 model simulation consists of two independent modules:

1. a flow calculation module, which balances energy supply and demand annually; and
2. a cost calculation module, which calculates the corresponding generation and fuel costs.

Note that this is not a dispatch model, such as the [R]E 24/7 power sector model used to calculate the future regional and hourly power, or a technical grid simulation (including frequency stability), such as DIgSILENT's PowerFactory, which is beyond the scope of this analysis.

The LT-[R]E 24/7 model is a bottom-up integrated energy balance model. Different modelling approaches each have their benefits and drawbacks. This model is particularly good at helping policy makers and analysts understand the relationships between different energy demand types in an economy—across all sectors and over a long time period, usually 30–40 years. In a simulation model, the user specifies the drivers of energy consumption, including the forecast population growth, GDP, and energy intensities.

Specific energy intensities are assumed for:

- electricity consumption per person;
- the ratio of industrial electricity and heat demand intensity to GDP;
- demand intensities for energy services, such as useful heat;
- energy intensities of different transport modes.

Electricity demand projections for the building and industry sectors are calculated with [R]E 24/7 (see section 4.4) as an input for the LT-[R]E 24/7 model of the alternative scenarios, but not for the REFERENCE scenario, in which they are taken from the Viet Nam Power Development Plant 7. The electricity demand for the transport sector has been calculated with the LT-[R]E 24/7 model. For both heat and electricity production, the model distinguishes between different technologies, which are characterized by their primary energy source, efficiency, and costs. Examples include biomass or gas burners, heat pumps, solar thermal and geothermal technologies, and several power generation technologies, such as photovoltaics, wind, biomass, gas, coal, nuclear, and combined heat and power. For each technology, the market share with respect to total heat or electricity production is specified based on a range of assumptions, including the renewable energy target, potential costs, and societal, structural, and economic barriers. The main outputs of the model are:

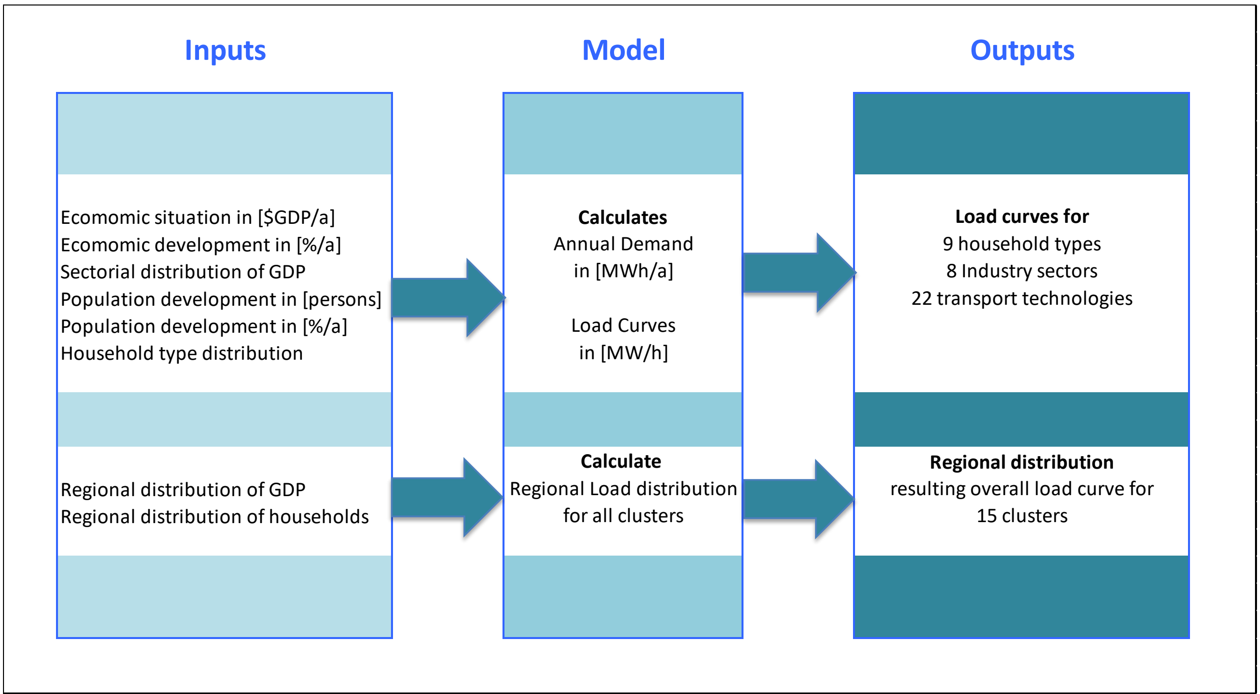
- final and primary energy demand, broken down by fuel, technology, and sector of the economy, as defined by the International Energy Agency (IEA): industry, power generation, transport, and other (buildings, forestry, and fisheries)[13];
- results broken down by the three main types of energy demand—electricity, heating, and mobility (transport); specifically, the energy required, technology deployment, and finance;
- total energy budget, or the total cost of energy for the whole energy system;
- energy-related greenhouse gas emissions over the projection period.

2.3 [R]E 24/7—POWER ANALYSIS

After the geographic analysis and the development of long-term energy pathways for Viet Nam, the power sector was analysed in a third step with the [R]E 24/7 module.

The energy demand projections and resulting load curve calculations are important factors, especially for power supply concepts with high shares of variable renewable power generation. Calculation of the required dispatch and storage capacities is vital for the security of supply. A detailed bottom-up projection of the future power demand based on the applications used, demand patterns, and household types allows a detailed forecast of the demand. Infrastructure needs, such as power grids, combined with storage facilities require an in-depth knowledge of the local loads and generation capacities. However, this model cannot simulate frequencies or ancillary services, which would be the next step in a power sector analysis.

Figure 4: Overview—Energy demand and load curve calculation module



[13] Note these industry sectors correspond to IEA energy statistics input into the model.

2.3.1 METEOROLOGICAL DATA

Variable power generation technologies are dependent on the local solar radiation and wind regimes. Therefore, all the installed capacities in this technology group are connected to cluster-specific time series. The data were derived from the database *Renewable Ninja* (RE-N DB 2018)[14], which allows the simulation of the hourly power output from wind and solar power plants at specific geographic positions throughout the world. Weather data, such as temperature, precipitation, and snowfall, for the year 2014 were also available. To utilize climatization technologies for buildings (air-conditioning, electric heating), the demand curves for households and services are connected to the cluster-specific temperature time series. The demand for lighting is connected to the solar time series to accommodate the variability in lighting demand across the year, especially in northern and southern regions, which have significantly longer daylight periods in summer and very short daylight periods in winter.

For every region included in the model, hourly output traces are utilized for onshore wind, offshore wind, utility solar, and rooftop solar photovoltaics. Given the number of clusters, the geographic extent of the study, and the uncertainty associated with the prediction of the spatial distribution of future-generation systems, a representative site was selected for each of the five generation types.
Once the representative sites were chosen, the hourly output values for typical solar arrays and wind farms were selected with the database of Stefan Pfenninger (at ETH, Zurich) and Iain Stafell (Renewables.ninja; see above). The model methodology used by the Renewables.ninja database is described by Pfenninger and Staffell (2016a and 2016b)[15], and is based on weather data from global reanalysis models and satellite observations (Rienecker and Suarez 2011[16]; Müller and Pfeifroth, 2015[17]). It was assumed that the utility-scale solar sites will be optimized, and as such, a tilt angle was selected within a couple of degrees of the latitude of the representative site. For rooftop solar calculations, this was left at the default 35° because it is likely that the panels matched the roof tilt.

The wind outputs for both onshore and offshore winds were calculated at an 80 m hub height because this reflects the wind datasets used in the mapping exercise. Although onshore wind and offshore wind are likely be higher than this, 80 m was considered a reasonable approximation and made our model consistent with the mapping-based predictions. A turbine model of Vestas V90 2000 was used.

<u>Limitations:</u> The solar and wind resources can differ within one cluster. Therefore, the potential generation output can vary within a cluster and across the model period (2020–2050).

[14] RE-N DB (2018) Renewables.ninja, onione database for hourly time series for solar and wind data for a specific geographical position, viewed and data down load took place between May and July 2018, https://www.renewables.ninja/

[15] Pfenninger, S, Staffell, I. (2016a), Pfenninger, Stefan and Staffell, Iain (2016). Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. Energy 114, pp. 1251-1265. doi: 10.1016/j.energy.2016.08.060

Pfenninger, S, Staffell, I. (2016b), Staffell, Iain and Pfenninger, Stefan (2016). Using bias-corrected reanalysis to simulate current and future wind power output. Energy 114, pp. 1224-1239. doi: 10.1016/j.energy.2016.08.068

[16] Rienecker, M, Suarez MJ, (2011) Rienecker MM, Suarez MJ, Gelaro R, Todling R, et al. (2011). MERRA: NASA's modern-era retrospective analysis for research and applications. Journal of Climate, 24(14): 3624-3648. doi: 10.1175/JCLI-D-11-00015.1

[17] Müller, R., Pfeifroth, U (2015), Müller, R., Pfeifroth, U., Träger-Chatterjee, C., Trentmann, J., Cremer, R. (2015). Digging the METEOSAT treasure—3 decades of solar surface radiation. Remote Sensing 7, 8067–8101. doi: 10.3390/rs70608067

2.4 POWER DEMAND PROJECTION AND LOAD CURVE CALCULATION

The [R]E 24/7 Power Analysis model calculates the development of the future power demand and the resulting possible load curves. Actual load curves, particularly for low- and middle-income countries, do not yet exist or are classified, and therefore must be calculated based on a set of assumptions. The model generates annual load curves with hourly resolution and the resulting annual power demands for three different consumer sectors:

- households;
- industry and business; and
- transport.

Although each sector has its specific consumer groups and applications, the same set of parameters is used to calculate the load curves:

- electrical applications in use;
- demand pattern (24 h);
- meteorological data
    - sunrise and sunset, associated with the use of lighting appliances;
    - temperature and rainfall, associated with climatization requirements;
- efficiency progress (base year 2015) for 2020 until 2050, in 5-year steps
    - possibility that the electricity intensity data for each set of appliances will change, e.g., change from CFL light bulbs to LEDs as the main technology for lighting.

Methodology: Load curve calculation for households

The model differentiates nine household groups with various degrees of electrification and equipment:

- Rural – phase 1: Minimal electrification stage
- Rural – phase 2: White goods are introduced and increase the overall demand
- Rural – phase 3: Fully equipped standard western household with electrical cooking, air conditioning, and vehicle(s)
- Urban single: Household with minimal equipment
- Urban shared flat: 3–5 persons share one apartment in the centre of a large city; fully equipped western household, but without vehicles
- Urban – family 1: 2 adults and 2–3 children, middle income
- Urban – family 2: 2 adults and > 3 children, and/or higher income
- Suburbia 1: Average family, middle income, full equipment for high transport demand because of extensive commuting
- Suburbia 2: High-income household, fully equipped, extremely high transport demand because of high-end vehicles and extensive commuting.

The following electrical equipment and applications can be selected from a drop-down menu:

- Lighting: 4 different light bulb types
- Cooking: 10 different cooking stoves (2+4 burners, electricity, gas, firewood)
- Entertainment: 3 different computer, TV, and radio types
- White goods: 2 different efficiencies for washing machines, dryers, fridges, freezers
- Climatization: 2 different efficiency levels each for fan, air-conditioning
- Water heating: a selection of direct electric, heat pump, and solar

For details of the household demand projections and categories developed for the Viet Nam analysis, see section 3.2.

Load curve calculation for business and industry

The industrial sector is clustered into eight groups based on widely used statistical categories:

- Agriculture
- Manufacturer
- Mining
- Iron and steel
- Cement industry
- Construction industry
- Chemical industry
- Service and trade

For each sector, 2–6 different efficiency levels are available. The data are taken from international statistical publications (IEA [2016][18], IRENA [2016][19], DLR [2012][20]).

For the Viet Nam modelling project, the business and industry load curve calculations were simplified by the limited data availability and to make our calculations comparable with those of the Viet Nam Power Development Plan 7. The demand and load curve calculations for industry and business are based on the following three economic sectors:

- Agriculture
- Industry and construction
- Service and trade

Thus, the industry-specific projections for *Manufacturing*, *Mining*, *Iron and steel*, *Cement industry*, *Construction industry*, and the *Chemical industry* are accumulated into one demand and one resulting load curve. For industry, the base load is assumed, whereas for agriculture and service & trade, core working hours from 6 am to 8 pm are assumed.

18 IEA (2016), World Energy Balances, 2016

19 Report citation IRENA (2016), REmap: Roadmap for a Renewable Energy Future, 2016 Edition. International Renewable Energy Agency (IRENA), Abu Dhabi, www.irena.org/remap

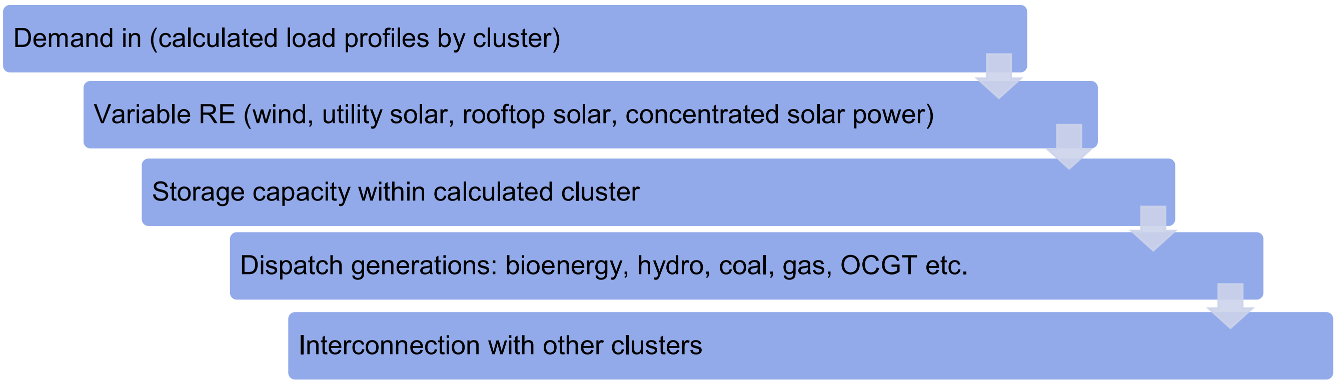
20 DLR et. al. (2012) Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global Schlussbericht BMU - FKZ 03MAP146 (DLR), (IWES), (IFNE), 29 March 2012

2.5 THE [R]E 24/7 DISPATCH MODULE

The [R]E 24/7 dispatch module simulates the physical electricity supply with an interchangeable cascade of different power generation technologies. The cascade starts with the calculated load in megawatts for a specific hour. The first generation technology in the exogenous dispatch order provides all the available generation, and the remaining load is supplied by the second technology until the required load is entirely met. In the case of oversupply, the surplus variable renewable electricity can be either moved to storage, moved to other regions, or—if neither option is possible—curtailed. Non-variable renewable sources reduce output. In the case of an undersupply, electricity is supplied either from available storage capacities, from neighbouring clusters, or from dispatch power plants. The key objective of the modelling is to calculate the load development by region, changing the residual loads (load minus generation), theoretical storage, and interconnection requirements for each cluster and for the whole survey region. The theoretical storage requirement is provided as “storage requirement to avoid curtailment”. The economic battery capacity is a function of the storage and curtailment costs, as well as the dispatch power plant availability and costs. This analysis requires detailed local technical parameters, which were not available for this analysis.

Figure 5 provides an overview of the dispatch calculation process. The dispatch order can be changed in terms of the order of renewables and the dispatch power plant, as well as in the order of the generation categories: variable, dispatch generation, and storage. The following key parameters are used as input: generation capacity by type, demand projection and load curve for each cluster, interconnection with other clusters, and meteorological data from which to calculate solar and wind power generation with hourly resolution. The installed capacities are derived from the long-term projections described in section 4.4, and the resulting annual generation in megawatt hours is calculated on the basis of meteorological data (in cases of solar and wind power) or dispatch requirements.

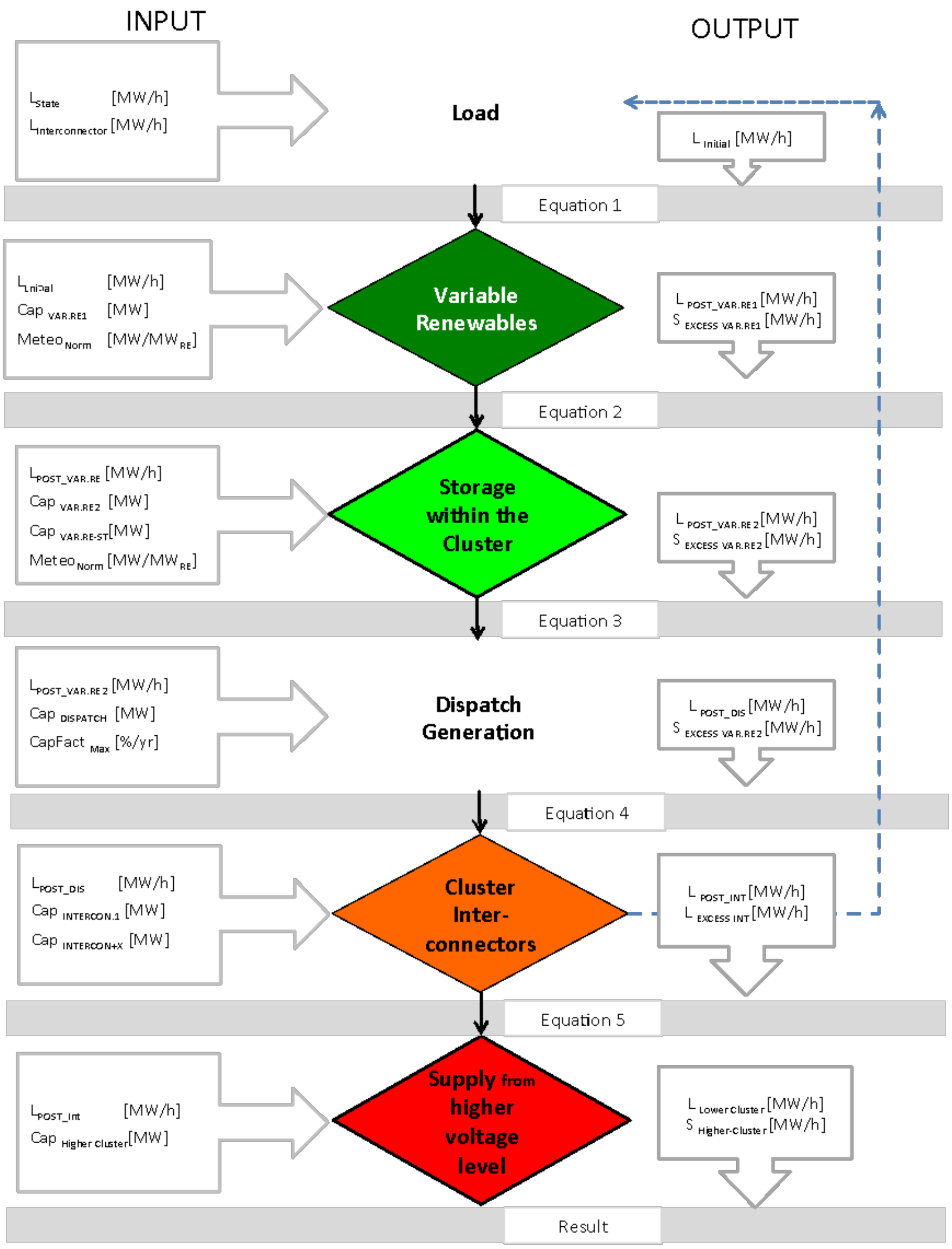
Figure 5: Dispatch order within one cluster



Overview: input and output—[R]E 24/7 energy dispatch model

Figure 6 gives an overview of the input and output parameters and dispatch order. Although the model allows changes in the dispatch order, a 100% renewable energy analysis always follows the same dispatch logic. The model identifies excess renewable production, which is defined as the potential wind or solar photovoltaic generation that exceeds the actual hourly demand in MW during a specific hour. To avoid curtailment, the surplus renewable electricity must be stored with some form of electrical storage technology or exported to a different cluster. Within the model, excess renewable production accumulates through the dispatch order. If storage is present, it will charge the storage within the limits of the input capacity. If no storage is included, this potential excess renewable production is reported as ‘potential curtailment’ (pre-storage). It is assumed that a certain number of behind-the-meter consumer batteries will be installed, independent of the system requirements.

Figure 6: Overview—input, output, and dispatch order



2.6 OSEMOSYS—POWER GENERATION COST OPTIMIZATION[21]

The development of the alternative long-term energy pathways (see sections 2.2 and 3.7) and the power sector analysis (Chapter 4and 5) are based on Viet Nam's current power development plan and existing power plants. Therefore, a cost optimization of the entire power supply for Viet Nam until 2030 (and even beyond) is not possible because more than half the required power-generation capacity is already either installed or will come into operation soon. Various power-generation projects are in different stages of development under Viet Nam's current legal framework, power purchase contracts, or other previously taken investment decisions. Furthermore, an innovative renewable electricity policy has been implemented in Viet Nam, which has already resulted in a significant uptake of sustainable renewable electricity generation. Therefore, pure cost optimization models will not reflect the actual situation of Viet Nam's electricity market. However, a cost optimization model has been used for the sensitivity analysis.

The Open Source energy MOdelling SYStem OSeMOSYS is specifically designed as a tool to inform the development of energy strategies. It does not use proprietary software or commercial programming languages and is freely available. It was developed in collaboration with a range of institutions, including the International Atomic Energy Agency, the United Nations Industrial Development Organization, KTH Royal Institute of Technology, Stanford University, University College London, University of Cape Town, Paul Scherrer Institute, Stockholm Environment Institute, and North Carolina State University. The first version of OSeMOSYS became available in 2008, and the first peer-reviewed publication describing its ethos and structure was available in 2011 [Howells et al. 2011][22].

OSeMOSYS determines a cost-optimized energy supply mix in terms of the generation capacity and energy delivery within user-defined constraints, such as the carbon price or emissions limit. The model aims to meet the energy services demand across the modelling time steps and period, while calculating the total discounted costs, emissions, fuel demand, etc. The electricity demands can be met through a range of technologies, which have specific techno-economic characteristics and draw on a specific set of resources, defined by certain potentials and costs. In mathematical terms, OSeMOSYS is a deterministic, linear optimization, long-term modelling framework. Mixed-integer linear programming can be applied to certain functions, such as the optimization of discrete expansions of power plant capacities.

In the Viet Nam project, OSeMOSYS was used to verify and compare the results of the models described in sections 4.3 and 4.4. Different methodologies do not always allow direct comparison, but certain trend developments can be confirmed and cost estimates for the coming decades further validated.

After a careful analysis of the hourly demand data for the Northern, Central, and Southern regions of Vietnam in 2008–2018, the yearly demand was divided into 20 unique time periods over which the demand was required to be met, including combinations of the following:

- summer/winter and rainy/dry seasons;
- morning, midday, afternoon, evening, and night time;
- weekends and week days.

The demand could be met by the following power generation types, with fuel import technologies defined where necessary:

- Coal
- Gas
- Fuel oil
- Nuclear
- Hydro
- Biomass
- Rooftop solar
- Utility-scale solar
- Onshore wind
- Offshore wind

For each technology, the following attributes were taken into account:

- fixed, variable, operating, and salvage costs;
- carbon dioxide, methane, NO_x, and SO_x emissions;
- efficiencies and fuel demand;
- operational life.

21 This section is based on the OSeMOSYS documentation website https://osemosys.readthedocs.io/en/latest/manual/Introduction.html

22 Howells et al., 2011. OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. Energy Policy, 39 (10), pp. 5850-5870.

3 VIET NAM: SCENARIO ASSUMPTIONS

3.1 SOCIO-ECONOMIC PARAMETERS

Projections of population and economic growth are important factors in building energy scenarios because they affect the size and composition of the energy demand, both directly and through their impact on economic growth and development.

POPULATION DEVELOPMENT

Viet Nam has a population density of 291 persons per km^2 [25]. Five Vietnamese cities have populations over 1 million: the two largest are Ho Chi Minh City with a population of 8,636,899 and Hanoi with 7,781,631 people; the remaining three cities with over 1 million people are Hai Phong, Da Nang, and Can Tho. Between 1955 and 1990, the annual population growth rate dropped to the current rate of 1%. Further reductions to 0.9% (2025) and 0.5% (2035) are expected[11] Based on these estimates, the population will reach 117.6 million in 2040 and start to decline to 115.8 million by 2050 (see Table 11).

ECONOMIC DEVELOPMENT

Viet Nam has enjoyed a remarkable economic development during the past 30 years and has transformed from one of the poorest countries in the world to a lower-middle-income country (WORLDBANK 2019A)[23]. The per capita income increased from US$388 in 2000 to US$2,342 in 2017 (WORLDBANK 2019 B)[24], compared with the global average of US$10,748[25]. Viet Nam is among the 10 fastest -growing economies in the world[26], with an annual growth rate of over 5% per since 2000[13].

This sustained economic expansion has increased the demand for infrastructure to support the continued growth of industry and services, such as telecommunications, transport, and energy. Viet Nam's economy is transitioning away from its historic reliance on the agricultural sector, with manufacturing growing strongly and steadily (Bloomberg 2018)[27]. In 2018, the economic growth rate for the full year was 7.1%, and the main pillars were manufacturing for export markets and trade[15].

Projections of population and economic growth are important factors in the development of energy scenarios because they affect the size and composition of the energy demand, both directly and through their impact on economic growth and development.

Table 11: Viet Nam: Population and GDP projections

	t	2015	2020	2025	2030	2035	2040	2045	2050
GDP	[billion $$_{2015}$/a]	193.2	258.5	369.4	527.9	716.5	927.6	1,150	1,333
GDP/Person	[$/capita]	2.065	2.616	3.557	4.836	6.245	7.886	9.780	11.509
Population	[million]	93.5	98.8	103.8	109.1	114.7	117.6	117.6	115.8
			2015–2020	**2020–2025**	**2025–2030**	**2030—2035**	**2035–2040**	**2040–2045**	**2045–2050**
Economic growth	[%/a]		6.7%	8.2%	7.2%	5.9%	4.6%	3.3%	2.0%
Population growth	[%/a]		1.0%	0.9%	0.7%	0.5%	0.4%	0.3%	0.3%

The population and GDP shown in Table 11 are based on projections of the Viet Nam Government, and were used for Power Development Plan 7 2016 (PDP7 2016)[28].

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[23] Worldbank (2019) A, last update of website 24 April 2019, https://www.worldbank.org/en/country/vietnam/overview
[24] Worldbank (2019) B, https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=VN
[25] According to the World Bank definition, countries with an per capita GDP of around US$ 2,200 are classified as "Lower middle income" countries.
[26] Viet Nam News, December 7th 2018, https://vietnamnews.vn/economy/481550/vn-among-10-fastest-growing-economies.html#4i6dRQKYeJkuQQP8.97
[27] Bloomberg (2018), 27th December 2018, Economic: Viet Nam Economy Remains Outperformer as Growth Tops 7% Mark, https://www.bloomberg.com/news/articles/2018-12-27/vietnam-s-economy-remains-outperformer-as-growth-tops-7-mark
[28] PDP 7 (2016), Viet Nam Energy Outlook Report 2017, Danish Energy Agency, https://ens.dk/sites/ens.dk/files/Globalcooperation/Official_docs/Vietnam/vietnam-energy-outlook-report-2017-eng.pdf

3.2 VIET NAM: ELECTRICITY DEMAND DEVELOPMENT PROJECTION

The electricity demand projections documented in this section were calculated for the residential and business sectors with the [R]E 24/7 model in a bottom-up process. The further electricity demand entailed by transport (especially under the two alternative scenarios, with increased electric mobility) and by the internal electricity demand of power plants ("own consumption"), and the distribution losses are calculated with the long-term model (see sections 2.2 and 4.2) and added to the calculated demand projections. However, the [R]E 24/7 power analysis only takes into account the additional electricity demand for distribution losses because the power plant consumption does not influence storage or grid requirements.

DEMAND PROJECTIONS IN THE CONTEXT OF VNEEP

The Viet Nam National Energy Efficiency Program started in 2006[29]. The last program, VNEEP III, started in March 2019 (VNEEP III 2019)[30] and has a target of 10% total energy savings, equivalent to 2,512 PJ, between 2019 and 2030. The specific objectives for VNEEP III are to:

1. achieve energy savings of 8%–10% compared with the total national energy consumption for the 2019–2030 period;
2. reduce power losses in transmission to < 6.0%;
3. increase energy efficiency in various industrial sectors, with the following energy demand reduction targets, between 2015 and 2018:
   (i) steel industry: 5.00%–16.50% (depending on the product type and production technology);
   (ii) chemical industry: minimum 10.00%;
   (iii) plastics production industry: 21.55%–24.81%;
   (iv) cement industry: minimum 10.89%;
   (v) textile industry: minimum 6.80%;
   (vi) beverage industry: 4.6%–8.44% (depending on the product type and production scale);
   (vii) paper industry: 9.90%–18.48% (depending on the product type and production scale);
4. reduce gasoline and oil consumption by in transportation by 5% compared with the sector's fuel consumption demand forecast until 2030; develop fuel standards for new and imported two-wheel motorbikes and minibuses (nine seater);
5. ensure that 90% of industrial parks and 70% of industrial clusters access and apply energy-efficiency measures;
6. implement energy labelling for 50% of all thermal insulation building material products;
7. develop and approve local energy efficiency plans for 100% of all cities and provinces under the central government.

VNEEP III targets in terms of energy demand projections under the alternative scenarios

The overall energy demand in 2030 under both alternative scenarios will be 9% below the energy demand projection for the reference case. In terms of sectorial targets, the alternative scenarios will reduce the industrial energy demand by 8.7% across all sub-sectors. For the overall transport sector, the RENEWABLES 1 (RE1) scenario will reduce the demand by 3% by 2030 compared with the REFERENCE scenario and RE2 will reduce it by 8%. Increased electrification of the transport sector will play a significant role in the reduction of the energy demand in the RE2 scenario. Compared with the REFERENCE case, the primary energy demand in 2030 in the RE1 scenario will be reduced by 1,000 PJ/a and by 1,250 PJ/a in the RE2 scenario. Both alternative scenarios will reduce the cumulative energy demand beyond the VNEEP III target of 2,512 PJ between 2015 and 2030: RE1 will avoid a cumulative energy demand of 6,477 PJ between 2020 and 2030, and RE2 will avoid a cumulative energy demand of 7,272 PJ during the same period.

[29] VNEEP-I: 2006-2015 - Energy saving target 3.4%—with a total target of 4.9 mega tons of oil equivalent (Mtoe) (205 PJ/a)
VNEEP-II: 2006-2015 - Energy saving target 5.65%—with a total target of 11.2 mega tons of oil equivalent (Mtoe) (469 PJ/a)

[30] VNEEP III(2019), DECISION, On approval of the National Energy Efficiency Programme (VNEEP) for the period of 2019 – 2030, Hanoi, March 13 2019, No.: 280/QD-TTg; http://vepg.vn/wp-content/uploads/2019/03/the-signed-version-of-VNEEP-3_ENG_Final.pdf

VIET NAM: ELECTRICITY DEMAND PROJECTIONS—HOUSEHOLDS

The analysis of the current and future development of the electricity demand for Viet Nam's households was based on the "Overview of the Viet Nam Household Living Standard Surveys 2016" published by the General Statistic Office Viet Nam (GSOV 2016)[31]. The different electrification levels of households by region were converted into the nine household types. The assumed annual demand in kilowatt-hours per year for each household type is shown Table 12. Significant increases in demand, e.g., from *"Rural Phase 2"* to *"Rural Phase 3"*, are mainly attributed to the use of electrical air-conditioning. The average assumed efficiency gain across all appliances is assumed to be 0.75% per year across the entire modelling period.

Table 12: Household types used in both RENEWABLES scenarios and their assumed annual electricity demands

Household Type	Viet Nam Survey	Average Annual Electricity Demand	
		2020	2030
Rural - Phase 1	- Very-low-income rural household - Low-income rural household	760 kWh/a	700 kWh/a
Rural - Phase 2	- Lower-middle-income rural household	2,200 kWh/a	2,050 kWh/a
Rural - Phase 3	- Upper-middle-income rural household	5,000 kWh/a	4,635 kWh/a
Urban – Single	- Very-low-income urban household	1,000 kWh/a	925 kWh/a
Urban/Shared App.	- Lower-middle-income urban household	5,500 kWh/a	5,100 kWh/a
Urban - Family 1	- Middle-income-households (urban and rural)	3,200 kWh	2,950 kWh
Urban - Family 2	- Upper-middle-income urban household	5,600 kWh/a	5,195 kWh/a
Suburbia 1	- High-income rural household	3,400 kWh	3,150 kWh
Suburbia 2	- High-income urban household	6,000 kWh/a	5,565 kWh/a

With the development of the electricity demand until 2050, the electrical applications in each of the nine household types will gradually increase from those with very basic needs, such as light and mobile phone charging, to a household standard equivalent to that of industrialized countries. To phase out unsustainable biomass for cooking, a direct leap from fuel cooking stoves to electrical cooking is assumed. The third phase of a rural household will include an electric oven, fridge, washing machine, air-conditioner, and entertainment technologies, and will aim to provide the same level of comfort as is enjoyed by households in urban areas of industrialized countries. The levels of comfort for households in city and rural areas will be adjusted to discourage residents (especially young people) from leaving their home regions and moving into big cities.

Rapidly expanding cities are problematic because the infrastructure for transport and energy supply and the requirements of residential apartment buildings cannot match the demand, often leading to social tensions. The development of the country-wide electricity shares in the various household types is presented in Table 13. Electrification will commence in the basic household types, such as rural phase 1, urban family 1, and suburbia 1, and move on to the better-equipped households. Thus, the proportions of fully equipped households will increase constantly, although those in the basic households will increase in the early years and decrease towards the end of the modelling period. By 2050, most households will have a medium to high degree of comfort equipment.

[31] (GSOV 2016) - Overview of the Viet Nam Household Living Standard Surveys 2016" published by the General Statistic Office Viet Nam, http://www.gso.gov.vn/default_en.aspx?tabid=515&idmid=5&ItemID=18977

Table 13: Household types—changes in electricity shares countrywide

Household Type	Countrywide Share [%] (rounded)			
	2020	2030	2040	2050
No access to electricity	< 2%%	<1%	0%	0%
Rural - Phase 1	10.0%	7.5%	5.0%	0.0%
Rural - Phase 2	25.0%	25.0%	25.0%	25.0%
Rural - Phase 3	15.0%	22.5%	27.5%	33.0%
Urban – Single	10.0%	7.5%	7.5%	4.0%
Urban/Shared App.	10.0%	10.0%	10.0%	10.0%
Urban - Family 1	10.0%	7.5%	5.0%	2.5%
Urban - Family 2	10.0%	10.0%	10.0%	12.5%
Suburbia 1	5.0%	7.5%	7.5%	10.0%
Suburbia 2	5.0%	2.5%	2.5%	2.5%
Total	100%	100.0%	100%	100%

Source: VIET, Viet Nam Statistical Information and UTS-ISF research

The distributions of electricity shares across the household categories will vary regionally. All shares have been rounded and calibrated to the current regional electricity demand. The authors of this report have deliberately chosen a high standard for Viet Nam's households to close the gap between households in industrialized countries and those in developing countries to achieve greater equity. The projected development of the electricity demand for Viet Nam's households could be lower if all electrical appliances are of the best technical standard available and if electrical air-conditioning is reduced by the use of energy-efficient solar architecture, which would reduce the overall cooling demand.

VIET NAM: ELECTRICITY DEMAND PROJECTIONS—INDUSTRY AND BUSINESS

This analysis of Viet Nam's economic development is based on the GDP breakdown (Table 14). It assumes that the overall structure of the economy does not change and that all sectors grow at rates equal to that of GDP over the entire modelling period. Table 16 shows the assumed breakdown of GDP by sub-category. Although the GDP shares for industry, services, and agriculture for Viet Nam are available (CIA 2019)[32], sub-categories for specific industries vary by source, such as WORLDBANK, CIA, and the *Trading Economics* data service. For this analysis, the GDP by sector (Table 6) has been taken from the *Trading Economics* data service, because it has the most detailed data (TE 2019)[33].

Table 14: Development of GDP shares by industry sector across all regions of Viet Nam (2015)

Industry	35.6%
Manufacturing	22.9%
Mining	6.3%
Utilities	0.7%
Construction	5.7%
Services	52.5%
Public Administration + Service	48.9%
Transport	3.6%
Agriculture	11.9%
Agriculture	11.9%

The GDP distribution by region is based on 2015 data and is assumed to remain the same for the entire modelling period, until 2050.

In the industry sector, an efficiency gain of 0.5% per year has been calculated between 2020 and 2030 and 0.75% per year between 2031 and 2050. In the service and agricultural sectors, an efficiency development of 0.5% per year until 2030 has been calculated, with 0.25% for the rest of the modelling period.

[32] CIA (2019): CIA-Factbook + http://statisticstimes.com/economy/countries-by-gdp-sector-composition.php

[33] TE (2019): Trading Economics open access online database, https://tradingeconomics.com/vietnam/gdp-from-agriculture

Table 15: Development of Viet Nam's shares of GDP by region

Region	[%]
North West	2.6%
North East	6.8%
Red River Delta	25.1%
Northern Central Coast	6.0%
Central Highlands	3.5%
South Central Coast	7.7%
South East	35.8%
Mekong River Delta	12.4%

3.3 TECHNOLOGY AND FUEL COST PROJECTIONS

The parameterization of the model requires that many assumptions be made about the development of the characteristic technologies, such as the specific investment required and fuel costs. Therefore, because long-term projections are highly uncertain, we must define plausible and transparent assumptions based on background information and up-to-date statistical and technical information.

BACKGROUND: FUEL PRICE PROJECTIONS

The speed of an energy system transition depends, to some extent, on overcoming economic barriers. These largely relate to the relationships between the costs of renewable technologies and those of their fossil and nuclear counterparts. For our scenarios, the projection of these costs is vital, allowing valid comparisons of energy systems to be made. However, there have been significant limitations to these projections in the past in terms of investment and fuel costs. Moreover, efficiency measures also generate costs, which are usually difficult to determine, and depend on the technical, structural, and economic boundary conditions.

During the last decade, fossil fuel prices have seen huge fluctuations. Figure 7 shows the oil prices since 1997. After extremely high oil prices in 2012, we are currently in a low-price phase. Gas prices saw similar development (IEA 2017)[34]. Consequently, fossil fuel price projections have also seen considerable variations (IEA 2017[74]; IEA 2013[35]), and have considerably influenced scenario results ever since, especially those scenarios that are based on cost optimization algorithms.

Although oil-exporting countries have provided the best oil price projections in the past, institutional price projections have become increasingly accurate, with the International Energy Agency (IEA) leading the way in 2018 (Roland Berger 2018)[36]. An evaluation of the oil price projections of the IEA since 2000 by Wachtmeister et al. (2018)[37] showed that price projections have varied significantly over time. Whereas the IEA's oil production projections seem comparatively accurate, oil price projections have shown errors of 40%–60%, even when made for only 10 years ahead. Between 2007 and 2017, the IEA price projections for 2030 varied from $70 to $140 per barrel, providing significant uncertainty regarding future costs in the scenarios. Despite this limitation, the IEA provides a comprehensive set of price projections. Therefore, we based our scenario assumptions on these projections, as described below.

Because most renewable energy technologies provide energy with no fuel costs, the projections of investment costs become more important than the fuel cost projections, which limits the impact of errors in the fuel price projections. It is only for biomass that the cost of feedstock remains a crucial economic factor for renewables. Today, these costs range from negative costs for waste wood (based on credit for the waste disposal costs avoided), through inexpensive residual materials, to comparatively expensive energy crops.

[34] IEA (2017): IEA (2017) World Energy Outlook 2017. International Energy Agency, Organization for Economic Co-operation and Development, Paris
[35] IEA 2013: IEA (2013) World Energy Outlook 2013. International Energy Agency, Organization for Economic Co-operation and Development, Paris
[36] Roland Berger (2018) 2018 oil price forecast: who predicts best? Roland Berger study of oil price forecasts. https://www.rolandberger.com/en/Publications/pub_oil_price_forecast_2015.html. Accessed 10.9.2018 2018
[37] Wachtmeister H, Henke P, Höök M (2018) Oil projections in retrospect: Revisions, accuracy and current uncertainty. Applied Energy 220:138-153. doi:https://doi.org/10.1016/j.apenergy.2018.03.013

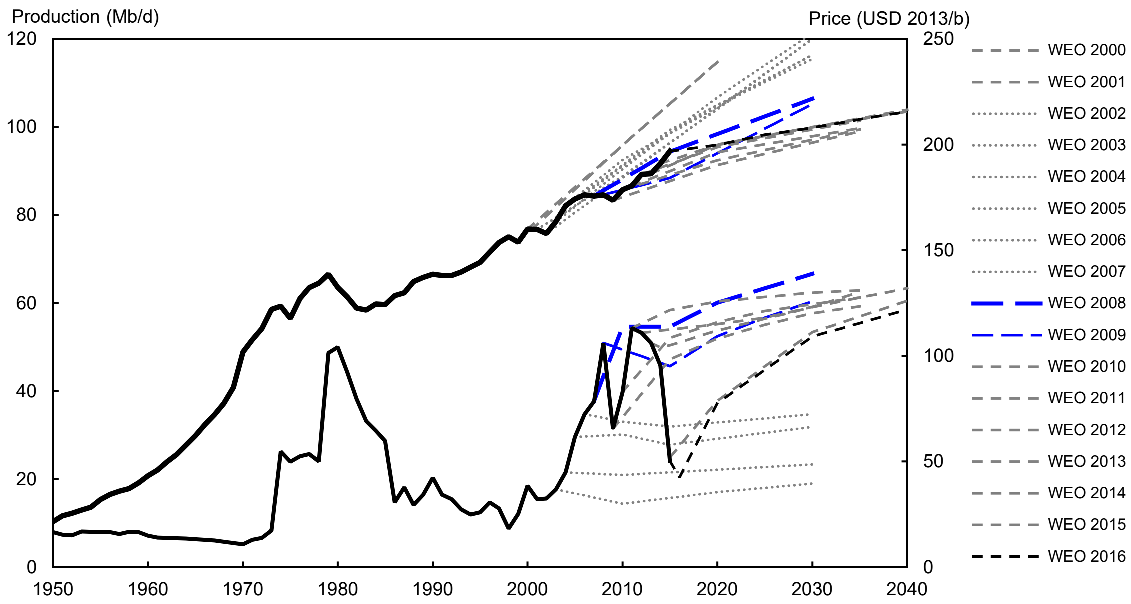


Figure 7: Historic development and projections of oil prices
by the IEA according to Wachtmeister et al. (2018)

The projection of investment cost also poses challenges for scenario development. Available short-term projections of investment costs depend largely on the data available for existing and planned projects. Learning curves are most commonly used to assess the future development of investment costs as a function of their future installations and markets (McDonald and Schrattenholzer 2001[38]; Rubin et al. 2015[39]). Therefore, the reliability of cost projections largely depends on the uncertainty of future markets and the availability of historical data.
Fossil fuel technologies provide a large cost dataset, featuring well-established markets and large annual installations. They are also mature technologies, where many potential cost reductions have already been exploited.

For renewable technologies, the picture is more mixed. For example, hydro power is (like fossil fuels) well established and provides reliable data on investment costs. Other technologies, such as solar photovoltaic and wind, are currently experiencing tremendous advances in installation and cost reduction. Photovoltaic and wind power are the focus of cost monitoring, and considerable data are already available on existing projects. However, their future markets are not easily predicted, as can be seen from the evolution of IEA market projections over recent years in the World Energy Outlook series (compare, for example, IEA 2007, IEA 2014, and IEA 2017). For photovoltaic and wind energy, small differences in cost assumptions will lead to large deviations in the overall costs, so cost assumptions must be made with especial care.

Furthermore, many technologies feature only relatively small markets, such as geothermal and modern bioenergy applications, for which costs are still high and for which future markets are insecure. The cost reduction potential is correspondingly high for these technologies. This is also true for technologies that might become important in a transformed energy system but are not yet widely available. Hydrogen production, ocean power, and synthetic fuels might deliver important technological options in the long term after 2035, but their cost reduction potential cannot be assessed with any certainty today.

Therefore, cost assumptions are a crucial factor in evaluating scenarios. Because costs are an external input into the model and are not calculated internally, we have assumed the same progressive cost developments for all scenarios. In the next section, we present a detailed overview of our assumptions for power and renewable heat technologies, including the investment and fuel costs and the potential CO_2 costs, in the various scenarios.

[38] McDonald A, Schrattenholzer L (2001) Learning rates for energy technologies. Energy Policy 29 (4):255-261. doi:https://doi.org/10.1016/S0301-4215(00)00122-1
[39] Rubin ES, Azevedo IML, Jaramillo P, Yeh S (2015) A review of learning rates for electricity supply technologies. Energy Policy 86:198-218. doi:https://doi.org/10.1016/j.enpol.2015.06.011

BACKGROUND: WEIGHTED AVERAGE COST OF CAPITAL (WACC)

Investment costs are an input parameter for cost calculations in the long-term model and in the [R]E 24/7 model and OSeMOSYS. The latter is a cost-optimizing model that calculates the low-cost generation mix for power generation at a given point in time. Thus, the input values for the investment costs for power generation (in $ per kilowatt), the assumed operation costs (in $ per megawatt hour), and the fuel costs (in $ per mega joule) determine the result for the calculated generation mix.

In this report, the client asked us to use the weighted average cost of capital (WACC) method for calculating cost. This method is mainly used to calculate a firm's cost of capital, in which each category of capital is weighted proportionately. All sources of capital, including common stock, preferred stock, bonds, and any other long-term debt, are included in a WACC calculation (Investopedia 2019)[40].
WACC is used to determine the investment decisions of companies, but is also used by government agencies to set prices for non-liberalized utilities, such as water utilities in New South Wales, Australia (IPART 2013)[41]. A WACC of 10% was used in this study to calculate investment annuities and levelized costs of electricity for all technologies (discounted over their entire technical lifetime). In addition, a similar discount rate (10%) was used to calculate the cost escalation over construction.

$$IDC = OCC \ X \ (IDC)_{fract}$$

with

$$(IDC)\ fract = \sum_{k=1}^{CT} Wk\ (1+r)^{\ CT-(k-1)} - 1$$

where

OCC:	*overnight construction cost;*
$IDC_{fract:}$	*interest during construction, additional fraction of the OCC due to interest during Construction;*
CT:	*construction time;*
W_k:	*fraction of the capital expended in year k;*
r:	*discount rate.*

Example:
The investment cost of a power plant is $1,400 per kilowatt of installed capacity, and the interest rate for the loan to finance the power plant is 10%. The construction time in this example is assumed to be 3 years—from the time the loan was issued to the first income from selling the electricity produced.
The *interest during construction* percentage ($IDC_{fract.}$) is calculated as 21.4% and the *interest during construction* (IDC) adds up to $299. The total investment costs with the IDC methodology will be $1,699 per kilowatt of installed capacity.
With a construction time of 2 years and the same interest rate of 10%, the investment costs will be $1,400/kW plus an IDC of $217, leading to a total investment cost of $1,617 per kilowatt of installed capacity. With an interest rate of only 5% and a 2-year construction time, the total investment cost with IDC will be $1,506 per kilowatt. The IDC investment costs for power plants increase as the construction time increases. Although we assume that the interest rate for all power plant technologies within Viet Nam will be the same, the construction times will differ and will be the most important factor in the resulting investment costs.

In this study, we assumed an average construction time of 3 years for a coal power plant. However, according to LAZARD 2019[42], the average construction time for coal power plants is 5–5.5 years (60–66 months), whereas gas combined cycle power plants take 2 years and gas peaking power stations 1–1.5 years. Therefore, the assumption of a 3-year construction time for coal represents the optimal construction condition, without any delays.
For the Viet Nam scenario, the suggested renewable power-generation technologies are rooftop solar photovoltaic (3 months), utility-scale photovoltaic (9 months), onshore wind (1 year), and offshore wind (1 year). Therefore, the WACC methodology is significantly more important for power-generation technologies with long construction times (coal and nuclear), whereas renewable power-generation technologies are less affected.
However, the cost of capital is a key factor for all technologies and will affect coal and all renewables equally if capital costs are equal for all technologies, which is assumed in this report.

[40] Investopedia viewed June 2019, https://www.investopedia.com/terms/w/wacc.asp
[41] IPART (2013), WACC Methodology – September 2013, Independent Pricing and Regulatory Tribunal of New South Wales 2013, ISBN 978-1-925032-32
[42] LAZARD 2019, Lazard's levelized cost of energy analysis – Version 12.0, page 18, https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

POWER AND COMBINED HEAT AND POWER (CHP) TECHNOLOGIES

The focus of cost calculations in our scenario modelling is the power sector. We compared the specific investment costs estimated in previous studies (Teske et al. 2019[43] and Teske et al. 2015[44]), which were based on a variety of studies, including investment cost projections by the IEA (IEA 2014) and current cost assumptions by IRENA and IEA (IEA 2016c). We found that the investment costs generally converged, except for the cost of solar photovoltaic, which was higher than average.

The cost projections for co-generation technologies are taken from Teske et al. (2019)[43] and the power generation technologies are taken from the Technology Catalogue for the Vietnamese Power published in May 2019, to achieve results comparable with the Viet Nam Energy Outlook 2017 of MOIT and the Danish Energy Agency (DEA)—especially its baseline scenario, representing PDP7rev[28]. The technology costs (overnight costs and escalation costs due to the interest rates during construction) are given in Table 16. A discount rate of 10% was used for the cost of capital (WACC). This discount rate was used to calculate investment annuities and levelized costs of electricity over the technical lifetime of the power plant.

Table 16: Investment cost assumptions for power generation plants (in $2015/kW) until 2050

Assumed Investment Costs for Power Generation Plants						
		2015	**2020**	**2030**	**2040**	**2050**
CHP coal	$/kW	2 500	2 500	2 500	2 500	2 500
CHP gas	$/kW	1 000	1 000	1 000	1 000	1 000
CHP lignite	$/kW	2 500	2 500	2 500	2 500	2 500
CHP oil	$/kW	1 310	1 290	1 240	1 180	1 130
Coal power plant	$/kW	1 700	1 700	1 700	1 700	1 700
Diesel generator	$/kW	900	900	900	900	900
Gas power plant	$/kW	670	500	500	500	670
Oil power plant	$/kW	800	800	800	800	800
Renewables						
CHP biomass	$/kW	2 550	2 500	2 450	2 350	2 250
CHP fuel cell	$/kW	5 000	5 000	2 500	2 500	1 120
CHP geothermal	$/kW	13 200	11 190	8 890	7 460	6 460
Biomass power plant	$/kW	2 000	2 000	2 000	2 000	2 000
Hydro power plant	$/kW	1 590	1 540	1 540	1 540	1 540
Ocean energy power plant	$/kW	6 950	6 650	4 400	3 100	2 110
Photovoltaic, rooftop	$/kW	1 008	1 008	850	780	700
Photovoltaic—utility scale	$/kW	1119	1110	840	745	650
CSP power plant (incl. storage)	$/kW	5 700	5 000	3 700	3 050	2 740
Wind turbine offshore	$/kW	2360	2323	2250	2090	1930
Wind turbine onshore	$/kW	1 700	1 600	1 310	1 210	1 110
Hydrogen production	$/kW	1 380	1 220	920	700	570

*Costs for a system with solar multiple of two and thermal storage for 8 h of turbine operation
**Values apply to both run-of-the-river and reservoir hydro power

[43] Teske (2019), Achieving the Paris Climate Agreement Goals—Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2.0°C, ISBN 978-3-030-05842-5, Springer, Switzerland 2019

[44] Teske S, Sawyer S, Schäfer O, Pregger T, Simon S, Naegler T, Schmid S, Özdemir ED, Pagenkopf J, Kleiner F, Rutovitz J, Dominish E, Downes J, Ackermann T, Brown T, Boxer S, Baitelo R, Rodrigues LA (2015) Energy [R]evolution - A sustainable world energy outlook 2015. Greenpeace International

Several renewable technologies have seen considerable cost reductions over the last decade. This is expected to continue if renewables are extensively deployed. Fuel cells are expected to outpace other CHP technologies, with a cost reduction potential of more than 75% (from currently high costs). Hydro power and biomass will remain stable in terms of costs. Tremendous cost reductions are still expected for solar energy and offshore wind, even though they have experienced significant reductions already. However, photovoltaic costs could drop to 35% of today's costs. Offshore wind has experienced significant cost reductions over the past decade, and could drop a further 30% over the next decade, whereas the cost reduction potential for onshore wind seems to have been exploited already to a large extent.
The investment costs provided in the table below are only the technology costs, and exclude the costs for operation and maintenance and the land fuel costs.

Three main scenarios have been developed and analysed in this report, a reference case, based on PDP7, and two scenarios with high proportions of renewable power generation and different levels of coal power plant capacities. In these, hydrogen is introduced as a substitute for natural gas, with a significant share of power generation after 2030. Hydrogen is assumed to be produced by electrolysis. With electrolysers just emerging at a larger scale on the markets, they have considerable cost reduction potential. Based on the Plan-DelyKaD studies (Michalski et al. 2017)[45], we assume that their costs could decrease to $570/kW in the long term.

HEATING TECHNOLOGIES

Assessing the costs in Viet Nam's industrial heating sector is even more ambitious than in the power sector. The costs of new installations differ significantly between regions and are linked to construction costs and industry processes, which are not addressed in this study. Moreover, no data are available to allow the comprehensive calculation of the costs of existing heating appliances in Viet Nam. Therefore, we concentrate on the additional costs that will result from the application of new renewable resources in the heating sector.

Our cost assumptions for heat generation are based on a previous survey of renewable heating technologies in Europe, which focused on solar collectors, geothermal, heat pumps, and biomass applications. Biomass and simple heating systems in the residential sector are already mature. However, more-sophisticated technologies, which can provide higher shares of the heat demand from renewable sources, are still under development and rather expensive. Market barriers will slow the further implementation and cost reduction of renewable heating systems, especially for heating networks. Nevertheless, significant learning rates can be expected if renewable heating is increasingly implemented, as projected in our high-renewables scenarios.

Table 17 presents the investment cost assumptions for heating technologies in OECD Europe, disaggregated by sector. Geothermal heating displays the same high costs in all sectors. In Europe, deep geothermal applications are being developed for heating purposes at investment costs ranging from $500/kW$_{thermal}$ (shallow) to $3000/kW$_{thermal}$ (deep), and the costs are strongly dependent on the drilling depth. The cost reduction potential is assumed to be around 30% by 2050 (Teske et al. 2019)[7].

Table 17: Specific investment cost assumptions (in US$2015) for heating technologies in the scenarios until 2050

Investment costs for heat-generation plants in OECD Europe							
			2015	**2020**	**2030**	**2040**	**2050**
Geothermal		$/kW	2,390	2,270	2,030	1,800	1,590
Heat pumps		$/kW	1,790	1,740	1,640	1,540	1,450
Biomass heat plants		$/kW	600	580	550	510	480
Residential biomass stoves	Industrialized countries	$/kW	840	810	760	720	680
Residential biomass stoves	Developing countries	$/kW	110	110	110	110	110
Solar collectors	Industry	$/kW	850	820	730	650	550
	In heat grids	$/kW	970	970	970	970	970
	Residential	$/kW	1,060	1,010	910	800	680

45 Michalski et al. (2017) Michalski J, et al., Hydrogen generation by electrolysis and storage in salt caverns: Potentials, economics and systems aspects with regard to the German energy transition, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.02.102,

Heat pumps typically provide hot water or space heat for heating systems with relatively low supply temperatures, or they supplement other heating technologies. Therefore, they are currently mainly used for small-scale residential applications. Costs currently cover a large bandwidth and are expected to decrease by only 20% to $1450/kW by 2050 (Teske et al. 2019)[7]. For biomass and solar collectors, we assume the appropriate differences between the sectors. There is a broad portfolio of modern technologies for heat production from biomass, ranging from small-scale single-room stoves to heating or CHP plants on a megawatt scale.
Investment costs show similar variations: simple log-wood stoves can cost from $100/kW, but more sophisticated automated heating systems that cover the whole heat demand of a building are significantly more expensive. Log-wood or pellet boilers range from $500–1300/kW. Large biomass heating systems are assumed to reach their cheapest in 2050 at around $480/kW for industry. For all sectors, we assume a cost reduction of 20% by 2050. In contrast, solar collectors for households are comparatively simple and will become cheap at $680/kW by 2050. The cost of simple solar collectors for swimming pools might have been optimized already, whereas their integration into large systems is neither technologically nor economically mature. For larger applications, especially in heat grid systems, the collectors are large and more sophisticated. Because there is not yet a mass market for such grid-connected solar systems, we assume there will be a cost reduction potential until 2050 (Teske et al. 2019)[7].

FUEL COST PROJECTIONS

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions on GreenID (2018)[46] and LAZARDS (2018)[47]. Although these price projections are highly speculative, they provide a set of prices consistent with our investment assumptions.

Table 18: Development projections for fossil fuel prices

Development projections for fossil fuel prices						
All Scenarios		**2015**	**2020**	**2030**	**2040**	**2050**
Biomass	$/GJ	0.42	0.42	0.42	0.42	0.42
Oil	$/GJ	13.1	16.5	26.80	26.8	26.8
Gas	$/GJ	12.6	13.64	14.76	14.76	14.76
Coal	$/GJ	3	3.2	3.55	3.55	3.55
Nuclear	$/GJ	2.5	2.5	2.5	2.5	2.5

46 GreenID (2018), Analysis of Future Generation Capacity Scenarios for Viet Nam, Website: www.greenidvietnam.org !OT: 0243 795 6372 I, Email: info@greenidvietnam.org.vn I Fanpage: GreenID Vietnam,

47 LAZARDS (2018); Lazard's Levelized Cost of Energy Analysis—Version 12.0, November 2018

3.4 VIET NAM: GEOGRAPHIC INFORMATION

The regional distribution of the population and the availability of energy infrastructure correlate strongly with the socio-economic situation in Viet Nam and its future economic development. The following maps provide an overview of Viet Nam's regional population, the locations of power lines and power plants, a regional breakdown of the energy pathways, and a power sector analysis (section 5.9).

Distribution of population and power grid

The regional breakdown used for the energy model is shown in Figure 8, and the distribution of Viet Nam's population is shown in Figure 9. The most densely populated regions of Viet Nam are Hanoi in the north, Ho Chi Minh City in the south, and the coastal regions along the entire coastline. Further inland, the population density is significantly lower.

Figure 8: Regional breakdown of Viet Nam for the power sector analysis

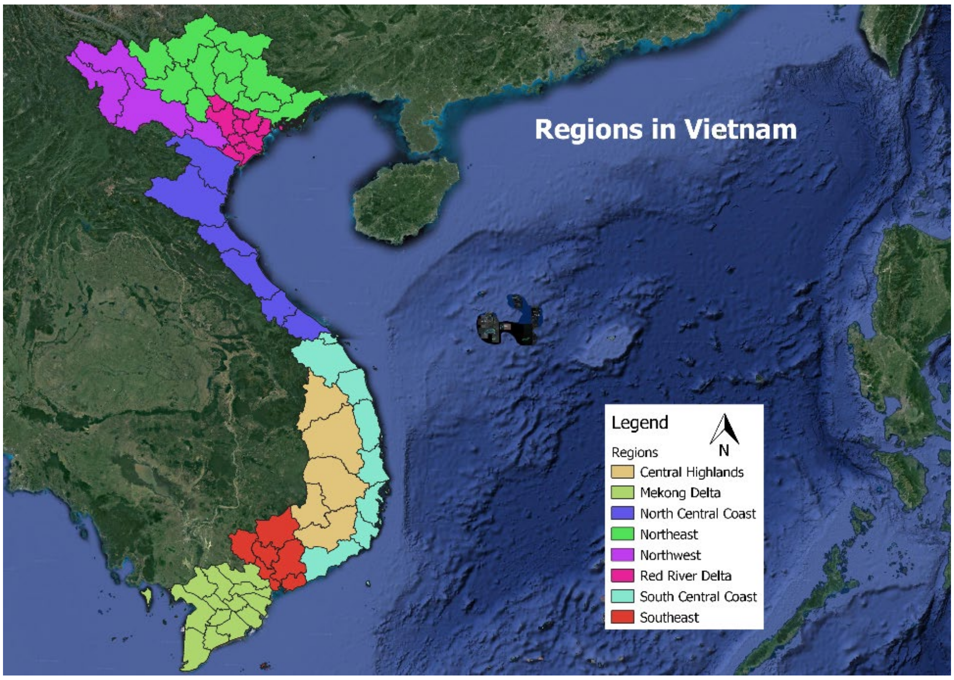
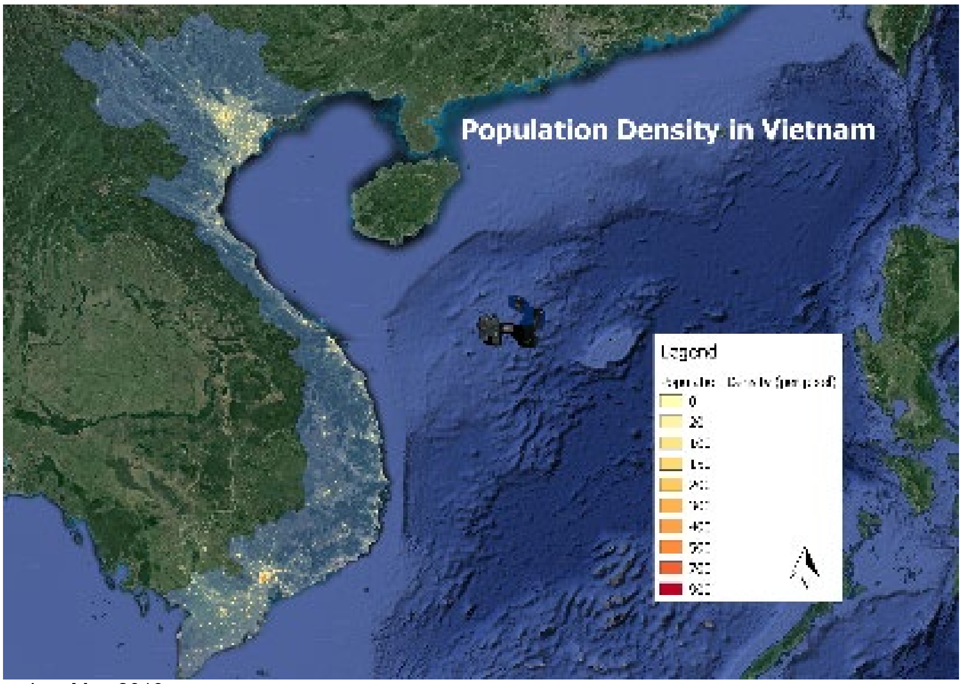


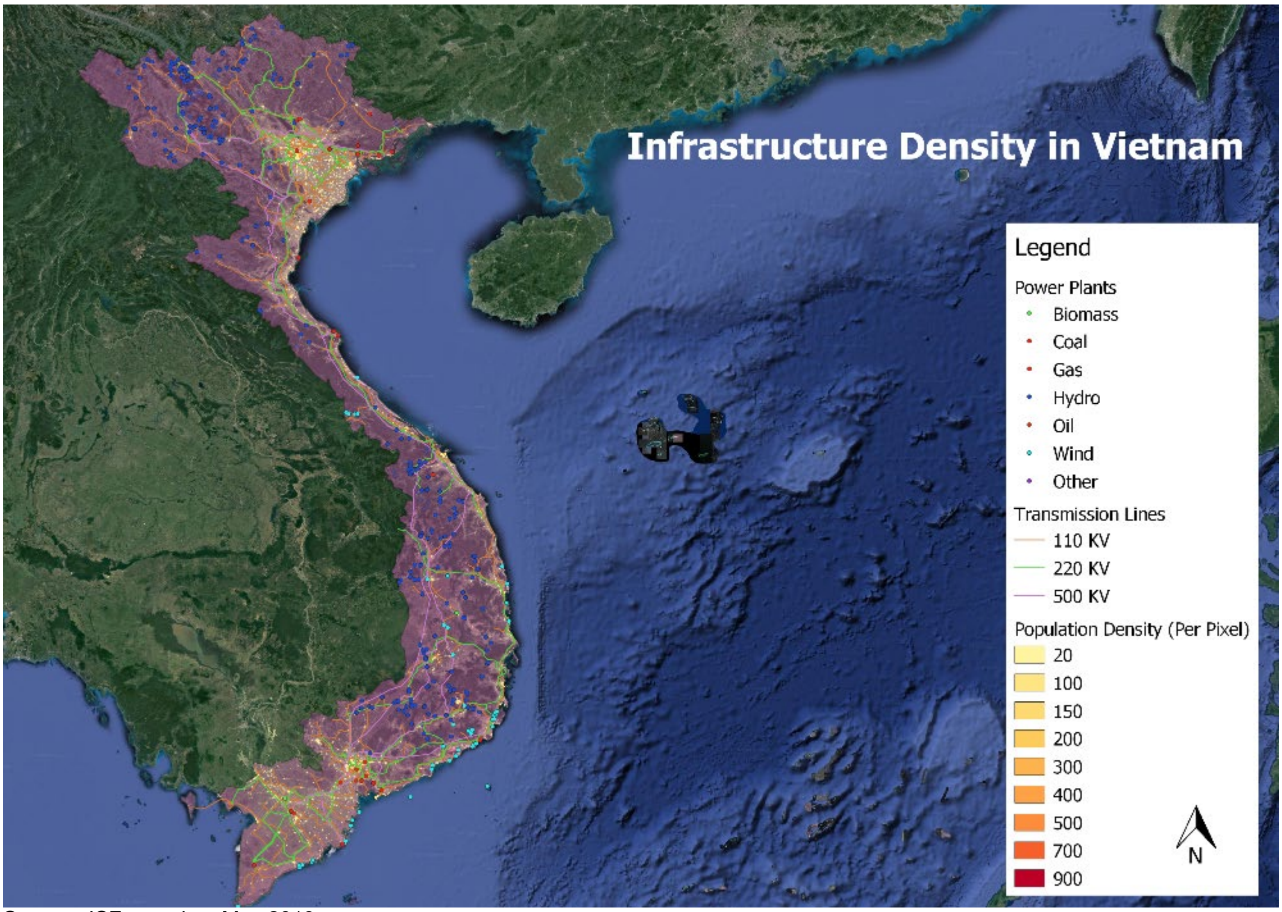
Figure 9: Distribution of population in relation to existing power grid and mini grids



Source: ISF mapping, May 2019

Figure 10 combines the population distribution and existing electricity infrastructure (power lines and power plants over 50 MW) with the different types of grids and power stations in the country. The different coloured dots mark grid-connected power plants—each colour stands for one technology, identified in the legend. The population density increases from light yellow (low population) to red (high population density). The lines represent power transmission power lines with different voltage levels. No GIS-based data on existing solar photovoltaic power plants are available.

Figure 10: Existing electricity infrastructure by type



Source: ISF mapping, May 2019

3.5 RENEWABLE ENERGY POTENTIAL

Viet Nam has a largely untapped potential for renewable energy, and the only resource used significantly is biomass. Biomass resources are predominantly exploited in traditional, non-commercial, and mainly unsustainable ways, although organic waste with greater potential is generated by the agricultural sector. Hydro power has limited potential for further increase because Viet Nam's utilization rate for hydro power plants is already high. Solar energy is abundant, with excellent potential for utility-scale photovoltaic power stations, particularly in rural areas. Initially successful policy support schemes, such as the feed-in law established in 2019, have shown very good preliminary results in the solar photovoltaic market.

Wind resources have been assessed by various organizations and there is significant potential for onshore wind power generation, and Viet Nam has one of the largest offshore wind potentials in South-East Asia.

SOLAR POTENTIAL ANALYSIS BY UTS-ISF

The average annual solar radiation levels in Viet Nam are 4–5 kWh/m^2 per day. This solar radiation is not suitable for concentrated solar power because of the cloudy conditions (concentrated solar power requires clear sky with direct sunlight). According to the International Renewable Energy Agency, Vietnam had an installed solar capacity of 237 MW, including rooftop photovoltaics, at the end of December 2018 (IRENA 2019)[48]. Utility-scale solar photovoltaic power plants grew rapidly in 2019. Whereas at the beginning of 2019, only 140 MW of solar photovoltaic facilities had be installed, this capacity had grown to 4.1 GW of utility-scale solar photovoltaic by mid-2019 (PV MAGAZINE 2019)[49].

Viet Nam's solar potential has been mapped under three different scenarios.

1. Available land—restricted by nature conservation, agricultural, commercial, or urban use (LU)

2. See above, with two additional restrictions: (1): maximum 10 km from existing transmission lines (PT); and (2) contiguous areas (CA)—fractured areas of less than 1 km^2 are excluded.

3. See above, with an additional restriction: (3) slope of less than 30% (mountain areas) and additional land-use restrictions.

Solar potential restrictions	Solar area in km^2	Solar potential in GW
LU	107,919.87	2,697
LU + PT + CA	9,688.79	242
LU + PT + CA + S30	1,908.75	48

Table 19: Utility-scale solar potential for Viet Nam under different restrictions

Figure 11 shows the land available for utility-scale solar photovoltaics under these land-use restrictions, but with no further restrictions, such as proximity to transmission lines or slope.

48 IRENA (2019) – Renewable Capacity Statistics 2019, https://www.irena.org/publications/2019/Mar/Renewable-Capacity-Statistics-2019

49 PV MAGAZINE (2019), June's FIT expiry may bring up to 4 GW of solar online in Vietnam, May 29, 2019, https://www.pv-magazine.com/2019/05/29/junes-fit-expiry-may-bring-up-to-4-gw-of-solar-online-in-vietnam/

Figure 11: Solar energy generation potential in Viet Nam

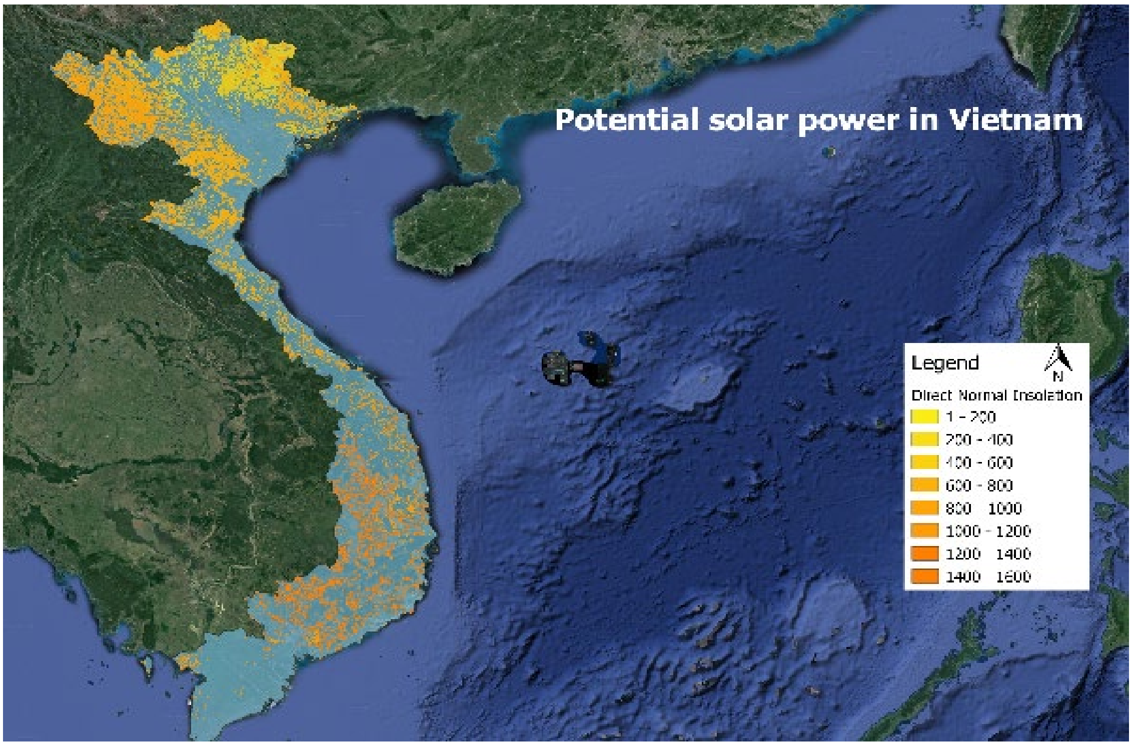
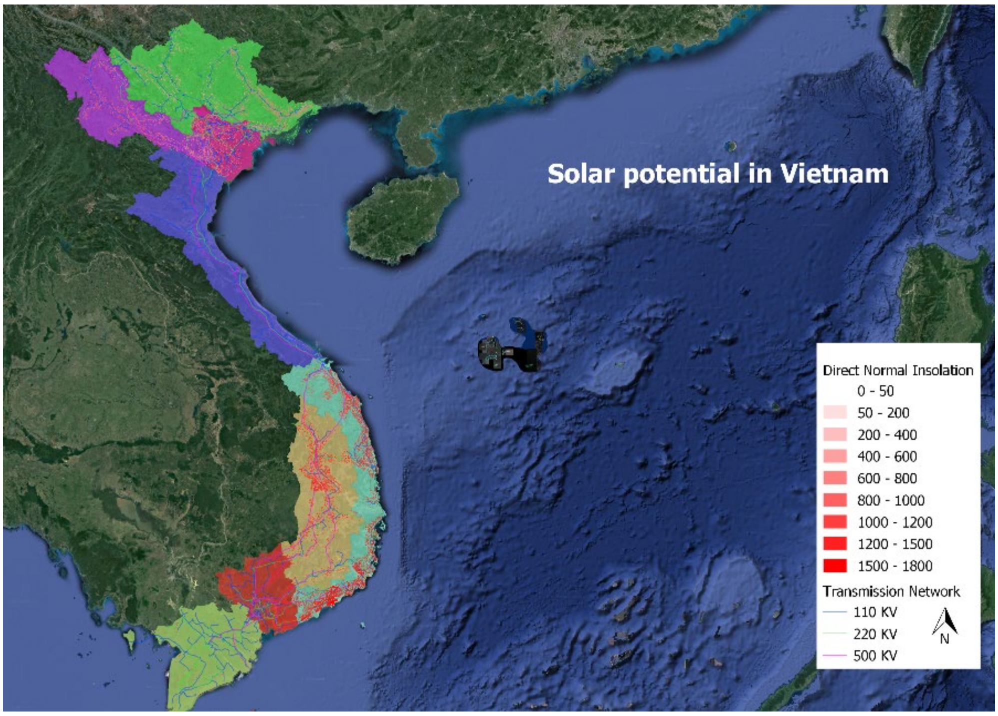


Figure 12 shows the solar potential when restricted by its proximity to power lines and terrain slope. Under this scenario, Viet Nam has over 1,900 km^2 of available land on which 48 GW of solar power can potentially be harvested by utility-scale solar farms. To avoid conflicts with national parks and other competing uses of land, only perennial cropland and open bush-land land-cover types were included in the analysis. Only utility-scale solar photovoltaic energy is included in the analysis, because the solar resource is not sufficient for concentrated solar power, which requires the highest direct normal irradiance.

Figure 12: Solar energy generation potential in Viet Nam—up to 10 km from existing power lines



Source: ISF mapping, December 2018

3.5.1 Wind Potential Analysis by UTS-ISF

Wind Energy

Currently, Vietnam's total installed wind power capacity is about 190 MW, with four wind farms onshore or near-shore with a capacity of 6–100 MW each. An additional 263 MW of wind power is under construction, and 412 MW is in the process of appraisal approval. Approximately 4,236 MW have been approved, increasing the total registered wind power capacity to 10,729 MW (IEEFA 2019)[50]. Based on available information, Viet Nam has abundant wind resources, both onshore and especially offshore. Wind resource assessments by the Ministry of Foreign Affairs of The Netherlands published in July 2018 determined the average annual offshore wind speed to be 7–11 m/s, among the highest in South-East Asia (Wind Minds 2018)[51].

Onshore Wind

Compared with other mainland South-East Asian countries, the overall wind resources on land are good in Viet Nam and the average annual wind speeds in most suitable land areas range between 6 and 7 m/s. Viet Nam's wind potential has been mapped under four different scenarios.

1. Available land——restricted by nature conservation, agricultural, commercial, or urban use (LU).
2. See above, with additional restriction: (1): maximum 10 km from transmission lines (PT).
3. See above, with additional restriction: (2) contiguous areas (CA).
4. See above, with additional restriction: (3) slope less than 30% (mountain areas) and additional land use restriction (S30).

Onshore wind potential restrictions	Onshore wind area in km^2	Onshore wind potential in GW
LU + WS	22,775.05	91
LU + WS + CA	21,535.35	86
LU + WS + PT + CA	20,309.60	81
LU + WS + PT + CA + S30	12,112.00	40

Table 20: Onshore wind potential for Viet Nam under different restrictions

Table 20 shows that the onshore wind potential for utility-scale wind farms under the assumed land-use restrictions is as high as 91 GW (see Figure 9). If mountain areas with slopes of > 30%, fractured spaces less than 1 km^2, and areas at a maximum distance of 10 km from a power line are excluded, this potential more than halves, to 40 GW.

Offshore Wind

Viet Nam has significant offshore wind potential, with average wind speeds up to 11 m/s, leading to capacity factors of more than 4,500 h per year. In this analysis, we used offshore wind as a backbone for renewable power generation in Viet Nam after 2030. Currently, the country has 100 MW of near-shore wind power plants installed in the south of Viet Nam.

This analysis took into account coastal areas with a maximum water depth of 50 m and a maximum distance to shore of 70 km. Within these restrictions, Viet Nam has a technical potential of 609 GW, spread over a total 3000 km coastline and over 150,000 km^2.

Further research is required to locate the exact offshore wind areas, both in terms of their distance to shipping lines, fisheries, and marine protection areas, access to infrastructure, such as the power grid, and access to harbour facilities for the operation and maintenance of wind farms. The offshore gas sector can benefit from the increased deployment of offshore wind power because workers and parts of the infrastructure can be re-used (e.g., ships, supply equipment). Further research is required to develop the R&D requirements for building up Viet Nam's offshore renewable energy industry.

50 IEEFA (2019), Vietnam looks to tap huge offshore wind potential – April 16, 2019, Nhan Dan: http://ieefa.org/vietnam-looks-to-tap-huge-offshore-wind-potential/

51 Wind Minds 2018; Wind Energy Potential Viet Nam, Ministry of Foreign Affairs The Netherlands, Final Report 27th July 2018; https://www.rvo.nl/sites/default/files/2019/02/Wind-Energy-Potential-Vietnam.pdf

Figure 13: Onshore wind power potential in Viet Nam—land-use restrictions only (91 GW)

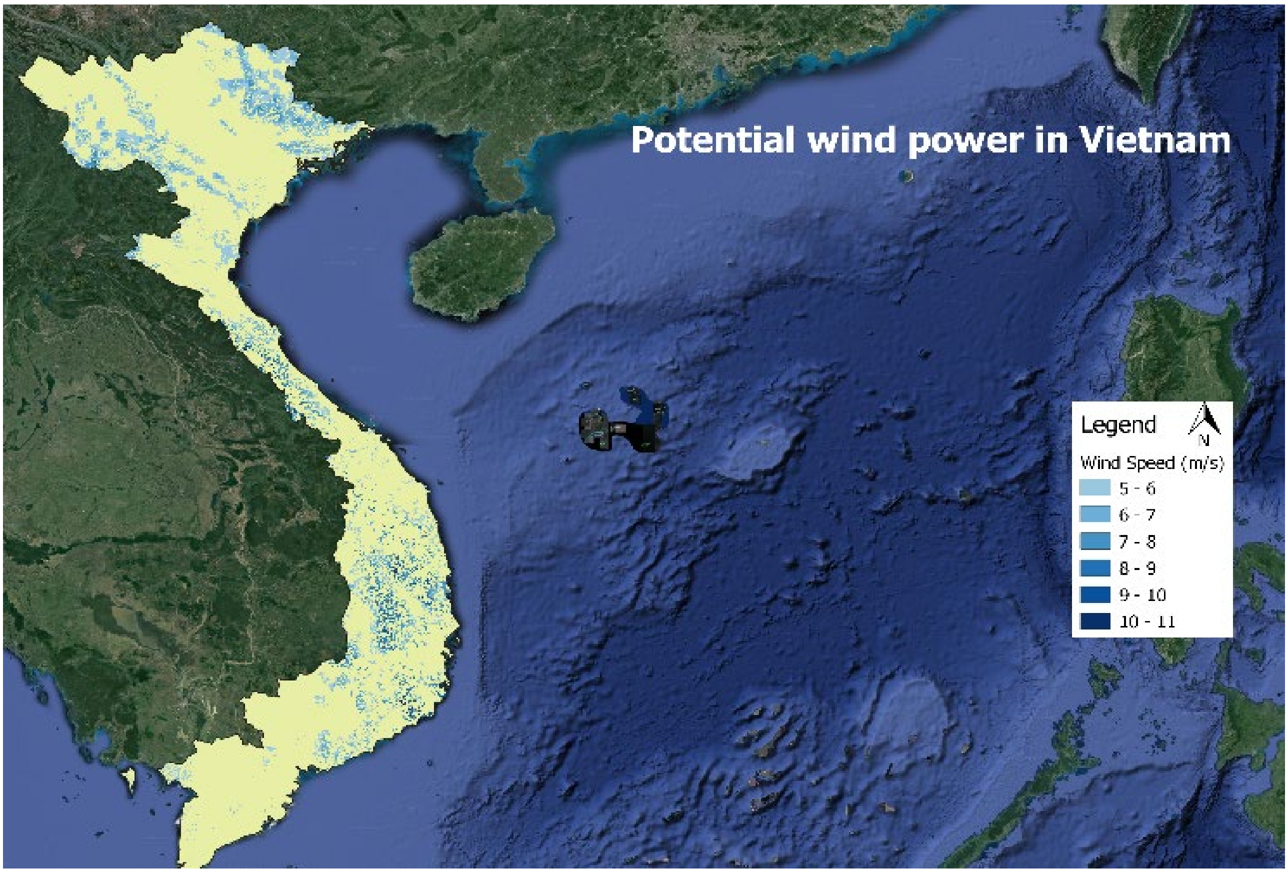
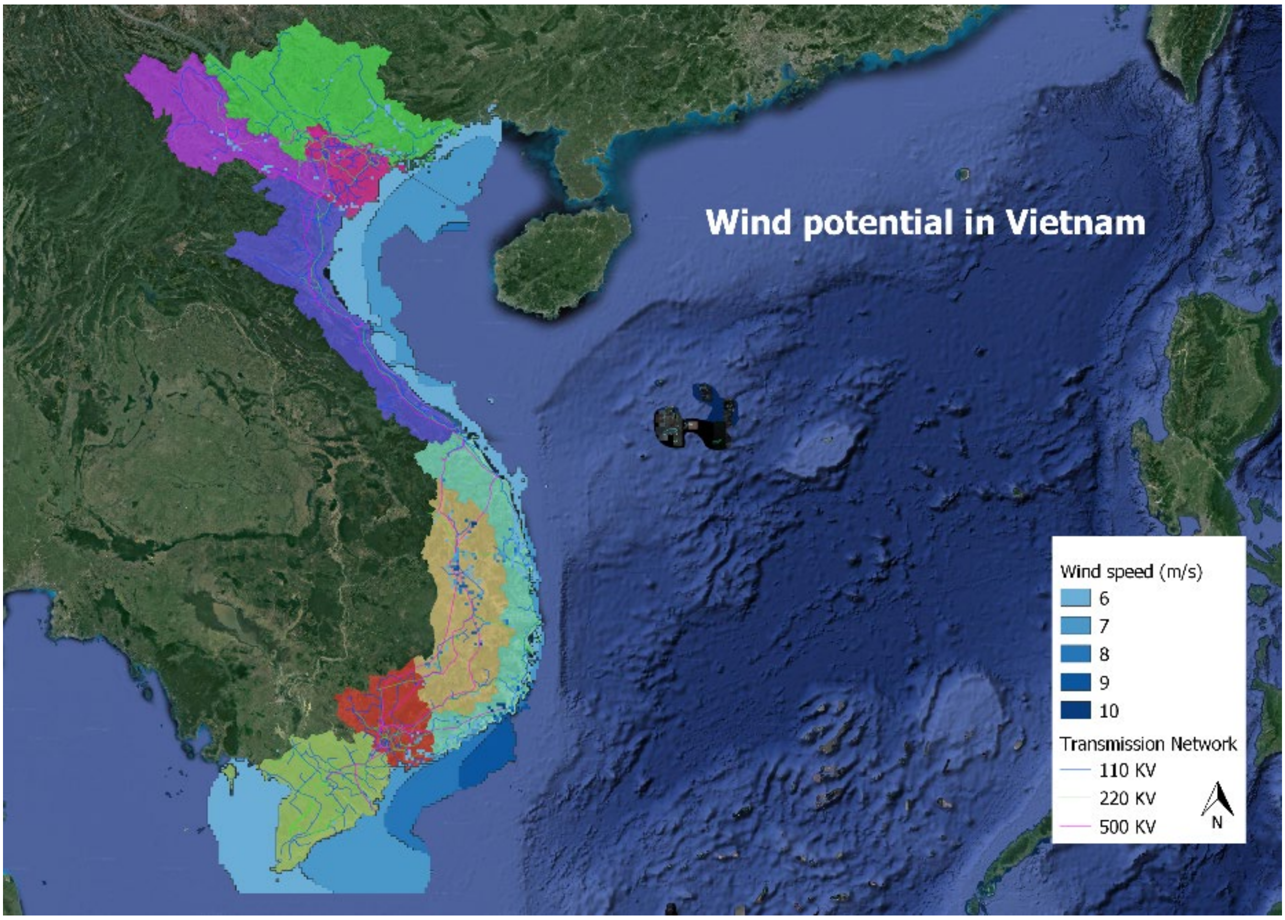


Figure 14: On- and offshore wind energy generation potential in Viet Nam



Source: ISF mapping, January 2019

3.5.2 Overview of solar and wind potential for Viet Nam by region

Table 21 shows Viet Nam's potential for utility-scale solar and wind power generation under the most restricted scenarios described in section 3.5

Table 21: Overview—Viet Nam's utility-scale solar photovoltaic, onshore wind, and offshore wind potential within 10 km of existing power lines

Cluster	Solar Area in km^2	Solar Potential in GW	Onshore Wind Area in km^2	Onshore Wind Potential in GW	Offshore Wind Area in km^2	Offshore Wind Potential in GW
Central highlands	361.8	9.05	3119.4	12.47	-	-
Mekong Delta	4.2	0.10	60.8	0.24	64,928.18	259.71
North Central Coast	4.8	0.12	86.9	0.35	28,241.36	112.97
North East	331.8	8.3	1148.6	4.59	16,132.06	64.53
North West	184.7	4.62	691.8	2.76	-	-
Red River Delta	317.8	7.95	376.4	1.50	16,664.05	66.66
South Central Coast	594.5	14.86	4210.8	16.84	19,698.60	78.79
South East	122.5	3.06	818.1	3.27	6,784.19	27.14
Total	**1922.3**	**48.06**	**10513.1**	**42.05**	**152,448.44**	**609.79**

3.5.3 Bio energy and hydro power

Mapping the bio energy and hydro power resources of Viet Nam was beyond the scope of this research. The following estimates are from the Danish Energy Agency.

Bio energy

According to the Danish Energy Agency (DEA 2017)[15], Viet Nam's technical potential for biomass is up to 10.3 GW, that for biogas is up to 5.3 GW, and that for solid waste is up to 1.5 GW.

Hydro power

DEA (2017) identified a possible increase in small run-of-river hydro power plants from the current 2.3 GW to 7.0 GW. The total installed capacity of all hydro power plants, including large-scale ones, reached 18.4 GW in 2018.

3.6 ECONOMIC AND POLICY ASSUMPTIONS

Viet Nam must build up and expand its power generation system to keep pace with its economic development and to ensure a reliable power supply. Building new power plants—regardless of the technology—will require new infrastructure (such as power grids), spatial planning, a stable policy framework, and access to finance.

With the reductions in prices for solar photovoltaic and onshore wind that have occurred in recent years, renewables have become an economic alternative to building new gas power plants. Consequently, renewables have achieved a global market share of over 60% of all newly built power plants since 2014. Viet Nam has significant solar and wind resources and a vast potential for offshore wind. The costs of renewable power generation are generally lower in situations with greater solar radiation and higher wind speeds. However, constantly shifting policy frameworks often lead to high investment risks, and therefore to higher project development and installation costs for solar and wind projects relative to those in countries with more stable policies.

The scenario-building process for all scenarios includes assumptions about policy stability, the role of future energy utilities, centralized fossil-fuel-based power generation, population and GDP, firm capacity, and future costs.

- **Policy stability:** This research assumes that Viet Nam will establish a secure and stable framework for the deployment of renewable power generation. In essence, financing a gas power plant or a wind farm is quite similar. In both cases, a power purchase agreement, which ensures a relatively stable price for a specific quantity of electricity, is required to finance the project. Daily spot market prices for electricity and/or renewable energy or carbon are insufficient for long-term investment decisions for any kind of power plant with a technical lifetime of 20 years or longer. In short, the better the investment certainty, the lower the cost of capital. If construction delays are avoided, the WACC is reduced (see section 4.3.2).
- **Strengthened energy efficiency policies:** Existing policy settings (i.e., the energy efficiency standards for electrical applications, buildings and vehicles) must be strengthened to maximize the cost-efficient use of renewable energy and achieve high energy productivity by 2030.
- **Role of future energy utilities:** With the 'grid parity' of rooftop solar photovoltaics under most current retail tariffs, this modelling assumes that energy utilities of the future will take up the challenge of increased local generation and develop new business models that focus on energy services, rather than simply on selling kilowatt-hours.
- **Population and GDP:** All three scenarios are based on the same population and GDP assumptions. The projections of population growth are taken from the *World Population Review*[61], and the GDP projections are taken from Viet Nam's Power Development Plan 7, which assumes long-term average growth of around 7% per year until 2030 (section 5.1).
- **Cost assumptions:** The same cost assumptions are used across all three scenarios. Because technology costs decline as the scale of deployment increases rather than with time, the renewable energy cost reduction potential in both RENEWABLES scenarios may be even larger than in the REFERENCE scenario because of the larger market sizes. The reverse is true for the fuel cost assumptions because all the scenarios are based on the same fossil fuel price projections, but whereas both RENEWABLES scenarios have a significant drop in demand, the REFERENCE scenario assumes an increased demand, which may lead to higher fuel costs. Therefore, these costs should be considered conservative. The cost assumptions are documented in section 5.3.

3.7 ASSUMPTIONS FOR SCENARIOS

3.7.1 COAL PATHWAYS: THREE SCENARIOS FOR COAL POWER IN VIET NAM

A global analysis of 6,685 existing coal plants[52] found that in 35% of all cases, it would be cheaper to stop operating the power plants and build new renewable-power-generating systems instead. For these companies, holding on to coal power plant assets is not economically interesting, even if they are fully amortized. This is already happening. American utilities Xcel in Colorado[53] and NIPSCO in Indiana[54] are retiring coal-fired power plants to build new capacity based on renewable energy sources with storage. The same report concludes that by 2030, renewables will exceed most of today's existing and planned coal-fired power generation in Viet Nam. The average plant age at retirement will be 13 years, which will create a stranded assets risk of US$11.7 billion. Based on investors' reactions to Genco 3's initial public offering, it is clear that the markets do not see a very profitable future for Vietnamese power-generation companies holding many coal assets.

Narratives for three coal scenarios
We developed three narratives for coal scenarios: "OLD PLAN", "NEW NORMAL", and "FACTOR THREE". The first corresponds to the PDP7rev plan. The second represents a possible development under current market forces in terms of the economics of renewable power generation. The third pathway describes what could happen if the government of Viet Nam continues to steer the electricity system into the energy transition, decisively and without imposing high costs upon stakeholders.

4. **OLD PLAN:** Coal power generation units will come online according to the "Expected" date listed in reference 61[55]. The plan to procure a fleet of build–operate–transfer (BOT) projects will proceed with small delays, and foreign investors will be satisfied with the 12% internal rate of return allowed in their power purchase agreements[56]. The government will interpret the "No new coal" policy to mean that projects lacking an investor as of 2019 will not be pursued, and no new projects will be registered beyond those existing in PDP7A. Units will be decommissioned after 40 years.

5. **NEW NORMAL:** Investors will recognize that the economic window for building new coal generation projects in Viet Nam is closed. Only already-permitted coal power generation units with scheduled completion in or before 2025 will be retained. The government will terminate all other projects on the basis of Circular 43[57], bringing relief to investors who were struggling to obtain financing and the administrative and social licenses to operate. It will be recognized that after 2035, operating coal power plants will be cost ineffective, so EVN will decommission the plants as soon as the BOT investors transfer them back to the state. Subcritical units will cease operation after 20 years, and the others after 24 years. Exit from coal will be complete by 2050.

6. **FACTOR THREE:** The pilot renewable energy auctions for solar and wind power in 2020 have shown that procuring electricity from domestic renewable sources will be more competitive than the price given to foreign companies to build and operate plants running on imported coal—the BOT program is not cost efficient. In the same year, power shortages will emphasize that this program has not been effective or provided energy security. Investors who are not yet committed will jump ship, recognizing that coal assets will soon lose profitability. No new coal plant will begin construction after 2019, and none will be commissioned after the end of 2022. The 13th National Congress in January 2021 will adopts the Asian concept of ecological civilization as a key goal for Vietnamese society, and will direct the country to accelerate its energy transition. MONRE will impose stricter pollution control norms and MOF will raise fossil fuel taxes and import duties. The National Assembly will vote a 2021 Renewable Energy Law that enacts Renewable Portfolio Standards for BOT plants. In application, the Prime Minister will order MOIT to submit a coal exit plan to be integrated in revision. Coal power plants cannot operate profitably after 2035, and will be decommissioned after 20 years. The coal exit will be complete before 2045.

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[52] Gray, M., Ljungwaldh, S., Watson, L. & Kok, I. Powering down coal. Navigating the economic and financial risks in the last years of coal power. (Carbon Tracker Initiative, 2018).
[53] Pyper, J. Xcel to Replace 2 Colorado Coal Units With Renewables and Storage. gtm: GreenTechMedia (2018). Available at: https://www.greentechmedia.com/articles/read/xcel-retire-coal-renewable-energy-storage. (Accessed: 5th June 2019)
[54] Walton, R. NiSource subsidiary announces plan to end coal use within 10 years. Utility Dive (2018). Available at: https://www.utilitydive.com/news/nisource-subsidiary-announces-plan-to-end-coal-use-within-10-years/532876/.(Accessed: 5th June 2019)
[55] Hoang Quoc Vuong. Progress of implementing some key power source projects in PDP VII revised - Tình hình thực hiện các dự án điện trong Quy hoạch điện VII điều chỉnh. (MOIT, EREA, 2019).
[56] Cao Quoc Hung. Circular 56/2014/TT-BCT on method of determination of electricity generation costs, sequence of inspection of power purchase agreement (PPA). 50 (Ministry of Industry and Trade, 2014).
[57] Trần Tuấn Anh. Circular 43/2016/TT-BCT on Commitments for Project Development and Mechanism of Handling Electrical Factory Projects Not Performing a Practice Progress. 11 (Ministry of Industry and Trade, 2016).

Trajectories

Figure 15 shows the trajectories corresponding to the three coal pathways, based on an analysis of coal power generation units in Viet Nam reported by EVN up to March 2019. The OLD PLAN scenario represents the PDP7A coal generation capacity objectives formulated in 2016. The capacity gap in 2020 compared with the OLD PLAN will be partly filled by surpassing the solar photovoltaic capacity objectives, but transmission issues will remain. In terms of the area under the curves in the 2020–2050 interval—which are roughly proportional to the greenhouse gases emissions—the NEW NORMAL scenario is 45% of the OLD PLAN scenario, and FACTOR THREE is 27% of the OLD PLAN scenario.

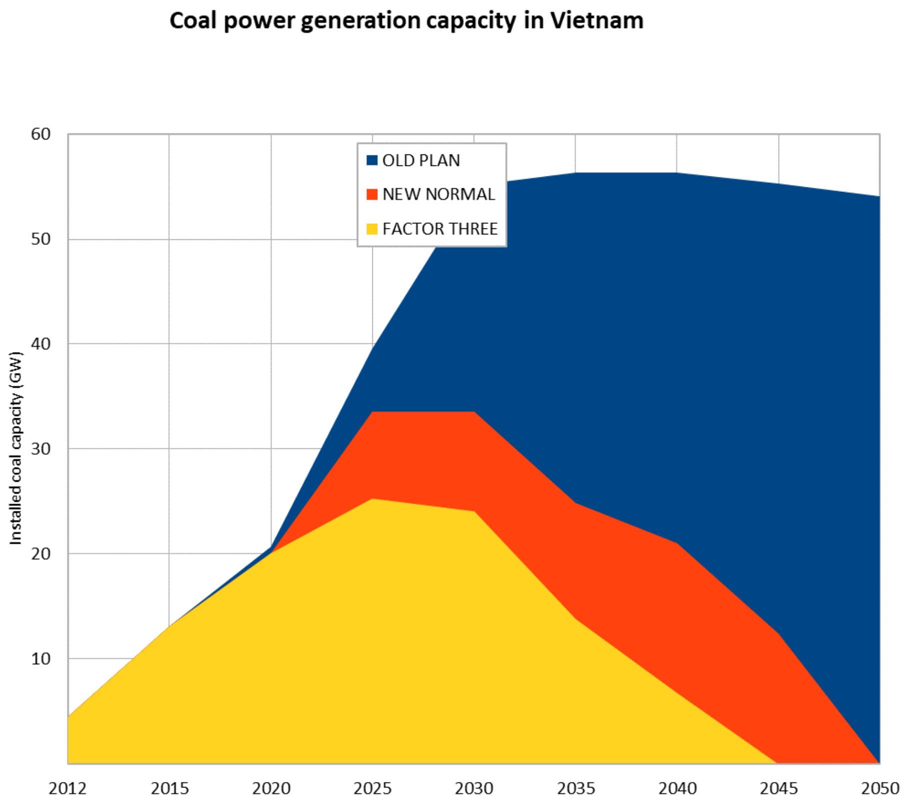


Figure 15: Coal power trajectories under three different scenarios

COMPARISON WITH OTHER SCENARIOS

We found[58] that almost all studies anticipated that a huge part of the demand will be covered by (carbon-intensive) coal. The capacity mix by 2030 for 19 scenarios have been reviewed, which were derived from five studies.

- Coal is still dominant in term of installed capacity in the previous PDP7 (2011) and currently planned PDP 7rev (2016). By 2030, we observed that the group of scenarios with the highest installed capacity of coal includes PDP7 (2011) with 75.7 GW and PDP7rev (2016) with 55 GW. The "OLD PLAN" scenario is very close to the latter, by definition.

- The group of scenarios that target renewables shows the lowest range of installed coal capacities with 18.7 GW (WWF 2016, ASES) and 19.8 GW (WWF 2016, SES), and also includes the GreenID (2017) EE and the RE scenarios. The installed coal capacity under the "FACTOR THREE" scenario is close to the latter, and largely updates them based on the same fundamental idea that only coal plants already under construction will go forward.

- The "NEW NORMAL" scenario reaches 33 GW of coal generation capacity in 2030. This is close to the Vietnam Energy Outlook 2017[59] scenario "CO_2 price high". Although it is easy to see where our scenario fits into the variety of trajectories from Outlook 2017, it was designed independently, based on the drivers of free market forces. The coincidence of our "NEW NORMAL" scenario with the Outlook 2017 scenario driven by an increase in the CO_2 shadow price to US$40/ton in 2030 and then US$45/ton in 2035–2050 can be interpreted as follows. Vietnam is a small open economy. Its infrastructure building is influenced by international market conditions. In the international market, there are forces acting against coal power generation. The effective magnitude of these forces is congruent with the magnitude of the shadow price.

[58] Tran, H. A., Nguen Trinh Hoang Anh & Ha-Duong, M. A critical review of energy scenarios in Vietnam: Low-carbon options and policy implications. (2019).
[59] MOIT. Vietnam Energy Outlook Report 2017. 78 (2017).

3.7.2 Renewable pathways

While the three coal pathways are input, the possible future development of the remaining power generation required —gas power generation and renewable electricity—is modelled in the various scenarios based on the current situation of Viet Nam's power sector.

The long-term energy scenarios, developed with the methodology documented in section 4.3, compare the REFERENCE case with the two RENEWABLES scenarios.

- RENEWABLES 1 (RE1) combines the coal pathway "NEW NORMAL" with a high level of renewables and energy efficiency.
- RENEWABLES 2 (RE2) has a more ambitious coal-phase-out horizon, FACTOR THREE, and therefore increases renewable power generation faster than RE1, while assuming the same energy efficiency projections as RE1. A higher electrification rate than in RE1, especially for the transport sector, is also assumed.

In the following section, we provide a detailed overview of all the assumptions of the REFERENCE case and the two RENEWABLES scenarios.

3.7.3 Assumptions for the Reference Scenario

The REFERENCE scenario (REF) reflects a continuation of current policies and is based on Viet Nam's Power Development Plan 2017rev (section 3.1). The energy statistics are taken from the International Energy Agency's World Energy Balances of OECD Countries 2018[60] and other documented sources.

In this analysis, the REFERENCE scenario is the baseline scenario of Viet Nam Energy Outlook 2019. The 2020 values have been updated to the current situation (early 2019).

The following box documents the *Key Findings* of the *Viet Nam Energy Outlook Report 2017*, a joint project of the Viet Nam Government and the Danish Energy Agency. The baseline scenario documented in this report was selected as the REF scenario for this analysis, against which to compare the different scenarios (PDP 2017)[16].

[60] International Energy Agency, 2019, *World Energy Balances of OECD Countries 2018.* Available at: https://www.iea.org/statistics/relateddatabases/energybalancesofoecdcountries/

Box: Power Development Plan 7: Base case

Surging energy demand

According to the draft report of the National Energy Development Plan for the period 2016–2025 with vision to 2035, which is currently in preparation by the Institute of Energy under the Ministry of Industry and Trade, the forecast for the energy demand in the business-as-usual (BAU) scenario indicates that by 2035, the total final energy demand will be nearly 2.5 times higher than in 2015. In 2035, the energy consumption in the transportation sector (covering 27.5%) is projected to achieve the highest growth rate (5.7%/year), whereas the industrial sector (covering 45.3%) will have a growth rate of 5.0%/year in the period 2016–2030.

Shares of coal and renewables in the primary energy supply

In 2000, renewable energy (RE), including biomass and hydro, together contributed 53% of the total primary energy supply. However, this share dropped to 24% in 2015. In the same period, the coal share grew from 15% to 35% of the total supply. This trend is expected to continue far into the future because the domestic supply of hydro and biomass seems to be unable to meet the increasing demand. Power plants play a key role in domestic coal consumption, followed by the cement, fertilizer, and chemical sectors. The total domestic coal consumption in 2015 was about 43.8 million tons, of which the power plants consumed 23.5 million tons and the final coal consumption was 20.3 million tons (the industrial sector accounted for 87% of the final coal consumption).

Environmental protection challenges that significantly affect the environment

The challenges of the environmental impact entailed by energy supply will increase very significantly in response to the combination of the fast growth in the domestic energy demand and the fast-growing share of fossil fuels, particularly coal, in the energy supply mix.

Security of energy supply

Viet Nam has moved from a position of an energy exporter to a net importer. This change will affect the security of the energy supply. It is expected that the imported share of the total primary energy supply will increase to 37.5% in 2025 and to 58.5% in 2035. The consequent impacts on the security of supply could be significant, and Viet Nam will have to rely on imported fuel, particularly coal. However, this dependence can be reduced by increased energy efficiency and by exploiting domestic RE sources.

The electricity sector

In the period 2011–2015, the national electricity consumption grew at an average rate of 10.6%/year, which was lower than the average growth in the period 2006–2010, of 13.4%/year. Electricity is taking an increasing share of the final energy consumption mix, and the electricity demand is expected to grow by 8% annually, on average, until 2035. This corresponds to a need for 93 GW of additional power generation capacity during this period. Almost half the new capacity is expected to be coal fueled, whereas almost 25% will be RE.

Renewable energy strategy and capacity of renewable energy development

The revised National Power Development Plan in the period 2011–2020 with vision to 2030 (revised PDP7) and the Renewable Energy Development Strategy together set relatively concrete directions for the development of the power sector in the coming years. Studies have also shown that even considerably more ambitious targets for reducing CO_2 emissions and the dependence on energy import could be achieved by imposing a price on CO_2 emissions. Such measures would create an incentive for investment in additional natural gas and RE power capacity, through which the RE strategy goals could be achieved with low additional costs compared with the BAU scenario, and within the capability of the economy. Very significant levels of RE can be efficiently integrated into the Vietnamese electricity system to satisfy the national RE policies.

Energy efficiency as a “first fuel”

Viet Nam is currently an energy-intensive economy in this region and in the world. Several studies of the industrial sector and building sector have shown considerable financially viable potential for reducing this energy intensity by upgrading technologies and adopting measures for the more efficient management of resources. Untapped energy efficiency potentials will be about 8.1% by 2030. The cost of reducing greenhouse gas (GHG) emissions by energy savings will be considerably less than the benefits of these energy savings. Therefore, the energy efficiency options and fuel substitution opportunities offer economic gains while reducing GHG emissions and improving the national energy security. A 17% potential for electricity saving by 2030 has been identified. The energy efficiency policy framework of Viet Nam must be strengthened.

Activating the large potential for biomass energy

Biomass is a largely overlooked source of energy. In addition to nearly 4,000 MW of electricity generation capacity, biomass could substitute for coal and oil to a large extent in the industrial sector.

Overall evaluation

The nationally determined contributions of Viet Nam following the United Nations Framework Convention on Climate Change (UNFCCC), with a conditional 25% reduction target in GHGs could be achieved by strengthening energy efficiency and exploiting RE sources, with international support. These measures could help reduce the environmental impact of energy supply activities and our dependence on imported energy.

ASSUMPTIONS FOR BOTH RENEWABLES SCENARIOS

Both the RE1 and RE2 scenarios are built on a framework of targets and assumptions that strongly influence the development of the individual technological and structural pathways for each sector. The main assumptions made in this scenario-building process are detailed below.

- **Emissions reductions:** The main measures undertaken to reduce CO_2 emission in the RE1 and RE2 scenarios include strong improvements in energy efficiency, resulting in an increase in energy productivity of 30% between 2020 and 2030, and the dynamic expansion of renewable energy across all sectors.
- **Renewables industry growth:** The dynamic growth of new capacities for renewable heat and power generation is assumed, based on current knowledge of potentials, costs, and recent trends in renewable energy deployment (see energy potentials, discussed in section 5.4). Communities will play a significant role in the expansion of renewables, particularly in terms of project development, the inclusion of local populations, and the operation of regional and/or community-owned renewable power projects.
- **Future power supply:** The capacity of large hydro power and bio-energy facilities will grow slowly and within economic and ecological limits. The supply from all bio-energy facilities supported by sustainable biofuels is a key issue and may come from either within Viet Nam or from certified imports. Wind power (on- and offshore) and solar photovoltaic power are expected to be the main pillars of the future power supply, complemented by contributions from bio-energy and gas power plants. The solar photovoltaic figures combine both rooftop and utility-scale photovoltaic plants. The potential for offshore wind is significantly higher than that for onshore wind, so the majority of wind power under both RENEWABLES scenarios will be offshore wind. The solar resources for concentrated solar power are insufficient and are therefore not included in the analysis.
- **Firm capacity:** The scale of each technology deployed and the combination of technologies in each of the scenarios are designed to target a firm capacity. Firm capacity is the "proportion of the maximum possible power that can reliably contribute towards meeting the peak power demand when needed."[61] Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewables also have a firm capacity rating, and the combination of technology options increases the firm capacity of a portfolio of options. Storage will add to the firm capacity as the share of variable power generation increases.
- **Security of energy supply:** The scenarios limit the share of variable power generation and maintain a sufficient share of controllable, secured capacity. This includes storage technologies. Power generation from biomass or hydro power, and a share of gas-fired back-up capacity and storage, are considered important for the security of supply in a future energy system, and are related to the output of firm capacity discussed above.
- **Sustainable biomass levels:** The sustainable level of biomass used in Viet Nam is assumed to be limited to 2000 PJ. Low-tech biomass use, such as inefficient household wood-burners, is largely replaced in the RENEWABLES scenarios by state-of-the-art technologies, predominantly highly efficient co-generation plants.
- **Electrification of transport**: Efficiency savings in the transport sector will result from fleet penetration by new highly efficient vehicles, such as electric vehicles, but also from assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The RE scenarios assume a limited use of biofuels for transportation, given the limited supply of sustainable biofuels.
- **Hydrogen and synthetic fuels:** Hydrogen and synthetic fuels, generated by electrolysis using renewable electricity, can be introduced as a third renewable fuel in the transportation sector, complementing biofuels, the direct use of renewable electricity, and battery storage. Hydrogen generation can have high energy losses. However, the limited potential of biofuels and probably also of battery storage for electric mobility means it will be necessary to have a third renewable option in the transport sector. Alternatively, renewable hydrogen could be converted into synthetic methane and liquid fuels, depending on the economic benefits (storage costs versus additional losses) and the technological and market developments in the transport sector (combustion engines versus fuel cells). Hydrogen and synthetic fuels will be imported. In the industry sector, hydrogen can be an additional renewable fuel option for high-temperature applications, supplementing biomass in industrial processes whenever the direct use of renewable electricity is not possible. In this analysis, we did not

61 http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf

include hydrogen or synthetic fuels, but the authors recommend their use as a replacement for natural gas after 2035 when a 100% renewable energy scenario is desired.

ASSUMPTIONS FOR RENEWABLES 1

The RENEWABLES 1 scenario (RE1) is designed to meet Viet Nam's energy-related targets and to lead towards a pathway of 100% renewable electricity in the second half of this century.
In 2030, the electricity demand will increase significantly, to a final electricity consumption of around 475 TWh, more than twice that in 2020. Renewable electricity generation will increase at the same pace and achieve a share of 40% by 2030.
The expansion of renewables was calculated under the constraint of an increasing coal power plant capacity for another decade, in the "NEW NORMAL" pathway.

ASSUMPTIONS FOR RENEWABLES 2

The RENEWABLES 2 (RE2) scenario takes a more ambitious approach to transforming Viet Nam's entire energy system to a 100% renewable energy supply—including the heating and transport sectors—in the second half of this century. The consumption pathways remain almost the same as in the RE1 scenario, but under the RE2 scenario, a much faster introduction of electrification will replace fuel for thermal processes, for industrial process heating, and for transportation. The latter will entail a strong role for storage technologies, such as batteries, synthetic fuels, and hydrogen. The expansion of renewables is calculated under the constraint that the coal power plant capacity will remain constant for another decade, in the "FACTOR THREE" pathway.

The resulting final energy demand for transportation is lower in RE2 than that in the RE1 scenario based on the assumptions that:

- future vehicles, and particularly electric vehicles, will be more efficient; and
- there will be greater improvement in the public transport system.

The increasing shares of variable renewable power generation, principally by wind farms and photovoltaics, will require the implementation of smart grids, storage, and other load-balancing capacities. Other infrastructure requirements will include an increasing role for on-site renewable process heat generation for industries and mining, and the generation and distribution of synthetic fuels.

The following results are from both the long-term scenario model (LT) and the [R]E 24/7 model described in the methodology chapter, Chapter 2. The models are not directly connected, and the results for power generation can vary by ± 5% because the modelling methodologies differ. The [R]E 24/7 model calculates hourly generation profiles with a chosen dispatch order, which influences the capacity factors, whereas the long-term model calculates annual accounting totals with assumed capacity factors. As a result, it may calculate higher capacity factors for dispatch power plants than [R]E 24/7.

4 KEY RESULTS FOR VIET NAM: LONG-TERM ENERGY SCENARIO

In this section, we outline the key results across a range of areas, both in terms of the impacts and the costs of the different scenarios. First, we consider stationary energy, focusing on electricity generation, capacity, and breakdown by technology. We then examine the energy supply for heating, focusing on industrial heat supply. This is followed by a consideration of the impacts and costs of the different scenarios on transport and the development of CO_2 emissions. The chapter ends with an examination of the final costs, and an outline of the required energy budget.

This chapter provides an overview to three energy pathways for Viet Nam until 2050, focusing on the 2030 results. The scenarios describe a holistic approach to the entire energy sector—power, heat, process heat, and transport. Increased electrical mobility and the electrification of heating processes will lead to "*sector coupling*" or the interconnection of historically rather separate energy sectors. As a result, the electricity demand will increase, even under ambitious electricity efficiency assumptions. Therefore, the following chapter, Chapter 5—power sector analysis—focuses entirely on the electricity sector.

4.1 VIET NAM'S FINAL ENERGY DEMAND

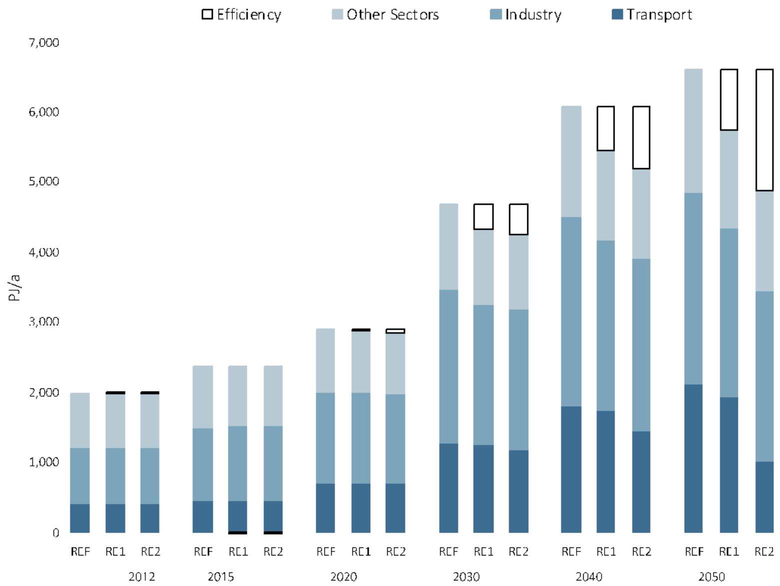
We combined the projections for population development, GDP growth, and energy intensity to generate the future development pathways for Viet Nam's final energy demand. This includes the electricity demand development, which was calculated with a bottom-up analysis. The final energy demands are shown in Figure 16 for the REFERENCE and RENEWABLES scenarios. Under the REFERENCE scenario, the total final energy demand will increase by 198%, from 2,352 PJ/a in the base year to 4,670 PJ/a in 2030. In the RE1 scenario, the final energy demand will increase at a much lower rate (by 184%) compared with current consumption, and is expected to reach 4,320 PJ/a by 2050. The RE2 scenario will result in some additional reductions that result from a higher proportion of electric cars (see section 4.4).

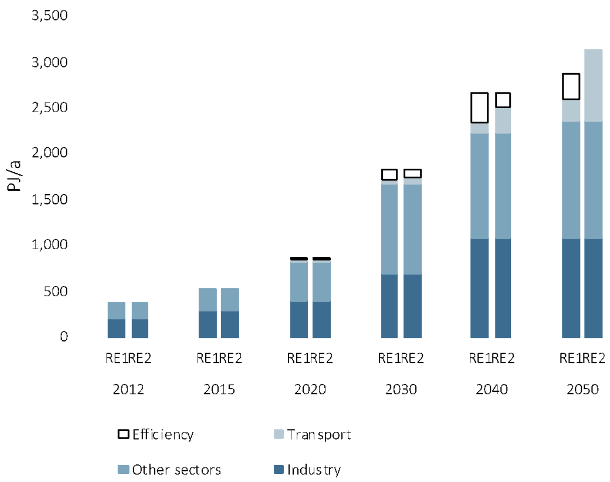
Under both alternative scenarios, the overall electricity demand is expected to increase in response to economic growth, higher living standards, and the electrification of the transport sector, despite efficiency gains in all sectors (see
Figure 17). The total electricity demand will increase from about 150 TWh/a in the base year to 476 TWh/a by 2030 in the RE1 scenario. Compared with the REF scenario, efficiency measures in the industry, residential, and service sectors will avoid the generation of about 30 TWh/a.

This reduction can be achieved, in particular, by introducing highly efficient electronic devices, using the best available technology, in all demand sectors. It is assumed that the implementation of efficient devices across all sectors will mainly occur in response to strict and ever-evolving efficiency standards. The Japanese "top-runner" model was particularly successful because it included competitive incentives for the private sector and avoided additional subsidies. The advanced RE2 scenario includes more ambitious electrification, particularly of the transport sector, and will increase the electricity demand to 481 TWh by 2030 and 870 TWh/a by 2050. Electricity will become the major renewable 'primary' energy, not only for direct use for various purposes, but also for the generation of synthetic fuels to substitute for fossil fuels. Around 220 TWh will be used in 2050 for electric vehicles and rail transport (excluding bunkers) under the RE2 scenario.

Efficiency gains in the heating sector will be even larger than those in the electricity sector. Under both alternative scenarios, energy consumption equivalent to about 160 PJ/a will be avoided as a result of efficiency gains by 2030 compared with the REF scenario. This reduction is mainly attributable to increased efficiency measures in process heat for industries. The development of the energy intensity for the industry sector is assumed to decrease faster in both alternative scenarios than in the REF scenario.

Figure 16: Projection of total final energy demand by sector (excluding non-energy use and heat from CHP auto-producers)





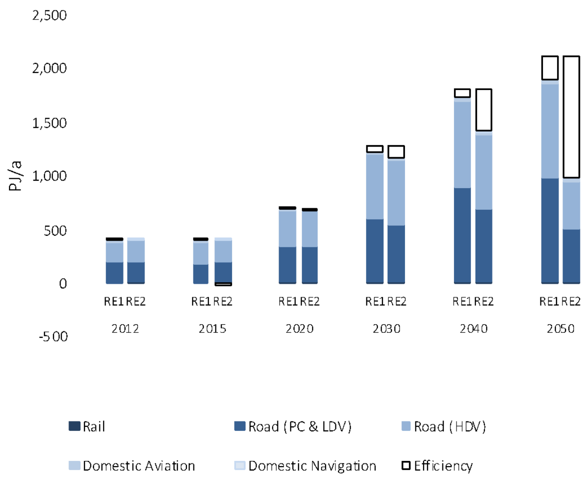


Figure 17: Development of the electricity demand by sector in both RENEWABLES scenarios

Figure 18: Development of the final energy demand for transport by sector in the RENEWABLES scenarios

4.2 ELECTRICITY GENERATION

The development of the electricity supply sector will be characterized by a dynamically growing renewable energy market and an increasing share of renewable electricity. This trend will more than compensate for the stagnation of new coal power plant installations and, after 2030, the phasing out of fossil-fuel-based power production in both alternative scenarios. By 2030, 38% of the electricity produced in Viet Nam will come from renewable energy sources in the RE1 scenario, increasing to 75% in 2050. 'New' renewables—mainly onshore wind, solar photovoltaic, and offshore wind – will contribute 19% to the total electricity generation in 2030 and 58% by 2050.

Table 22: Projections of renewable electricity generation capacity

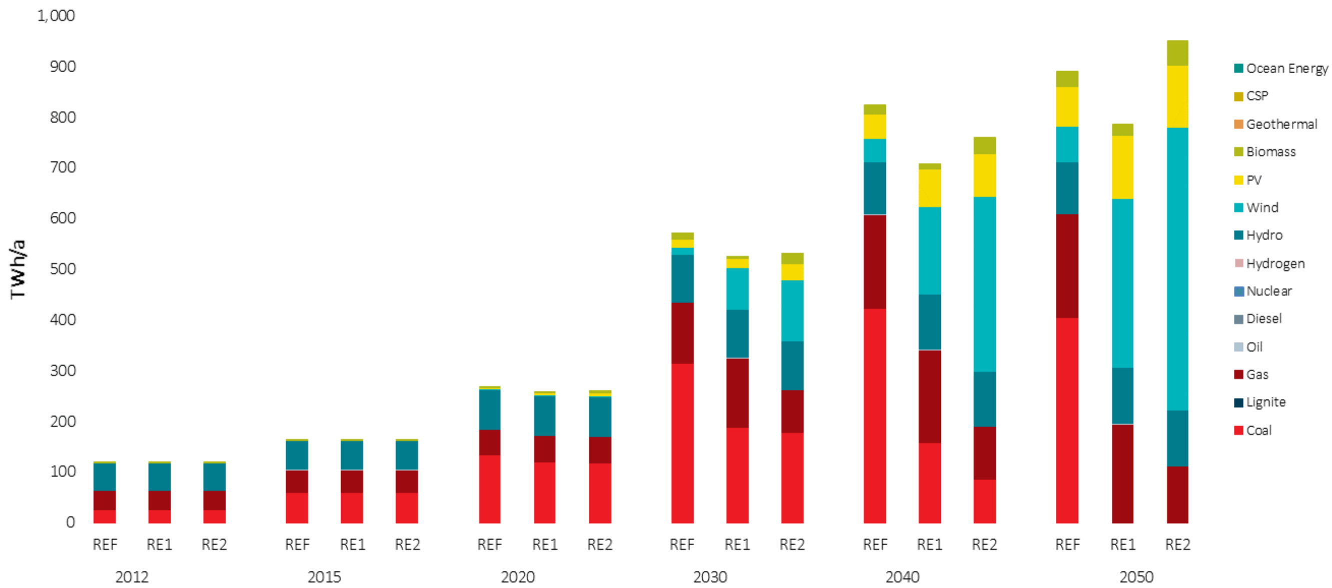
In GW		2015	2020	2030	2040	2050
Coal	REF	13,103	20,632	55,137	56,337	54,093
	RE 1	13,103	20,082	32,915	21,207	0
	RE 2	13,103	19,665	23,780	11,548	0
Gas	REF	7,543	8,013	24,000	24,789	27,045
	RE 1	7,543	8,174	23,295	24,628	26,476
	RE 2	7,543	8,475	13,142	14,122	15,382
Hydro	REF	18.424	21.602	27.800	29.042	29.042
	RE 1	18.424	20.555	25.303	28.642	29.074
	RE 2	18.424	20.555	25.303	28.642	29.074
Biomass	REF	0.024	0.575	2.100	3.284	5.762
	RE 1	0.024	0.141	0.783	1.831	3.958
	RE 2	0.024	0.582	3.566	5.887	9.338
Onshore Wind	REF	0.149	0.900	6,144	20,835	30,090
	RE 1	0.149	0.922	16,576	32,405	45,663
	RE 2	0.149	0.930	21,560	62,255	85,984
Offshore Wind	REF	0	0.1	0.150	1,000	2,139
	RE 1	0	0.1	9,485	21,269	52,573
	RE 2	0	0.1	20,941	54,307	90,220
Photovoltaic	REF	0.150	1.635	14.665	42.217	68.760
	RE 1	0.150	4 557	14.487	56.433	96.385
	RE 2	0.150	5 287	24.917	63.951	87.739
Total Renewables	REF	18.747	24.812	50.859	96.378	135.783
	RE 1	18.747	26.275	66.634	140.578	227.654
	RE 2	18.747	27.545	96.287	215.042	302.355

The installed capacity of renewables will reach close to 70 GW in 2030 and 230 GW by 2050. The RE2 scenario will achieve 50% renewable electricity generation in 2030 and almost 90% in 2050. The renewable capacity will increase to 96 GW by 2030 and 302 GW by 2050. Table 22 shows the comparative evolution of the different renewable technologies in Viet Nam over time. Until 2040, hydro power will remain the major renewable power source. By 2020, wind and photovoltaics will overtake biomass, currently the second largest contributor (after hydro power) to the growing renewable market. After 2020, the continuing growth of onshore wind and photovoltaics will be complemented by electricity from offshore wind. The renewable scenarios will result in a high proportion of variable power generation sources (photovoltaics and wind): 19%–29% by 2030 and 58%–72% by 2050. Therefore, smart grids, demand-side management, energy storage capacities, and other options must be expanded to increase

the flexibility of the power system to ensure grid integration, load balancing, and a secure supply of electricity.
The calculated potential for utility-scale solar photovoltaic under all restrictions (see section 3.5) is 48 GW, and 242 GW if the mountain areas and areas further than 10 km from transmission lines are taken into account. The most ambitious RE1 scenario can be implemented with 50% utility-scale solar photovoltaics under the most restricted potential, with rooftop solar photovoltaic for the remaining capacity.
The RE2 scenario has less solar photovoltaic power generation and more offshore wind power generation because the remaining dispatch capacity—mainly from gas—is lower in RE2 than in RE1.

In terms of onshore wind, both alternative scenarios use the onshore wind potential with the highest restriction identified in section 3.5.1 until 2030. Thereafter, areas further than 10 km from current transmission lines must be taken into account. The offshore wind potential is almost seven times larger than the most ambitious scenario requires.

Figure 19: Breakdown of electricity generation by technology



The 100% electricity supply from renewable energy resources in the RENEWABLES 2 scenario will lead to around 300 GW of installed generation capacity in 2050.

4.3 ENERGY SUPPLY FOR COOKING AND INDUSTRIAL PROCESS HEAT

Today, renewables meet around 47% of Viet Nam's energy demand for heating, with the main contribution from biomass. Dedicated support instruments are required to ensure the dynamic development of renewables, particularly for renewable technologies and renewable process heat production in the industry sector. In the RE1 scenario, renewables will already provide 23% of Viet Nam's total heat demand in 2030 and 57% in 2050.

- Energy efficiency measures will help to reduce the currently growing energy demand for heating by 10% in 2030 (relative to the REF scenario), despite the increased industry energy demand arising from economic growth.
- In the industry sector, solar collectors, geothermal energy (mainly heat pumps), and electricity will increasingly substitute for fossil-fuel-fired systems.
- A shift from coal and oil to natural gas in the remaining conventional applications will lead to a further reduction in CO_2 emissions.

Figure 20: Projection of heat supply by energy carrier (REF, RE1, and RE2)

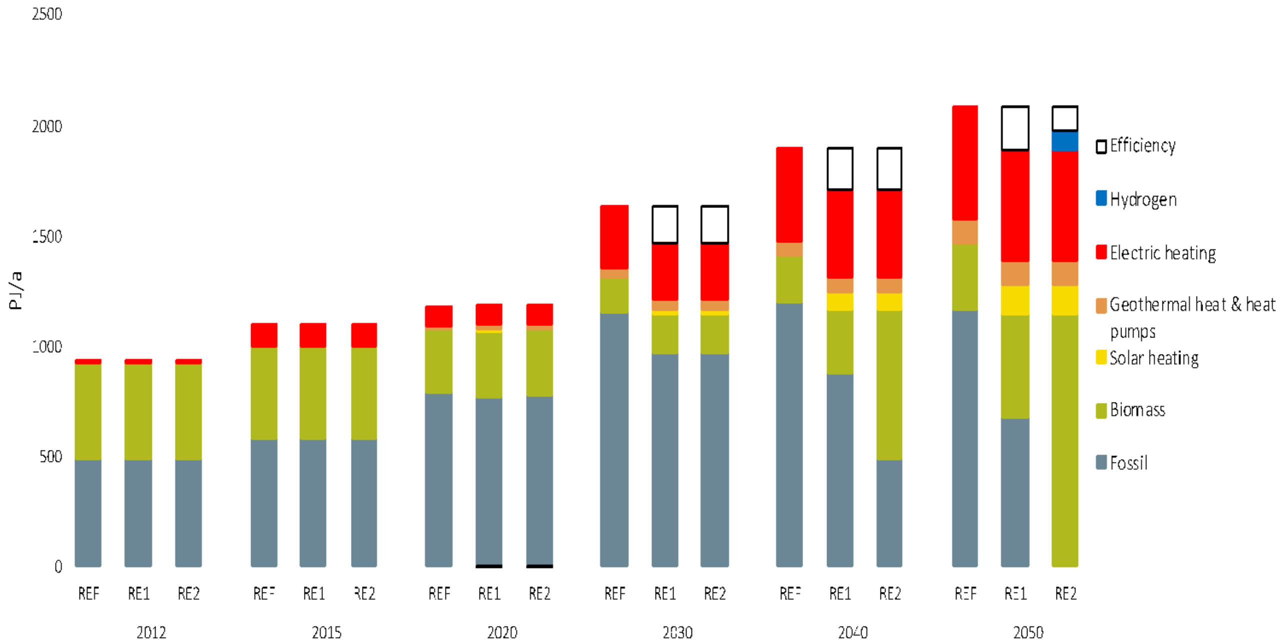


Table 23: Projection of renewable heat supply (cooking and process heat)

in PJ/a		2015	2020	2030	2040	2050
Biomass	REF	429	291	155	213	303
	RE 1	429	300	177	292	461
	RE 2	429	300	177	681	1,135
Solar heating	REF	0	0	0	3	0
	RE 1	0	6	22	75	137
	RE 2	0	6	22	75	137
Geothermal heat & heat pumps	REF	0	14	42	68	104
	RE 1	0	17	40	72	116
	RE 2	0	17	40	72	116
Hydrogen	REF	0	0	0	0	0
	RE 1	0	0	0	0	0
	RE 2	0	0	0	0	95
Total	REF	429	305	197	284	407
	RE 1	429	323	239	439	713
	RE 2	429	323	239	828	1,483

Table 23 shows the development of different renewable technologies for heating in Viet Nam over time. Biomass remains the main contributor, with increasing investment in highly efficient modern biomass technologies. After 2030, a massive growth in solar collectors and increasing proportions of geothermal and environmental heat and heat from renewable hydrogen will further reduce the dependence on fossil fuels. The RE2 scenario will result in the complete substitution of the remaining gas consumption, mainly by renewable electricity.

Table 24: Installed capacities for renewable heat generation

in GW		2020	2030	2040	2050
Biomass	REF	61	25	32	42
	RE 1	63	26	35	44
	RE 2	63	26	81	119
Geothermal	REF	0	0	0	0
	RE 1	0	0	0	0
	RE 2	0	0	0	0
Solar heating	REF	0	0	0	0
	RE 1	2	2	7	16
	RE 2	2	2	7	16
Heat pumps	REF	1	4	6	10
	RE 1	2	4	8	14
	RE 2	2	4	8	14
Total	REF	62	29	38	51
	RE 1	67	32	51	74
	RE 2	67	32	96	150

4.4 TRANSPORT

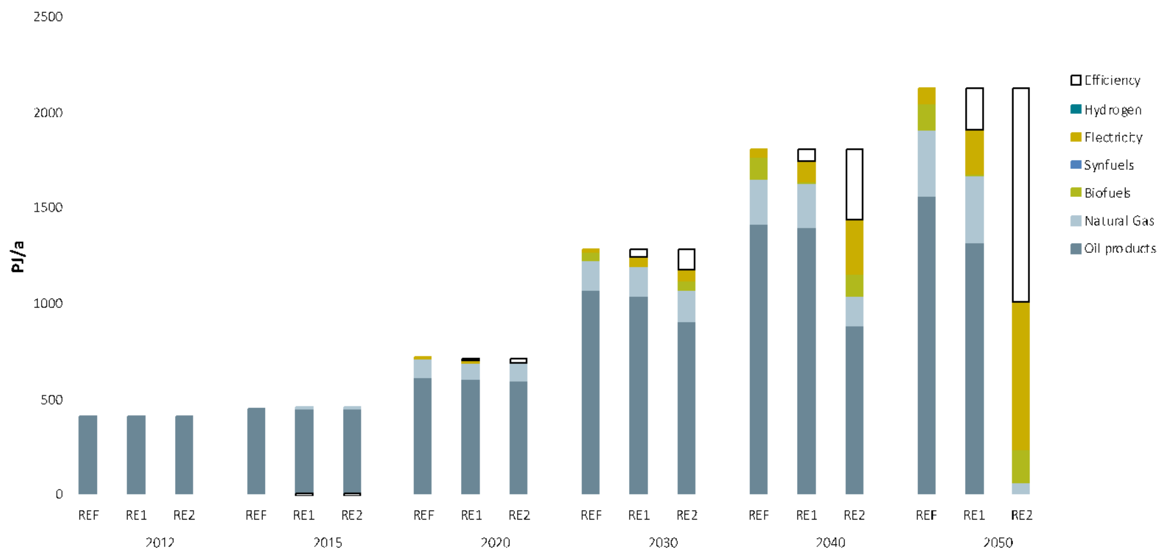
The transport energy demand is projected to increase significantly and will more than double under all scenarios. The shift to electrification in the transport sector will take more than a decade, so the transport scenarios will show small differences until 2030. To avoid further significant increases in—mainly oil-based—transport energy beyond 2030, the alternative scenarios implement a number of measures. It is vital to shift transport use to efficient transport modes, such as rail, light rail, and (electric) buses, especially in the expanding large metropolitan areas. Together with rising prices for fossil fuels, these changes will reduce the further growth in car sales projected under the REF scenario. As the population increases, with GDP growth and higher living standards, the energy demand from the transport sector is expected to increase in the REF scenario from 1,284 PJ/a in 2030 to 2,126 PJ/a in 2050, an increase of 166%. In the RE1 scenario, efficiency measures and modal shifts will save 10% of the energy demand (210 PJ/a) between 2030 and 2050 relative to the REF scenario.

Additional modal shifts and technology switches will lead to even higher energy savings in the RE2 scenario of 52% (1110 PJ/a) between 2030 and 2050 compared to the REF scenario. Highly efficient propulsion technology with hybrid, plug-in hybrid, and battery-electricity-powered trains will bring large efficiency gains. By 2030, electricity will provide 4% of the transport sector's total energy demand in the RE1 scenario, whereas in 2050, the share will be 12% (77% in the RE2 scenario). Hydrogen and other synthetic fuels generated with renewable electricity may be complementary options that further increase the renewable share in the transport sector.

Table 25: Projection of the transport energy demand by mode

in PJ/a		2015	2020	2030	2040	2050
Rail	REF	13	13	13	14	15
	RE 1	0	13	14	16	19
	RE 2	13	13	15	19	25
Road	REF	387	673	1,239	1,759	2,071
	RE 1	391	664	1,197	1,687	1,852
	RE 2	391	660	1,133	1,373	935
Domestic aviation	REF	10	12	20	29	35
	RE 1	7	12	20	29	35
	RE 2	7	8	15	22	26
Domestic navigation	REF	2	2	2	3	4
	RE 1	2	2	2	3	4
	RE 2	2	2	2	3	4
Total	REF	412	701	1,276	1,805	2,124
	RE 1	400	691	1,234	1,736	1,909
	RE 2	412	683	1,166	1,418	990

Figure 21: Final energy consumption by transport under the scenarios

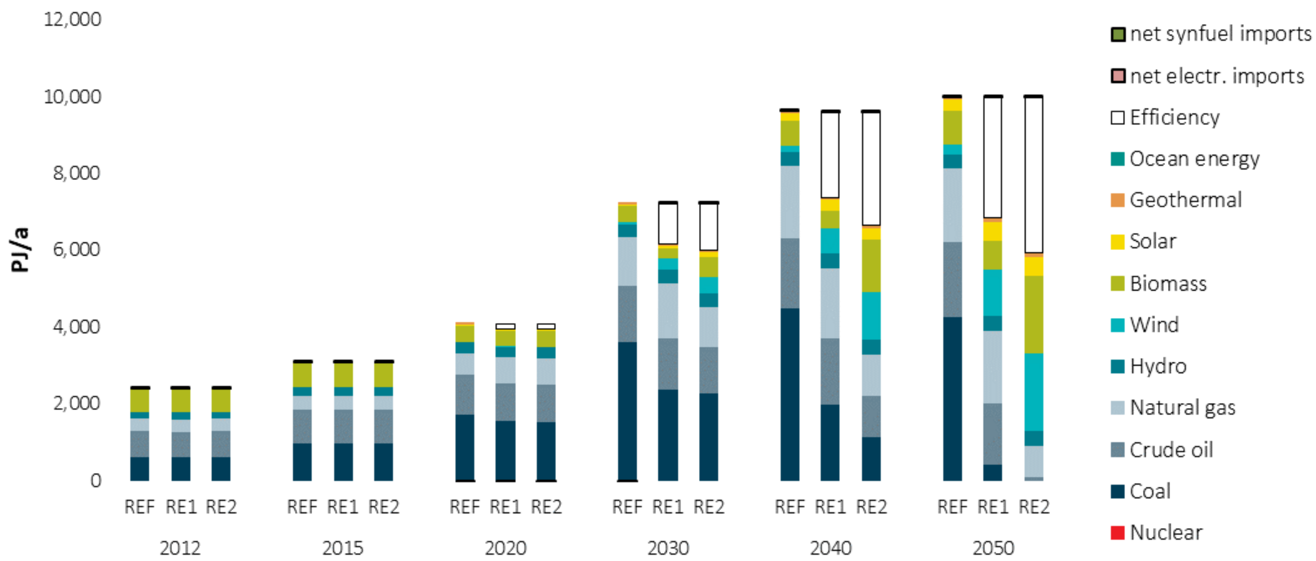


4.5 PRIMARY ENERGY CONSUMPTION

Based on the assumptions discussed above, the primary energy consumptions under both RENEWABLES scenarios and the REFERENCE scenario are shown in Figure 22. Under the RE1 scenario, the primary energy demand will increase from the present level of around 4,000 PJ/a to around 6,200 PJ/a in 2030, an increase of 150%. Compared with the REF scenario, the overall primary energy demand will be reduced by 1,000 PJ by 2030 under the RE1 scenario (REF: 7,250 PJ in 2030). The RE2 scenario will result in a primary energy consumption of around 5,900 PJ in 2030, and will remain at this level as a result of increased electrification between 2030 and 2050.

The RENEWABLES scenarios aim to reduce coal, gas, and oil consumption as fast as is technically and economically possible by the expansion of renewable energy generation and the rapid introduction of very efficient vehicles to the transport sector to replace oil-based combustion engines. This will lead to an overall renewable primary energy share of 16% in 2030 and 43% in 2050 in the RE1 scenario and of more than 84% in 2050 in the RE2 scenario (including non-energy consumption).

Figure 22: Projection of total primary energy demand by energy carrier (incl. electricity import balance)



4.6 CO_2 EMISSIONS TRAJECTORIES

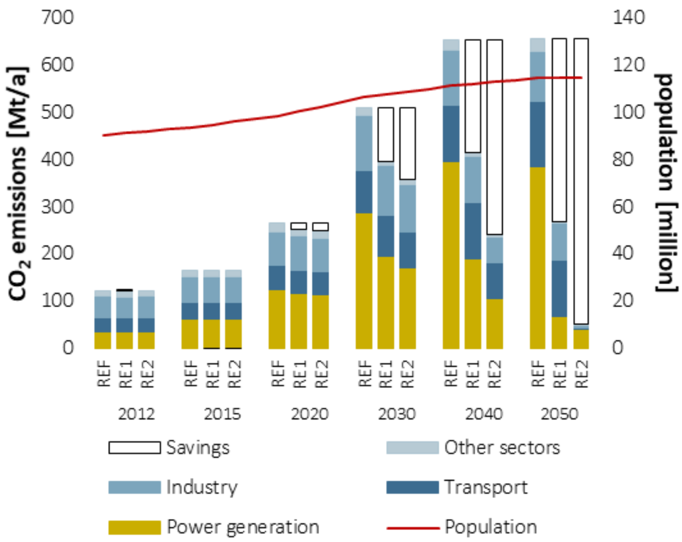
Although Viet Nam's energy-related CO_2 emissions will increase by a factor of 3 (from 163 million tons to over 511 million tons) between 2015 and 2030 under the REF scenario, the RE1 scenario will result in an increase to 396 million tons by 2030, as the population increases from 94 to 106 million people in the same period. Therefore, the annual per capita emissions will remain under 4 tons. Although the power demand will increase by a factor of 2 in the RE1 scenario between 2020 and 2030, the overall CO_2 emissions from the electricity sector will also double as a result of the completion of current coal power plant projects. In the long run, efficiency gains and the increased use of renewable electricity in vehicles will also dramatically reduce the emissions in the transport sector. The transport sector will be the largest source of emissions in 2050 under the RE1 scenario, with a 44% share of CO_2 generation.

The RE2 scenario will almost decarbonize the industry and transport sectors, whereas the power sector will remain responsible for 49 million tons of CO_2 by 2050, mainly due to gas-based process heat and power generation. Between 2020 and 2030, the RE2 scenario will reduce energy-related CO_2 emissions by 1.2 Gt of CO_2, whereas RE1 will save cumulative carbon emissions equivalent to 966 million tons. The greatest CO_2 emissions under the RE2 scenario will come from the power sector, with 39 million tons (78%) by 2050.

The full decarbonization of all sectors seems possible, with increased import shares of renewable electricity and fuels from neighbouring countries and/or imports of renewably produced synthetic fuels and hydrogen to replace natural gas.

Figure 23: Development of CO_2 emissions by sector under the RENEWABLES scenarios

('Savings = reduction compared with the REFERENCE scenario)



4.7 COST ANALYSIS: LONG-TERM ENERGY SCENARIO

FUTURE COSTS OF ELECTRICITY GENERATION

The costs provided in this section include all the construction costs for new power plants, the average standard operation and maintenance costs for each technology, and fuel costs. The infrastructure costs for possibly required additional coal or LNG capacities or grid expansion are not included because they are out beyond the scope of this research.

Figure 24 shows the introduction of renewable technologies without carbon costs. Under the REFERENCE scenario, power generation costs will remain around US$0.07 over the entire modelling period. By 2030, the average generation costs across all technologies will be US$0.074 and by 2050, US$0.067. The RE1 scenario will lead to slightly lower average generation costs of US$0.069 by 2030 and US$0.052 by 2050. The most favourable results will be in the RE2 scenario, in which the shares of solar photovoltaic and wind power are high, with significantly lower requirements for fuel and lower capital costs for installation.

Because the uncertainty in the assumed fossil fuel prices increases with time, especially for the REF scenario (which has 83% fuel-based generation), the costs of storage and grid integration are not taken into account in this calculation (see further discussion of storage in Chapter 5). Under the REF scenario, the growth in demand and increasing fossil fuel prices will result in an increase in total electricity supply costs from US$12 billion per year in 2015 to US$42 billion in 2030 compared with US$36 billion in RE1 and US$30 billion in RE2.

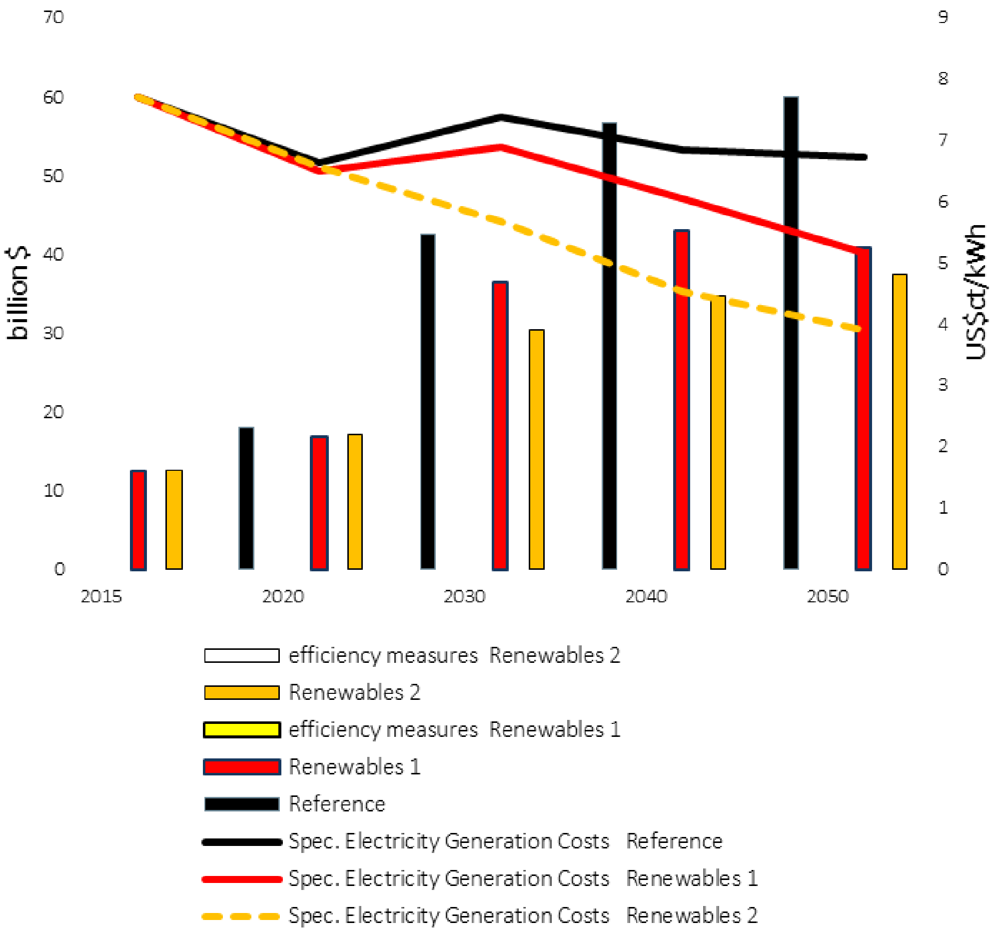


Figure 24: Development of total electricity supply costs and specific electricity generation costs in the scenarios—with no carbon costs

Figure 25 shows that both RENEWABLE scenarios will become more favourable in terms of CO_2 emissions, with an assumed carbon price of US$10 per ton of CO_2 in 2020, and US$20 per ton in 2030, gradually increasing to US$50 per ton of CO_2 in 2050. Both alternative scenarios will be more cost competitive than the REF case. The RE1 and RE2 scenarios will generate electricity for US$0.078 and US$0.066, respectively, compared with US$0.086 in the fossil-fuel-dominated scenario.

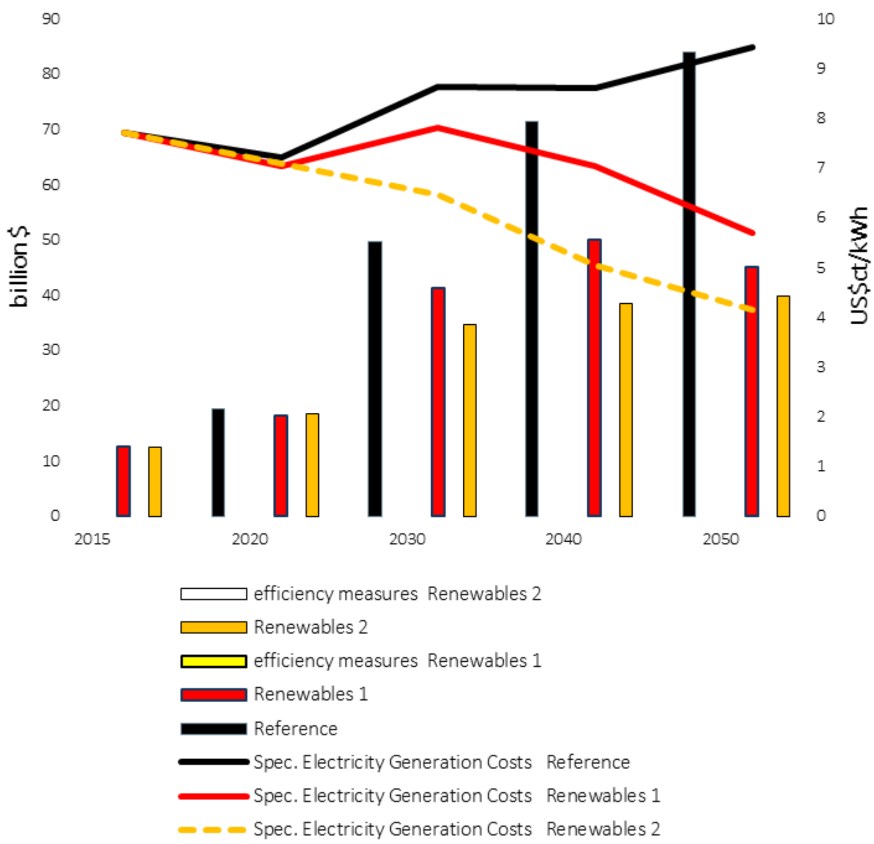


Figure 25: Development of total electricity supply costs and specific electricity generation costs in the scenarios—including carbon costs

COSTS OF ELECTRICITY GENERATION BY TECHNOLOGY

The following figures show the costs of electricity generation with different technologies and all the documented assumptions in terms of cost projections and financial parameters. The error bars show the impact of a 10% fuel cost deviation. In 2030, all the renewable options will have lower generation costs than coal or gas power plants.

Figure 26: Costs of electricity generation with different technologies in 2020

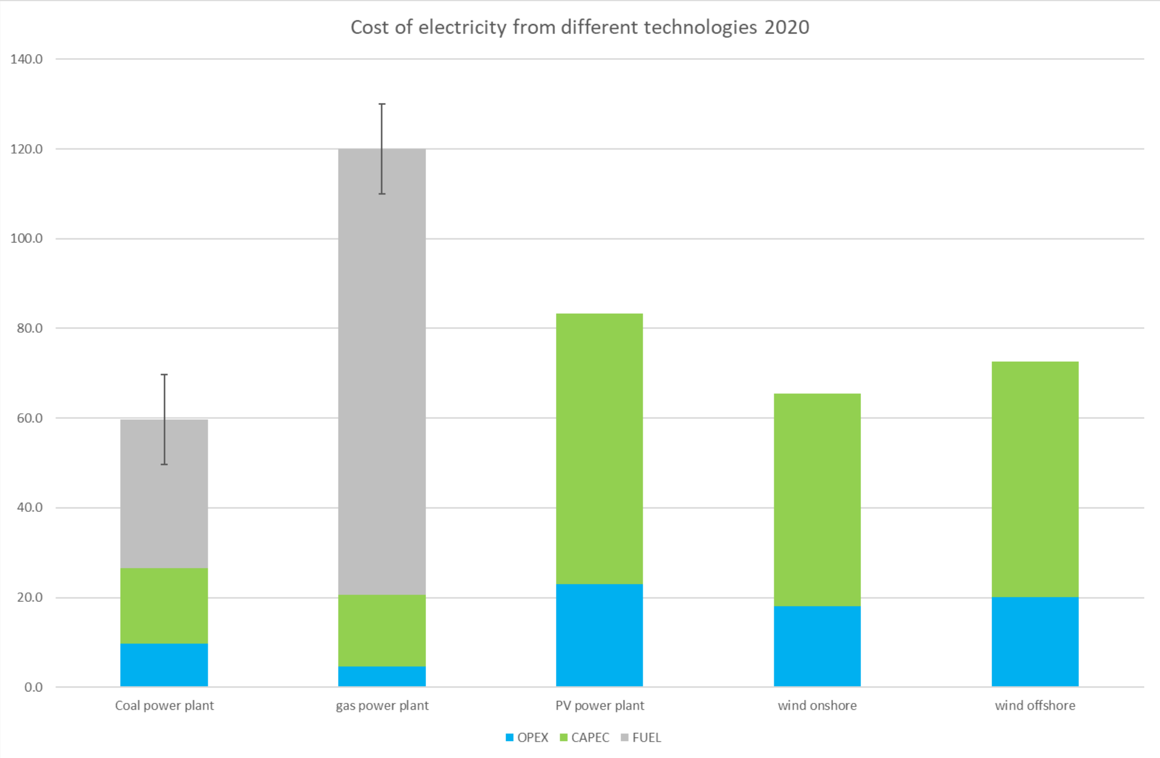
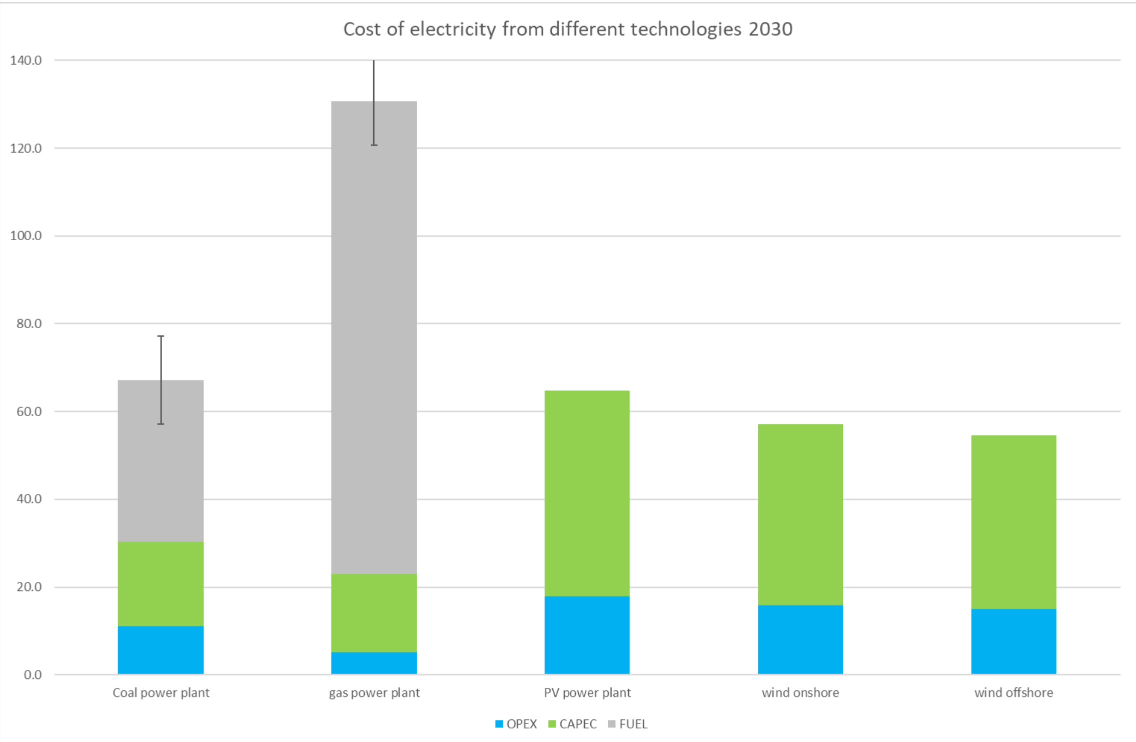


Figure 27: Costs of electricity generation with different technologies in 2030

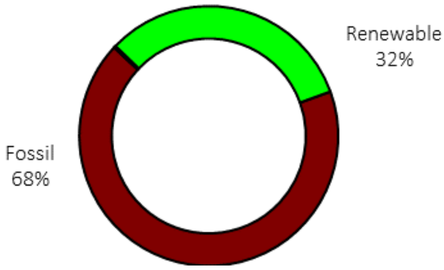


FUTURE INVESTMENTS IN THE POWER SECTOR

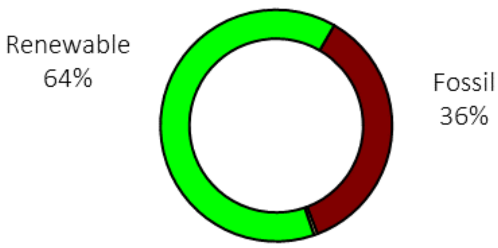
Around US$125 billion will be required in investment between 2020 and 2030 for the RE1 scenario to become reality—US$12 billion less than in the REFERENCE scenario. The RENEWABLES 2 scenario will require US$157 billion, US$24 billion more than the REF scenario. The additional annual investment in the RE2 scenario will be US$2.4 billion more than in the REF scenario and US$3.2 billion more than in the RE1 scenario. Under the REF scenario, the levels of investment in fossil fuel power plants will add up to almost 68%, whereas approximately 32% will be invested in renewable energies until 2050. However, under the RE1 scenario, Viet Nam will shift almost 64% of its entire investment towards renewables, with 36% towards fossil-fuelled power plants, between 2020 and 2030, which reverses the investment shares in the REF case. The RE2 scenario will direct 88% of all new investments into renewable electricity generation between 2020 and 2030.

Figure 28: Cumulative investment in power generation under the three scenarios in 2020–2030

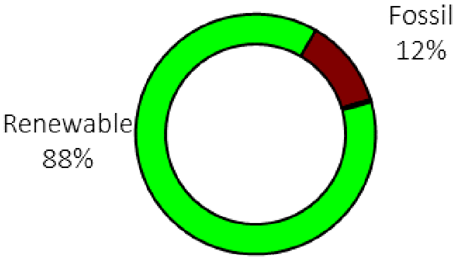
REFERENCE: 2020–2030 cumulative investment, US$133 billion



RENEWABLES 1: 2020–2030 cumulative investment, US$125 billion



RENEWABLES 2: 2020–2030: cumulative investment, US$157 billion



In the long term, until 2050, the fuel cost savings in the RE1 scenario will reach a total of US$510 billion up to 2050, or US$6 billion per year. Therefore, the total fuel cost savings will cover 390% of the total additional investments compared with the REF scenario. The fuel cost savings in the RE2 scenario will be even higher and sum to US$660 billion, or US$17 billion per year. Renewable energy sources will then go on to produce electricity without any further fuel costs beyond 2050, whereas the costs for coal and gas will continue to be a burden on national economies.

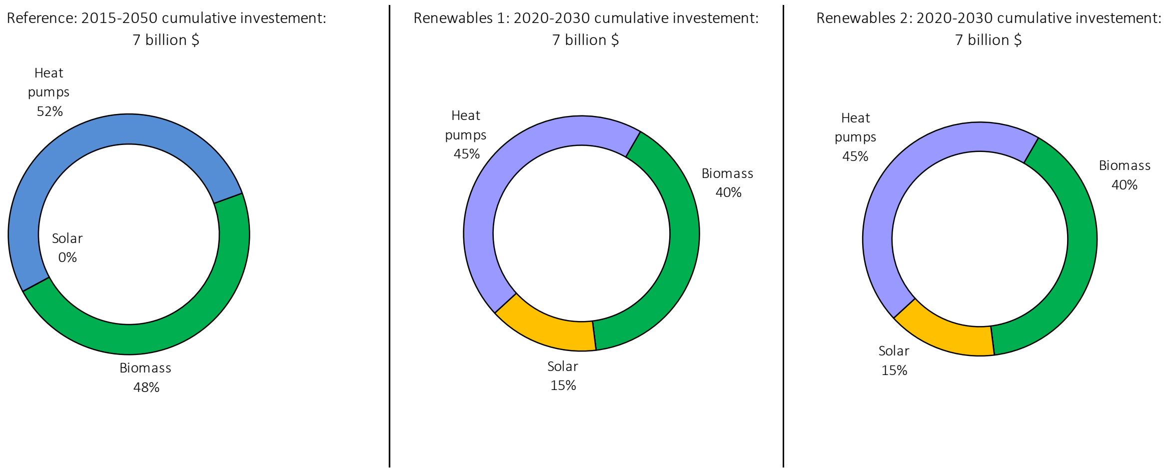
4.8 FUTURE INVESTMENTS IN THE HEATING SECTOR

Similarly, in the heating sector, both RENEWABLES scenarios will require a major revision of current investment strategies in heating technologies. In particular, solar thermal and geothermal heat pump technologies will require enormous increases in installations if their potentials are to be tapped for the—mainly industrial—heating sector. The use of biomass for heating purposes will shift from traditional biomass often used today to modern, efficient, and environmentally friendly heating technologies in the RENEWABLES pathways.

Renewable heating technologies are extremely variable, from low-tech biomass stoves and unglazed solar collectors to very sophisticated enhanced geothermal and solar systems. Although the investment volumes in all three scenarios will be similar (US$7 billion), the chosen technologies will differ. Both alternative scenarios will include solar thermal heating systems for low-temperature heating requirements.

In the long term, until 2050, cost projections can only be quantitative estimates. The RE1 scenario will require around US$60 billion in total to be invested in renewable heating technologies up to 2050 (including investments in replacements after the economic lifetimes of the plants), or approximately US$1 billion per year. The RE2 scenario assumes an equally ambitious expansion of renewable technologies, and will require an average investment of around US$2 billion per year.

Figure 29: Cumulative Investment in heat generation under the three scenarios in 2020–2030



4.9 INVESTMENT AND FUEL COST SAVINGS IN THE POWER SECTOR

Under the RE1 scenario, the investments saved between 2020 and 2030 are estimated to be US$7.8 billion, and compared with the REF scenario, the fuel cost savings will add up to US$7.9 billion. Thus, the overall savings will add up to over US$15 billion. Even under the assumption that there will be large uncertainties in both future investment costs for power generation equipment and the development of fossil fuel prices, it seems certain that the overall cost balance will be economically beneficial under the RE1 scenario.

Table 26: Accumulated investment costs for electricity generation and fuel cost savings under the RENEWABLES 1 scenario

ACCUMULATED INVESTMENT COSTS Difference: REFERENCE minus RENEWABLES 1 Positive figures are savings, negative additional investments		2020–2030	2020–2030 average per year	2031–2040	2041–2050	2020–2050	2020–2050 average per year
Conventional (fossil + nuclear)	billion $	44.9	4.5	3.3	16.6	69.2	2.3
Renewables (incl. CHP)	billion $	−37.0	−3.7	−49.0	−112.4	−202.1	−6.7
Total	**billion $**	**7.8**	**7.8**	**−45.7**	**−95.7**	**−133.6**	**−4.4**
ACCUMULATED FUEL COST SAVINGS							
Savings cumulative: RENEWABLES 1 versus REFERENCE							
Fuel oil	billion $	0.6	0.1	0.6	1.0	2.1	0.1
Gas	billion $	44.7	4.5	93.7	112.0	258.3	8.6
Hard coal	billion $	33.3	3.3	90.2	126.8	254.4	8.5
Total	**billion $**	**78.7**	**7.9**	**184.4**	**239.8**	**510.7**	**17.0**

Under the RE2 scenario, the additional investment between 2020 and 2030 is estimated to be around US$2.1 billion compared with the REF scenario. The fuel cost savings will add up to US$9.4 billion without the transport sector. As in the RE1 scenario, RE2 will lead to fuel cost savings that will more than compensate for the investment costs for renewable power generation.

Table 27: Accumulated investment costs for electricity generation and fuel cost savings under the RENEWABLES 2 scenario

ACCUMULATED INVESTMENT COSTS Difference: REFERENCE minus RENEWABLES 2 Positive figures are savings, negative additional investments		2020–2030	2020–2030 average per year	2031–2040	2041–2050	2020–2050	2020–2050 average per year
Conventional (fossil + nuclear)	billion $	71.1	7.1	3.6	27.0	108.7	3.6
Renewables (incl. CHP)	billion $	−94.7	−9.5	−145.2	−173.1	−422.3	−14.1
Total	**billion $**	**−23.6**	**−2.1**	**−141.5**	**−146.1**	**−313.6**	**−10.5**
ACCUMULATED FUEL COST SAVINGS							
Savings: cumulative RENEWABLES 2 versus REFERENCE							
Fuel oil	billion $	0.6	0.1	0.6	1.0	2.3	0.1
Gas	billion $	57.7	5.8	139.6	160.5	363.5	12.1
Hard coal	billion $	36.0	3.6	102.6	147.6	289.8	9.7
Total	**billion $**	**94.4**	**9.4**	**242.7**	**309.1**	**655.6**	**21.9**

5 VIET NAM: POWER SECTOR ANALYSIS

In this chapter, we summarize the results of the hourly simulations of the long-term scenarios (Chapter 4). The [R]E 24/7 model calculates the demand and supply by cluster. The electricity market in Viet Nam is in dynamic development. The Viet Nam Government is making great efforts to increase the reliability of the power supply and at the same time, keep power costs low. This analysis takes these key points as central to the development of both RENEWABLES scenarios, but also focuses on renewable and sustainable local resources and avoids limited and unsustainable resources, such as coal, oil, and gas, as much as possible. Foreign technologies, such as nuclear power, are not considered, to avoid high economic and logistical dependence on foreign countries by Viet Nam's future generations. We also calculated the REFERENCE (REF) case to compare our results for current and projected loads with other published analyses (RSL 2016[62] and Lahmeyer 2016[63]).

5.1 VIET NAM: DEVELOPMENT OF POWER PLANT CAPACITIES

PDP7 for Viet Nam will lead to a high dependence on imported fossil fuels. By 2040, the power plant capacities for coal will increase by a factor of 3 to around 5 GW annually, whereas gas will increase to a total capacity of around 25 GW. Coal and gas combined will generate over 60% of the installed capacity. The RE1 scenario will lead to renewable capacity shares of 54% by 2030 and 89% by 2050, whereas the RE2 scenario will lead to renewable shares of 72% (2030) and 95% (2050).

Table 28: Viet Nam: Average annual changes in installed power plant capacity

Power Generation: average annual change of installed capacity [GW/a]	2015–2025			2026–2035			2036–2050		
	REF	RE1	RE2	REF	RE1	RE2	REF	RE1	RE2
Hard coal	3.179	2.389	0.465	2.100	−1.039	−0.511	−0.187	−2.074	−1.744
Lignite	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gas	1.003	0.952	0.583	1.085	1.197	0.364	0.233	0.145	0.157
Oil/Diesel	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nuclear	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Biomass	0.119	0.046	0.373	0.185	0.110	0.270	0.275	0.224	0.396
Hydro	0.772	0.562	0.594	0.501	0.627	0.627	0.036	0.095	0.095
Wind (Onshore)	0.245	0.455	2.579	1.012	2.498	4.537	1.657	1.824	3.552
Wind (Offshore)	0.005	0.134	2.613	0.042	1.775	4.794	0.146	3.108	4.158
Photovoltaic (rooftop)	0.598	0.352	2.039	1.616	3.779	3.933	2.812	3.260	2.352
Photovoltaic (utility scale)	0.199	0.117	0.680	0.539	1.260	1.311	0.937	1.087	0.784

The annual installation rates for solar photovoltaic installations must increase to around 5 GW between 2025 and 2035 in both RENEWABLES scenarios, and remain between 3 GW and 4 GW per year until 2050. By 2035, the installation rates for offshore wind must be around 1.8 GW in the RE1 scenario and 4.8 GW in the RE2 scenario. There is significant potential for offshore wind power plants in all the coastal provinces of Viet Nam. Solar photovoltaics and offshore wind are the key renewable energy technologies that will achieve the decarbonization targets and generate domestic electricity.

[62] RSL 2016, Situation Analysis of the Viet Namese Electricity Sector, arepoconsult, March 2016, Berlin/Germany
[63] Lahmaeyer 2016, World Bank Live Wire, Is pumped hydroelectric power right for Viet Nam?, Worldbank, ESMAP 2017, http://documents.worldbank.org/curated/en/565671508913149200/pdf/120674-BRI-PUBLIC-24-10-2017-14-23-31-LWLJOKR.pdf

5.2 VIET NAM: UTILIZATION OF POWER GENERATION CAPACITIES

The division of Viet Nam into eight sub-regions is intended to reflect the main provinces and it is assumed that the interconnection of the sub-regions will increase to 15% of the regional peak load in 2030 and to 20% in 2050. The resulting net transmission capacities are provided in section 5.4.

Table 29: Viet Nam: Installed photovoltaic and wind capacities by region in the RENEWABLES 1 scenario (2030)

RENEWABLES 1 2030	North West	North East	Red River Delta	North Central Coast	Central Highlands	South Central Coast	South East	Mekong
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
Photovoltaic (rooftop)	328	946	2,917	942	513	913	3,212	1,819
Photovoltaic (utility scale)	82	237	729	236	128	228	803	455
Onshore wind	1,105	2,210	3,315	2,210	1,105	1,105	1,105	4,420
Offshore wind	0	593	2,371	1,778	0	1,186	593	2,964

Table 30: Viet Nam: Installed photovoltaic and wind capacities by region in the RENEWABLES 2 scenario (2050)

RENEWABLES 2 2050	North West	North East	Red River Delta	North Central Coast	Central Highlands	South Central Coast	South East	Mekong
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
Photovoltaic (rooftop)	2,030	6,026	17,690	6,164	3,302	5,565	17,680	11,748
Photovoltaic (utility scale)	508	1,506	4,423	1,541	826	1,391	4,420	2,937
Onshore wind	5,732	11,465	17,197	11,465	5,732	5,732	5,732	22,929
Offshore wind	0	5,639	22,555	16,916	0	11,277	5,639	28,193

Table 29 and Table 30 show the installed capacities for solar photovoltaic and wind for the RE1 scenario in 2030 and the more ambitious RE2 scenario in 2050, respectively. The distributions are based on the regional solar and wind potentials and the regional demand, and aim to generate electricity where the demand is located. Whereas solar photovoltaic power generation is modular and can be installed close to the consumer or even integrated into buildings, onshore wind must be kept at a distance from settlements. Therefore, onshore wind must be clustered into wind farms with double digit megawatt capacities, on average. Offshore wind is not a decentralized renewable energy technology and must be installed in a range of several hundred megawatts to a gigawatt. The distribution of offshore wind farms will be based on the available wind resources and existing infrastructure (harbours, transmission lines), and will aim to be close to centres. Therefore, the largest part of the offshore wind capacity in Viet Nam is located in the Hanoi and Ho Chi Ming City areas in our model calculations.

Both RENEWABLE scenarios aim for an even distribution of variable power plant capacities across all regions of Viet Nam by distributing the utility-scale solar photovoltaic and onshore wind power generation facilities accordingly. However, coastal regions have a significantly higher share of variable offshore wind resources than land-locked regions. By 2030, variable power generation will reach 15%–20% in most regions, whereas the proportions of dispatchable renewables—bio energy and hydro power—will vary significantly, from 87% in the Central Highlands to only 1% in the Mekong Delta.

The significant regional differences in the power system shares—the ratio between dispatchable and non-dispatchable, variable power generation—will require a combination of increased interconnection, storage facilities, and demand-side management incentives. Over time, the proportion of variable power generation will increase (Table 31) under all scenarios. The regions with large offshore wind capacities will have the highest shares of variable power generation in the grid, and will require greater interconnection with neighbouring regions than those with smaller shares of variable electricity.

Table 31: **Viet Nam: Power system shares by technology group**

Power Generation Structure in percentage of annual supply [GWh/a]		REFERENCE			RENEWABLES 1			RENEWABLES 2		
Viet Nam		Variable Renewables	Dispatch Renewables	Dispatch Fossil	Variable Renewables	Dispatch Renewables	Dispatch Fossil	Variable Renewables	Dispatch Renewables	Dispatch Fossil
North West	2015	1%	99%	0%	1%	99%	0%	1%	99%	0%
	2030	9%	91%	0%	20%	80%	0%	28%	72%	0%
	2050	24%	76%	0%	40%	60%	0%	42%	58%	0%
North East	2015	0%	57%	42%	0%	68%	31%	0%	68%	31%
	2030	8%	40%	53%	18%	37%	45%	30%	40%	30%
	2050	20%	26%	54%	64%	35%	2%	69%	30%	1%
Red River Delta	2015	0%	3%	96%	0%	4%	96%	0%	4%	96%
	2030	6%	6%	88%	15%	4%	81%	28%	10%	63%
	2050	16%	7%	77%	51%	8%	41%	66%	12%	21%
North Central Coast	2015	0%	64%	35%	0%	75%	25%	0%	75%	25%
	2030	7%	40%	53%	23%	36%	41%	39%	36%	25%
	2050	18%	24%	58%	71%	28%	1%	78%	22%	1%
Central Highlands	2015	0%	100%	0%	0%	100%	0%	0%	100%	0%
	2030	7%	93%	0%	13%	87%	0%	19%	81%	0%
	2050	17%	83%	0%	28%	72%	0%	27%	73%	0%
South Central Coast	2015	1%	99%	0%	1%	99%	0%	1%	99%	0%
	2030	6%	77%	17%	23%	69%	8%	44%	54%	2%
	2050	18%	47%	35%	66%	34%	1%	75%	25%	0%
South East	2015	0%	24%	75%	0%	30%	70%	0%	30%	70%
	2030	6%	20%	74%	10%	18%	72%	19%	26%	55%
	2050	17%	17%	66%	35%	18%	47%	45%	26%	30%
Mekong Delta	2015	0%	0%	100%	0%	0%	100%	0%	0%	100%
	2030	10%	3%	87%	35%	1%	64%	59%	5%	36%
	2050	25%	5%	70%	77%	2%	21%	89%	3%	8%
Average	**2015**	**0%**	**56%**	**44%**	**0%**	**59%**	**40%**	**0%**	**59%**	**40%**
	2030	**7%**	**46%**	**47%**	**20%**	**42%**	**39%**	**33%**	**40%**	**26%**
	2050	**19%**	**36%**	**45%**	**54%**	**32%**	**14%**	**61%**	**31%**	**8%**

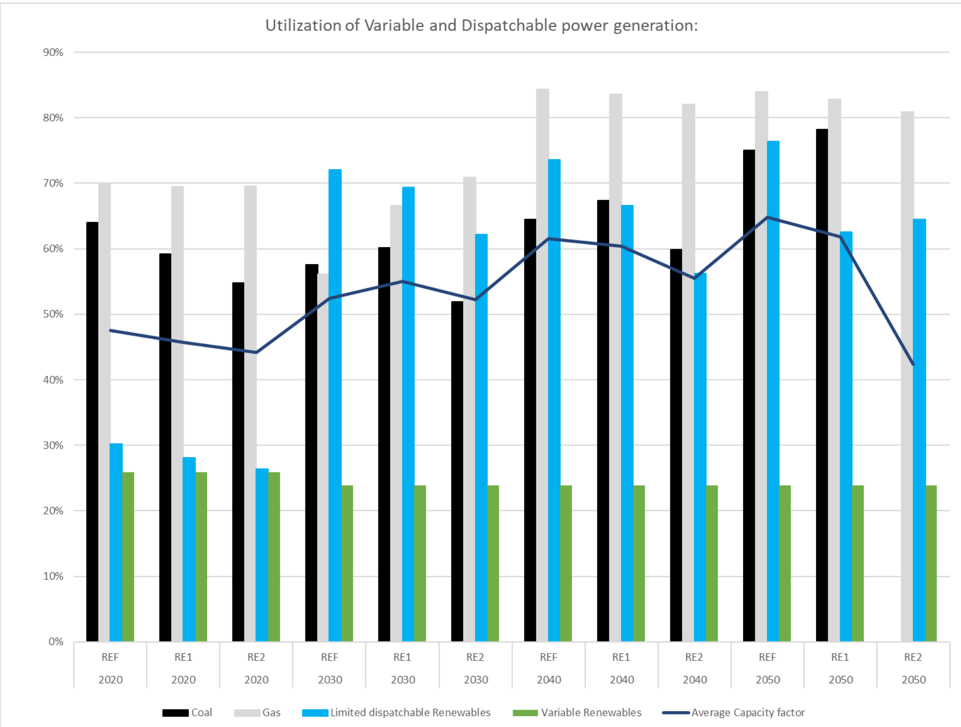
Table 32 shows the system-relevant technical characteristics of the various generation types. Future power systems must be structured according to the generation characteristics of each technology in order to maximize their synergy. Power utilities can encourage sector coupling—between industry, transport, and heating—in order to utilize various demand-side management possibilities and to maximize the cross-benefits. The integration of large shares of variable power generation will require a more flexible market framework. Those power plants requiring high capacity factors because of their technical limitations regarding flexibility ("base load power plants") might not be desirable for future power system operators. Therefore, capacity factors will become more a technical characteristic than an economic necessity. Flexibility is a commodity that increases in value over time.

Table 32: Viet Nam: System-relevant generation types

Generation type	Fuel	Technology
Limited dispatchable	fossil, uranium	coal, brown coal/lignite, nuclear, (incl. co-generation)
	renewable	hydro power, bio energy, geothermal, concentrated solar power (incl. co-generation)
Dispatchable	fossil	gas, oil, diesel (incl. co-generation)
		storage systems: batteries, pumped hydro power plants, hydrogen- and synthetic-fuelled power and co-generation plants
	renewable	bio energy, hydro, hydrogen- and synthetic-fuelled power and co-generation plants
Variable	renewable	solar photovoltaic, onshore and offshore wind

Viet Nam's average capacity factors for the entire power plant fleet will remain between 45% and 55% over the entire modelling period (Figure 30).
The capacity factor of coal will then start to decline, especially in the RE2 case, whereas the gas power plants will operate on high capacity factors throughout all scenarios. The capacity expansion of gas power plants in both alternative scenarios will be carefully chosen to avoid temporary overcapacity and long-term overcapacity. During the uptake phase of variable renewables around 2030–2040, gas will plays a vital role in the security of supply and in fast-reacting dispatch power plants. Gas power plants will reach their peak capacity in 2035, and this will be maintained until the end of the modelling period in 2050 in both alternative cases. However, this mid- to long-term gas capacity will be 25 GW in RE1 but only 15 GW in RE2. In both cases, high capacity factors can be maintained to achieve low average generation costs.

Figure 30: Viet Nam: Utilization of variable and dispatchable power generation



5.3 VIET NAM: DEVELOPMENT OF LOAD, GENERATION, AND RESIDUAL LOAD

Table 33 shows that Viet Nam's load is predicted to double or triple in all eight sub-regions between 2020 and 2030 under all scenarios. The REFERENCE and RENEWABLES 1 scenarios have almost identical load developments until the end of the modelling period in 2050. The RENEWABLES 2 scenario will lead to higher loads after 2030 in response to increased electric mobility. This is an indication of the need to expand the capacity of Viet Nam's power grid infrastructure until 2030, independent of the type of power generation. Increased electric mobility will require additional capacity in the power grid to accommodate the higher charging loads for vehicles. However, the locations of transmission grids will be dependent on the form of generation because the locations of generation and the demand centres may differ for decentralized and centralized power generation. The REF scenario will lead to a significant concentration of generation capacity in the north, around Hanoi, and in the south, near Ho Chi Minh City. Whereas coal power depends on fuel supplied via harbours and rail lines, gas is dependent on gas pipelines and LNG terminals for imported gas.

Table 33: Viet Nam: Load, generation, and residual load development

Viet Nam: Development of load and generation		REF				RE1				RE2			
		Max. Demand	Max. Generation	Max. Residual Load	Peak load increase	Max Demand	Max Generation	Max Residual Load	Peak load increase	Max Demand	Max Generation	Max Residual Load	Peak load increase
Viet Nam		[GW/h]	[GW/h]	[GW/h]	[%]	[GW/h]	[GW/h]	[GW/h]	[%]	[GW/h]	[GW/h]	[GW/h]	[%]
North West	2020	1.1	1.1	0.1	100%	1.0	1.0	0.1	100%	0.9	0.9	0.1	100%
	2030	1.9	1.9	0.1	178%	1.8	1.8	0.1	184%	1.7	1.9	0.1	187%
	2050	3.4	3.4	0.1	323%	3.3	4.9	0.3	345%	4.1	7.2	0.1	445%
North East	2020	3.3	3.3	0.2	100%	3.0	3.0	0.2	100%	2.9	2.7	0.3	100%
	2030	5.5	5.5	0.2	167%	5.1	5.1	0.2	172%	5.0	5.4	0.2	175%
	2050	9.8	9.8	0.2	301%	9.5	14.6	6.8	321%	11.9	21.0	8.9	418%
Red River Delta	2020	9.4	7.6	2.2	100%	8.5	7.6	1.2	100%	8.2	7.6	1.2	100%
	2030	15.8	15.8	0.8	167%	14.6	14.6	0.8	171%	14.2	14.2	3.2	173%
	2050	30.4	30.4	7.0	322%	28.9	36.4	17.6	339%	34.0	50.1	25.1	416%
North Central Coast	2020	3.5	3.5	0.3	100%	3.2	3.2	0.3	100%	3.1	3.0	0.4	100%
	2030	6.0	6.0	0.3	170%	5.6	5.6	0.3	175%	5.5	7.4	0.3	179%
	2050	11.5	11.5	1.4	326%	11.3	19.4	8.5	352%	14.3	30.3	11.1	460%
Central Highlands	2020	1.7	1.7	0.1	100%	1.6	1.6	0.1	100%	1.5	1.4	0.2	100%
	2030	3.2	3.2	0.1	183%	3.0	3.0	0.1	191%	2.9	2.9	0.1	196%
	2050	5.9	5.9	0.1	344%	5.8	5.9	0.5	374%	7.4	8.0	1.4	496%
South Central Coast	2020	3.2	3.2	0.3	100%	2.9	2.9	0.3	100%	2.8	2.6	0.5	100%
	2030	5.7	5.7	0.3	178%	5.3	5.3	0.3	184%	5.2	5.4	0.3	188%
	2050	10.6	10.6	1.7	331%	10.3	15.0	5.4	355%	12.7	21.5	7.5	459%
South East	2020	9.1	8.3	1.2	100%	8.2	7.6	0.7	100%	7.7	7.2	1.2	100%
	2030	16.8	16.8	0.5	184%	15.3	15.3	0.5	187%	14.7	14.7	3.3	190%
	2050	32.5	32.5	11.1	356%	30.0	27.7	14.2	367%	32.9	32.9	20.1	426%
Mekong Delta	2020	4.5	4.5	0.0	100%	3.9	3.9	0.0	100%	3.7	3.5	0.3	100%
	2030	11.2	11.2	0.0	248%	10.5	10.5	0.0	267%	10.3	14.3	1.0	278%
	2050	21.5	21.5	1.5	477%	21.0	37.9	11.6	533%	25.8	57.6	19.0	693%
Viet Nam	2020	35.9	33.2	3.0	100%	32.3	30.8	3.0	100%	30.8	28.8	4.2	100%
	2030	66.0	66.0	2.3	191%	61.2	61.2	2.3	191%	59.6	66.1	8.6	196%
	2050	125.7	125.7	64.8	373%	120.2	161.8	64.8	373%	143.1	228.6	93.1	477%

Important technical condition: Power grid capacities must increase proportionally to the increase in load.

5.4 VIET NAM: DEVELOPMENT OF INTERREGIONAL EXCHANGE OF CAPACITY

The increasing electricity load in all regions, shown in Table 33, will require an increase in the transmission and distribution networks in Viet Nam. This analysis assumes that those network upgrades will be implemented as the demand increases. Because it is a technical requirement, Viet Nam must increase its grid capacity proportionally to the increasing demand. If this technical condition is not met, the probability of blackouts will increase significantly. This technical requirement to expand the grid capacity as demand increases is largely independent of the type of power generation.

The interregional exchange of capacity is a function of the load development and generation capacity in all eight regions. The [R]E 24/7 model distributes the generation capacity according to the regional load and the conditions for power generation (see). The locations of coal and gas power plants are fixed and the installation of new capacities will depend on possibility of fuel supply. Renewable power generation is more modular and can be distributed according to the load in the first place. However, as the share of renewable electricity increases, and the space available for utility-scale solar and onshore wind generation facilities and the availability and quality of local resources (such as solar radiation and/or wind speed) decrease, power might be generated further from its point of consumption. This will require more transmission capacity to exchange generation capacities between the eight regions of Viet Nam analysed here. In our analysis, an increase in the necessary interregional exchange of capacity, in addition to the increase in grid capacity within the regions as demand increases, will start between 2030 and 2040. In particular, those regions with low demand but high generation potential, such as the North West (hydro power) and the offshore wind locations, will require significant increases in transmission capacity.

The current real interconnection capacities between the eight analysed regions were not available, so the modelling results are based on the assumptions described earlier. Furthermore, the transfer capacities for the REF (Figure 31) and both alternative scenarios (Figure 32 and Figure 33) are only estimates because capacities can be reduced by demand-side management measures, increased storage capacities, and variations in the actual distribution of power generation.

The net transfer capacity in the REF scenario in 2050 will follows the same pattern as that in the two alternative scenarios, whereas the 2040 values will differ. The modelling results indicate that interconnections must be built earlier in the alternative scenarios. The large offshore wind capacities along the coastal regions will require transmission capacities into the hinterlands.

Figure 31: Viet Nam: Maximum interregional exchange capacities—additional to the required grid capacity expansion in response to load increase—under the REFERENCE scenario

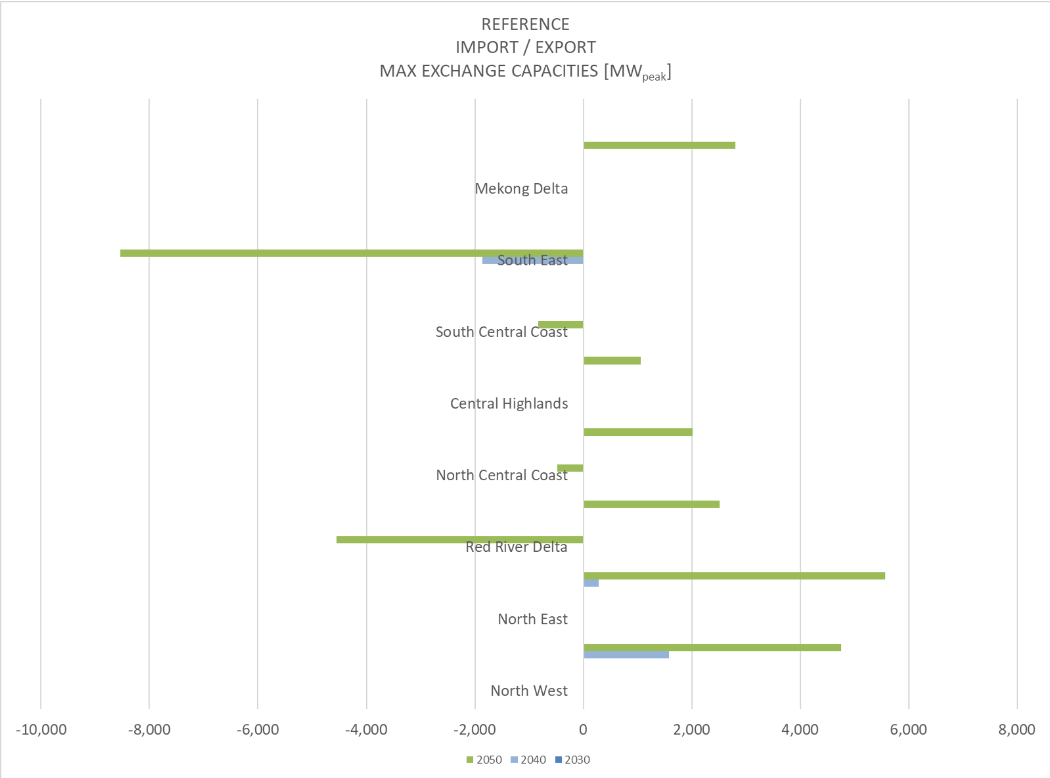


Figure 32: Viet Nam: Maximum interregional exchange capacities—additional to the required grid capacity expansion in response to load increase—under the RENEWABLES 1 scenario

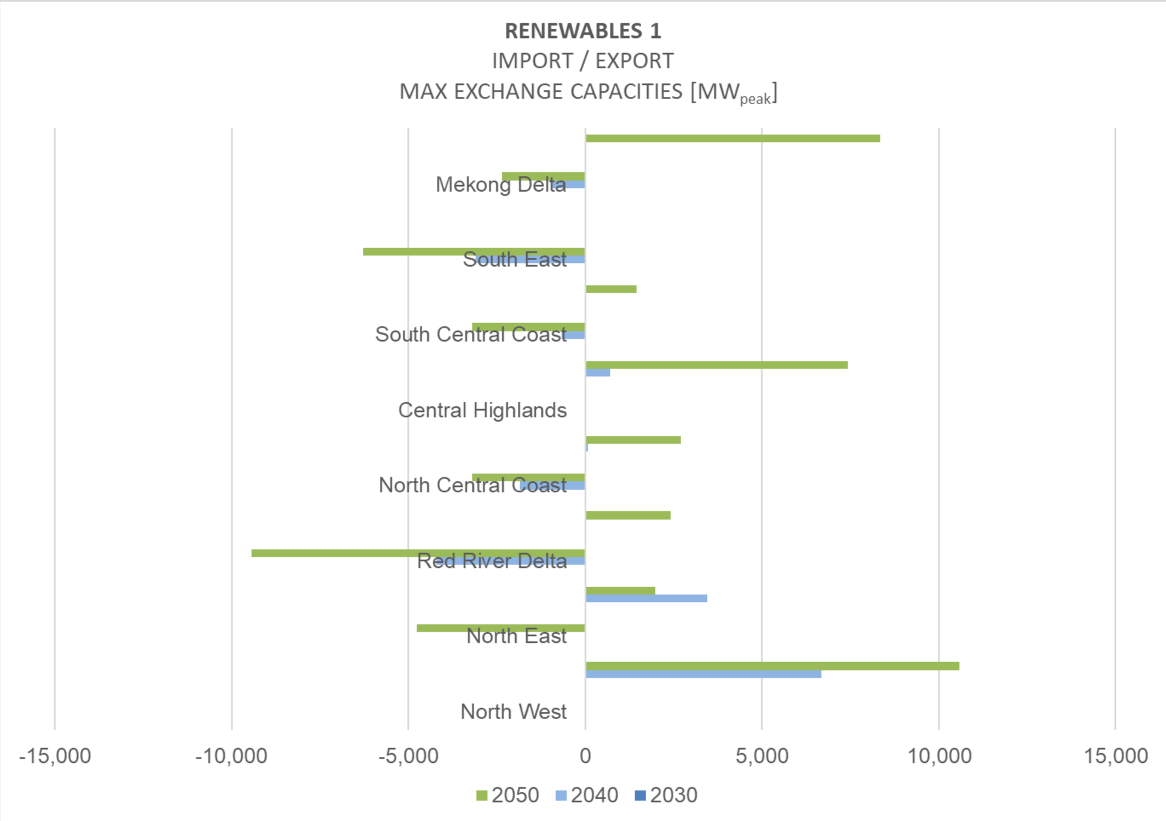


Figure 33: Viet Nam: Maximum interregional exchange capacities—additional to the required grid capacity expansion in response to load increase—under the RENEWABLES 2 scenario

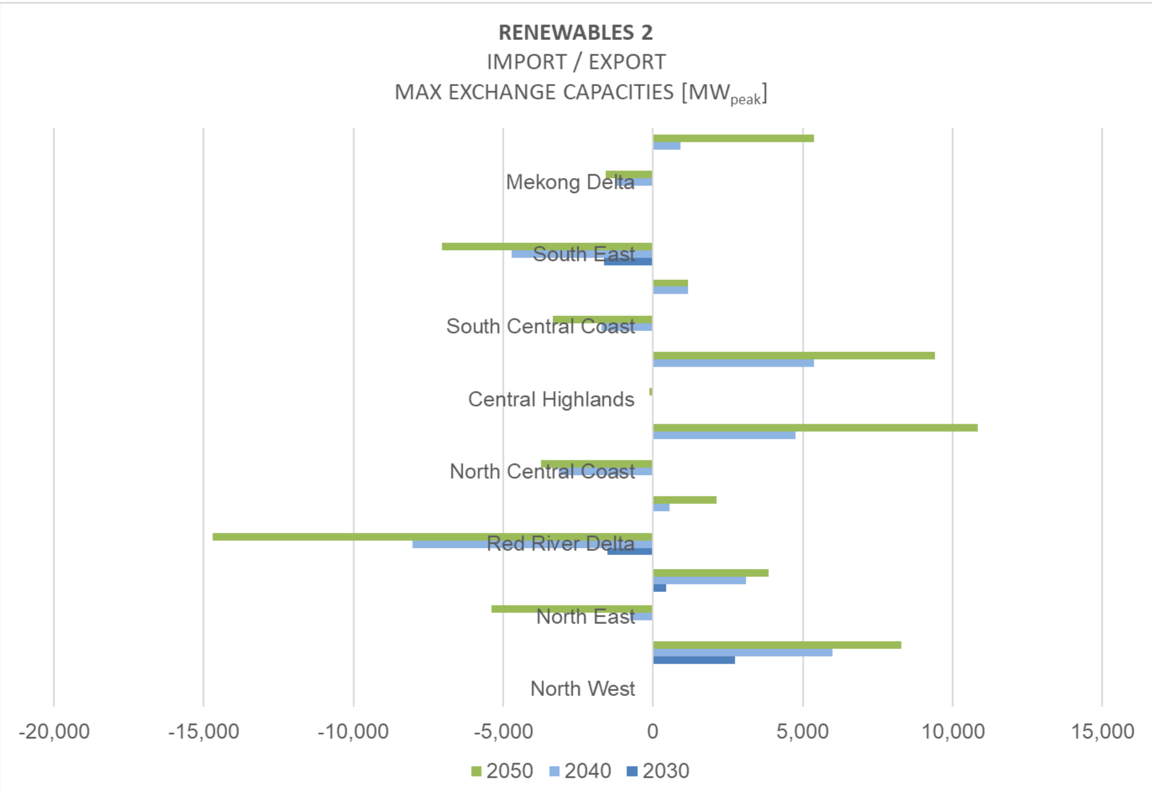
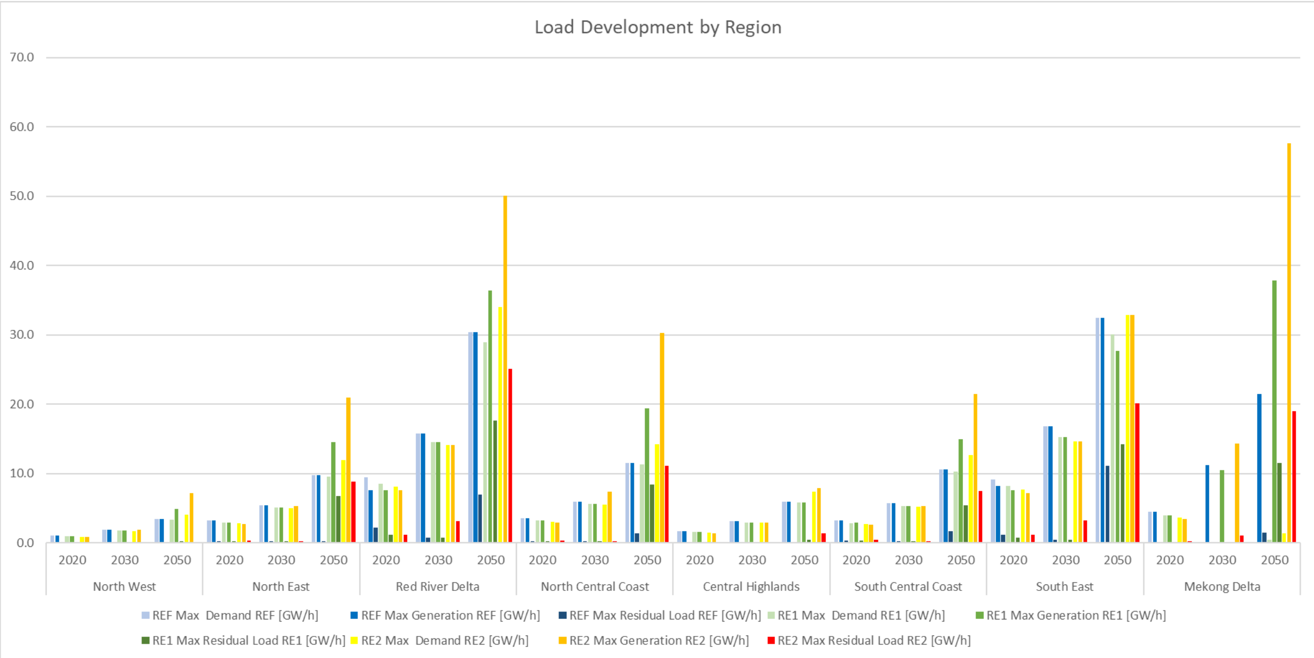


Figure 34: Peak load and maximum generation development by region, in GW



The metropolitan areas of the two main cities, Hanoi and Ho Chi Minh, are currently responsible for approximately one third of Viet Nam's total peak load each—about 10 GW. The remaining 10 GW is distributed across all other provinces. In this analysis, this will not change, but the overall load will increase by a factor of 3. The development of the peak load, peak demand, and maximum residual load (the difference between demand and supply) for Viet Nam's eight sub-regions is shown in Figure 34.

Peak load and peak generation events do not appear at the same time, so the values cannot be added. Moreover, the peak loads across all regions can vary and appear at different times. Therefore, to sum all the regional peak loads will only provide an indication of the peak load for the whole country. The maximum residual load[64] shows the maximum undersupply in a region and indicates the maximum load imported into that region. This event can only be several hours long, so the interconnection capacity might not be as high as the maximum residual load indicates. To optimize the interconnection for all regions was beyond the scope of this analysis.
To guarantee the security of supply, the residual load of a region must be supplied by the following options:

- imports from other regions through interconnections;
- charged storage facilities providing additional load;
- available back-up capacities, such as gas peaking plants;
- load and demand-side management.

In practice, security of supply will be achieved with a combination of several measures and will require the in-depth analysis of regional technical possibilities, e.g., whether or not a cable connection is possible.

Both RENEWABLE scenarios include significant amounts (20%–28%) of decentralized small-to-medium-scale generation (solar photovoltaics and onshore wind) that can generate close to the demand. The North Central Coast and South Central Coast regions have relatively low loads, whereas the combined regional onshore wind and utility-scale solar photovoltaic potential is well above the calculated load for 2050. Therefore, both regions can develop as net exporters of electricity, although they are importers at present. Both RENEWABLES scenarios have an offshore wind generation share of around 55% relative to the total installed capacity. Offshore wind allows centralized renewable power generation and requires specific transmission lines, exclusively to transport electricity from sea to land. UTS-ISF suggests a specific transmission corridor, which is described in the following section.

[64] Residual load is the load remaining after local generation within the analysed region is exhausted. There could be a shortage of load supply due to the operation and maintenance of a coal power plant or reduced output from wind and solar power plants.

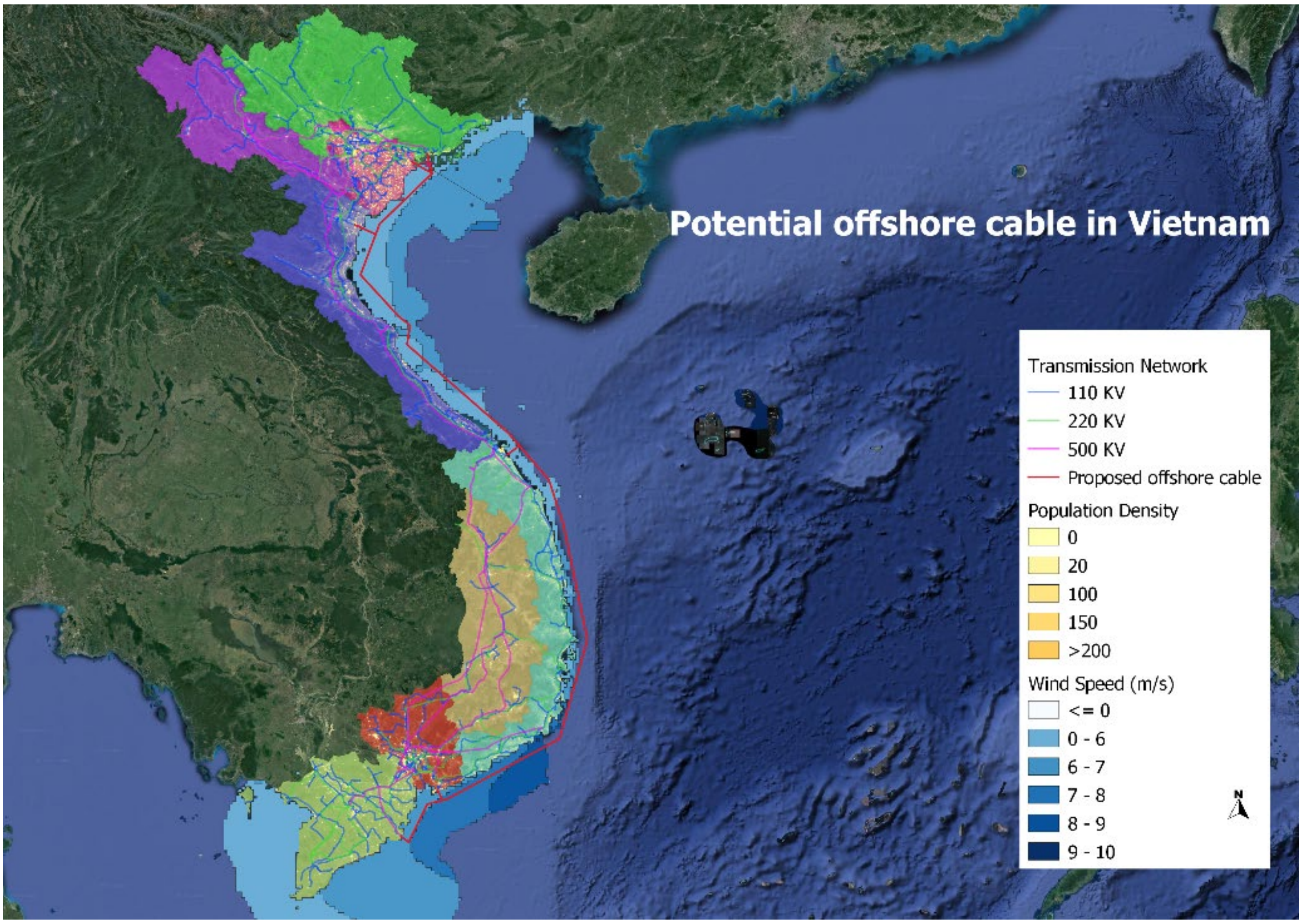
5.5 VIET NAM: OFFSHORE WIND INFRASTRUCTURE POSSIBILITY

Viet Nam has significant offshore wind potential and a very favourable geography for the use of electricity in all provinces, except the North Eastern region and the Central Highlands, which have no access to coastline. UTS-ISF suggests that a sea cable be laid parallel to the coastline to collect the electricity generated from offshore wind—an offshore wind busbar. This *Hanoi–Ho Chi Minh Power Link* will transport this power to the two load centres in the north and south and, with lower-capacity interconnections, to the other coastal provinces in between. These links can work both ways:

c. supplying electricity to those coastal region that have a lower generation capacity;
d. transporting surplus generation to the load centres; the South Central Coast has significant solar potential.

Figure 35 shows a possible position for this offshore wind power cable, which has interconnections via six currently existing grid knots to each of the six coastal regions. The total length of this cable would be 1775 km, including the land connections. The maximum load calculated for Hanoi/Red River Delta under scenario RE2 will be 34 GW in 2050, whereas the estimated load for the Ho Chi Minh City/South East region will reach 32.9 GW. The total maximum load for Viet Nam is expected to reach around 110–120 GW by 2050. The installed offshore wind capacity in the RE2 scenario will be 90 GW.

Figure 35: Proposed Hanoi to Ho Chi Minh offshore wind link



To date, ultra-high-voltage (UHV) cables have the largest transmission capacity of around 1 GW, with voltage levels of typically 1,000 kV per cable (FSG 2014)[65]. To quantify the optimal capacity required for an offshore wind link is beyond the scope of this analysis. The calculated peak loads of all remaining coastal regions will be in the range of 5–10 GW, which provides an indication of the capacity range needed for the offshore cable.

Although no offshore wind cable projects of similar size have yet been installed, there are similar ideas under discussion. According to the European Offshore Wind Journal *Riviera*, a 30 GW hub could connect offshore wind turbines and distribute electricity between the United Kingdom, Belgium, the Netherlands,

65 FSG (2014); Friends of the Supergrid, Roadmap to Super Grid Technologies, Update Report, June 2014, https://www.friendsofthesupergrid.eu/wp-content/uploads/2014/06/WG2_Supergrid-Technological-Roadmap_20140622_final.pdf, page 46

Germany, Denmark, and Norway (RIVIERA 2019)[66]. The Centre for Electric Power and Energy at the Technical University of Denmark (DTU) is leading a research project that examines the feasibility of a wind power 'hub' in the North Sea that would handle power from multiple wind farms and distribute power to countries in the region. The DTU is focusing on the technology required to make such a hub feasible, and is working closely with partners from the industry, including Energinet, Vestas, MHI Vestas, Siemens Gamesa, ABB, NKT, Siemens, and Ørsted.

5.6 STORAGE REQUIREMENTS

The quantity of storage required is largely dependent on the storage costs, grid expansion possibilities, and the generation mix itself. In terms of grid expansion, the geographic situation greatly influences the construction costs; crossing mountains, rivers, or swamps is significantly more expensive than crossing flat lands (Wendong 2016)[67]. Furthermore, the length of the permitting process and whether people will be displaced by grid expansions may make storage economically preferable to grid expansion, even though the current transmission costs are lower per megawatt-hour than storage costs. Cebulla et al. (2018)[68] reported that "in general terms, PV-dominated grids directly correlate to high storage requirements, in both power capacity and energy capacity. Conversely, wind-dominated scenarios require significantly lower storage power and energy capacities, if grid expansion is unlimited or cheap". They also found, in an analysis of 400 scenarios for Europe and the USA, that once the share of variable renewables exceeds 40% of the total generation, the increase in electrical energy storage power capacity is about 1–2 GW for each percentage of variable renewable power generation in wind-dominated scenarios and 4–9 GW in solar-photovoltaic-dominated scenarios.

In the RE1 scenario, the share of variable generation will exceed 40% between 2040 and 2045, whereas the RE2 scenario will arrive there 10 years earlier.

Table 35 shows the storage and dispatch requirements to avoid curtailment under both the RENEWABLE and REFERENCE scenarios. The table identifies the capacity (= storage volume) in gigawatt hours (GWh/a) per yearthe required annual through-put capacity of the storage system. It also shows the installed capacity required to avoid curtailment, in terms of the load in gigawatts (GW). These results are consistent with the findings of Cebulla et al., with 55 GW storage required in RE1 by 2050 and 97 GW in RE2.

However, there is no "hard number" for storage requirements because they are dependent upon the available dispatch capacity,= (e.g., from [bio-]gas power plants) and the possibility of demand-side management. The economic optimal storage capacity, in terms of both the overall storage volume and the installed capacity, is also a function of the storage costs, the wind and solar generation costs, and the power system requirements.

Over the past decade, the cost for batteries, especially lithium batteries, has declined significantly. However, solar photovoltaic costs have also declined significantly. Storage is economic when the cost per kilowatt-hour is equal to or lower than the cost of generation. Therefore, if storage costs are high, curtailment could be economic. However, there are various reasons for curtailment, including transmission constraints, system balancing, or economic reasons (NREL 2014)[69]. The California Independent System Operator (CISO)[70] defines economic curtailment during times of oversupply as a market-based decision. "During times of oversupply, the bulk energy market first competitively selects the lowest cost power resources. Renewable resources can "bid" into the market in a way to reduce production when prices begin to fall. This is a normal and healthy market outcome. Then, self-scheduled cuts are triggered and prioritized using operational and tariff considerations. Economic curtailments and self-scheduled cuts are considered "market-based" (…).

[66] Riviera (2019), 30-GW hub would connect thousands of offshore turbines, 10 May 2019, David Foxwell, https://www.rivieramm.com/opinion/opinion/30-gw-hub-would-connect-thousands-of-offshore-turbines-54741

[67] Wendong (2016), Wei, Wendong et al. Regional study on investment for transmission infrastructure in China based on the State Grid data,10.1007/s11707-016-0581-4, Frontiers of Earth Science, June 2016

[68] Cebulla et. al. (2018), How much electrical energy storage do we need? A synthesis for the U.S., Europe, and Germany, Journal of Cleaner Production, February 2018, https://www.researchgate.net/publication/322911171_How_much_electrical_energy_storage_do_we_need_A_synthesis_for_the_US_Europe_and_Germany/link/5a782bb50f7e9b41dbd26c20/download

[69] Wind and Solar Energy Curtailment: Experience and Practices in the United States; Lori Bird, Jaquelin Cochran, and Xi Wang, National Renewable Energy Laboratory (NREL), March 2014, https://www.nrel.gov/docs/fy14osti/60983.pdf

[70] Impacts of renewable energy on grid operations, factsheet, https://www.caiso.com/Documents/CurtailmentFastFacts.pdf

In this analysis, we assume that a curtailment rate of 5% with regard to the annual generation (in GWh/a) for solar photovoltaic and onshore and offshore wind will be economically viable by 2030. By 2050, we assume an "economic curtailment rate" of 10%. However, economic curtailment rates are dependent on the available grid capacities and can vary significantly, even within Viet Nam. Curtailment will be economic when the power generated from a wind turbine or photovoltaic power plant exceeds the demand for only a few hours per day, and this event occurs rarely across the year. Therefore, grid expansion will not be justifiable. Table 34 shows the storage required to avoid curtailment, or in other words, the entire surplus generation at any given time, by region and in all three scenarios.

Table 34: Viet Nam: Storage requirements to avoid curtailment

Storage requirement to avoid curtailment		REF		RE1		RE2	
		Required storage to avoid curtailment (Overproduction)	Required storage capacity to avoid curtailment	Required storage to avoid curtailment (Overproduction)	Required storage capacity to avoid curtailment	Required storage to avoid curtailment (Overproduction)	Required storage capacity to avoid curtailment
Viet Nam		[GWh/a	[GW/a]	[GWh/a]	[GW/a]	[GWh/a]	[GW/a]
North West	2020	0	0	0	0	0	0
	2030	0	0	0	0	23	1
	2050	2	0	232	2	1,041	4
North East	2020	0	0	0	0	0	0
	2030	0	0	0	0	72	2
	2050	0	0	893	7	3,590	11
Red River Delta	2020	0	0	0	0	0	0
	2030	0	0	0	0	8	1
	2050	0	0	600	11	3,754	20
North Central Coast	2020	0	0	0	0	0	0
	2030	0	0	0	0	484	3
	2050	0	0	2,799	9	9,399	17
Central Highlands	2020	0	0	0	0	0	0
	2030	0	0	0	0	0	0
	2050	0	0	5	1	10	1
South Central Coast	2020	0	0	0	0	0	0
	2030	0	0	0	0	71	1
	2050	0	0	1,702	6	7,109	10
South East	2020	0	0	0	0	0	0
	2030	0	0	0	0	0	0
	2050	0	0	0	0	0	0
Mekong Delta	2020	0	0	0	0	0	0
	2030	0	0	1	0	2,576	6
	2050	0	0	14,509	20	49,299	35
Viet Nam	2020	0	0	0	0	0	0
	2030	0	0	1	0	3,233	14
	2050	2	0	20,740	55	74,201	97
		No storage required	No storage required				

The REFERENCE scenario requires no storage capacity, except in the North West region in 2050, although it is within the economic curtailment range. The oversupply in the North West region will result from the high installed capacity (relative to the local load) of onshore wind and solar photovoltaic. The RE1

scenario will lead to only minor oversupply situations by 2030, and only in the Mekong region, again within the curtailment range. However, by 2050, oversupply will occur in almost all regions.
The most ambitious scenario RE2 will requires storage to avoid curtailment in six of the eight regions by 2030 and in all regions by 2050. The storage requirements have been assessed based on the assumptions that all the regions will have established interconnection capacities as indicated in section 5.3 and that the economic curtailment rates are fully exhausted.

Table 35: Viet Nam: Estimated electricity storage requirements for both RENEWABLES scenarios

Storage and H_2 Dispatch		RENEWABLES 1		RENEWABLES 2	
		Total storage throughput	Storage capacity (1)	Total storage throughput	Storage capacity (1)
Viet Nam		[GWh/yr]	[GW]	[GWh/yr]	[GW]
North West	2020	0	0.0	0	0.0
	2030	0	0.0	10	0.0
	2050	104	0.1	468	0.5
North East	2020	0	0.0	0	0.0
	2030	0	0.0	32	0.0
	2050	402	0.4	1,616	1.7
Red River Delta	2020	0	0.0	0	0.0
	2030	0	0.0	4	0.0
	2050	270	0.3	1,689	1.8
North Central Coast	2020	0	0.0	0	0.0
	2030	0	0.0	218	0.2
	2050	1,260	1.3	4,230	4.5
Central Highlands	2020	0	0.0	0	0.0
	2030	0	0.0	0	0.0
	2050	2	0.0	5	0.0
South Central Coast	2020	0	0.0	0	0.0
	2030	0	0.0	32	0.0
	2050	766	0.8	3,199	3.4
South East	2020	0	0.0	0	0.0
	2030	0	0.0	0	0.0
	2050	0	0.0	0	0.0
Mekong Delta	2020	0	0.0	0	0.0
	2030	0	0.0	1,159	1.2
	2050	6,529	6.9	22,185	23.4
Total	**2020**	0	0.0	0	0.0
	2030	0	0.0	1,455	1.5
	2050	9,333	9.8	33,390	35.1

(1) Calculated with an average capacity factor of 950 hours per year

The estimates provided for the storage requirements also presuppose that variable renewables are first in the dispatch order, ahead all other types of power generation. Priority dispatch is the economic basis for investment in utility-scale solar photovoltaic and wind projects. The curtailment rates or storage rates will be significantly higher with the priority dispatch of other types of power. This case has not been calculated because it would involve a lack of investment in solar and wind in the first place. With decreasing storage costs, as projected by Bloomberg (2019)[71], interconnections might become less economically favourable than batteries. This would increase even further the economic advantage of decentralized solar photovoltaics close to the electricity demand over centralized coal or gas power plants concentrated in the north and south of the country.

Table 35 gives an overview of the estimated storage capacity requirements for both RENEWABLES scenarios. The majority of storage facilities will be required in the Mekong Delta because this regions has Viet Nam's largest demand and a significant proportion of the offshore wind generation is concentrated here. For the whole of Viet Nam, the required storage capacity to avoid curtailment under the RE1 scenario will be 4.5% of the total variable generation in 2050, and 10.9% under the RE2 scenario. However, there are significant regional differences. To remain within the economic curtailment range, storage will be required in six of the eight regions under both scenarios. For the whole of Viet Nam, the simulation of the renewable power generation in scenarios RE 1 and RE2 leads to storage requirements of 9.3 TWh/a and 33.4 TWh/a, respectively, with installed input/output capacities of 10 GW and 35 GW, respectively. The requirement for utility-scale storage will occur between 2030 and 2050. The storage demand will vary significantly and will be a function of the regional distribution of variable power generation and the extent to which the regions can exchange load via interconnections.

However, an expansion of the electricity network as demand increases is unavoidable in any case. To reduce the storage requirement and increase the load transfer options for Viet Nam, UTS-ISF suggests a north–south offshore wind link (section 7.1.4). The optimization of the storage demand and interconnections requires further research and is beyond the scope of this analysis.

[71] Bloomberg (2019), A Behind the Scenes Take on Lithium-ion Battery Prices, Logan Goldi-Scot, BloombergNEF, March 5 2019, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

5.6.1 EXAMPLES OF RESIDUAL LOAD

To visualize the simulation results of the UTS-ISF [R]E 24/7 model, we plotted four charts with supply and demand patterns over a one week period. The simulations of solar photovoltaic and onshore and offshore wind farms are based on meteorological data for 2015.

Figure 36 shows the power supply situation under the RE2 scenario in 2030 for the Red River Delta region during for one week in August. The majority of the power supplied during this week comes from coal and gas, whereas solar photovoltaic and wind make only minor contributions. The region is almost entirely self-sufficient with regard to electricity generation, and only minor amounts have been imported. In the figure, imported electricity is the white field between the red load curve and the black coal generation.

Figure 36: Red River Delta—example of very low renewable electricity production (6th to 13th August 2030)

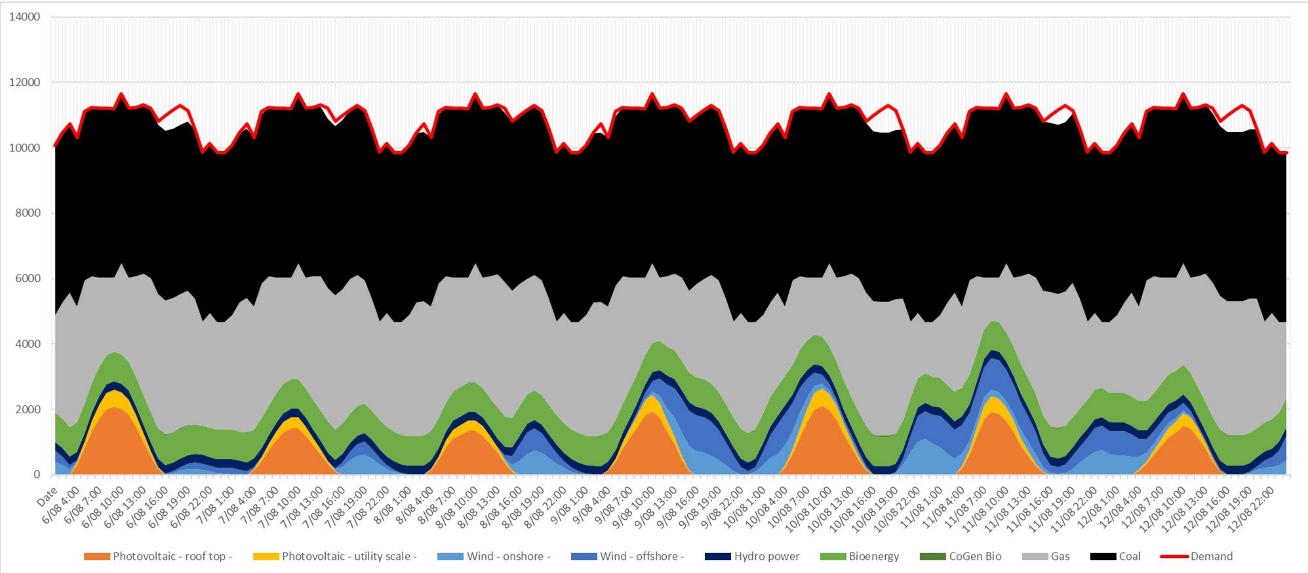


Figure 37 shows the Red River Delta in the same scenario (RE2) and scenario year (2030), but during a high-wind-generation situation in May. The [R]E 24/7 model was set to the priority dispatch of variable renewables across all clusters. The white fields indicate "*unmet load"* and appear when there is an undersupply within the region or an oversupply of wind or solar power in neighbouring regions. In this case, wind power from the North East and/or North Central Coast regions pushed into the Red River Delta and displaced coal generation (see also interconnection, section 5.4).

Figure 37: Red River Delta—example of very high renewable electricity production (16th to 23th May 2030)

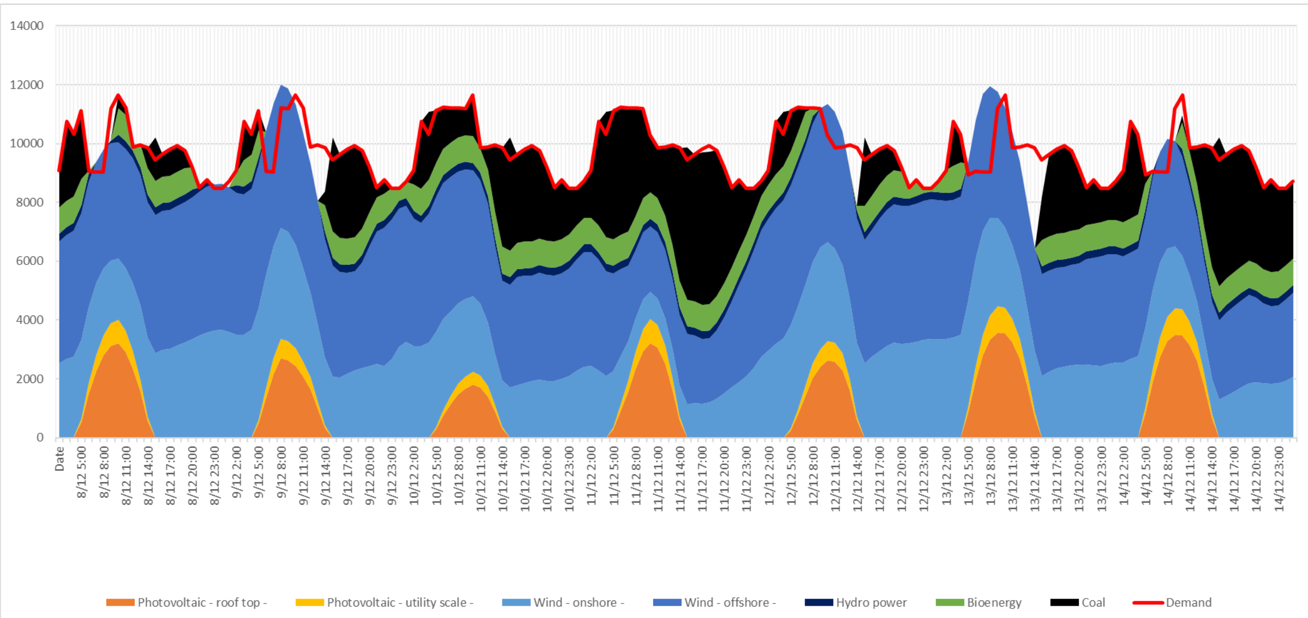
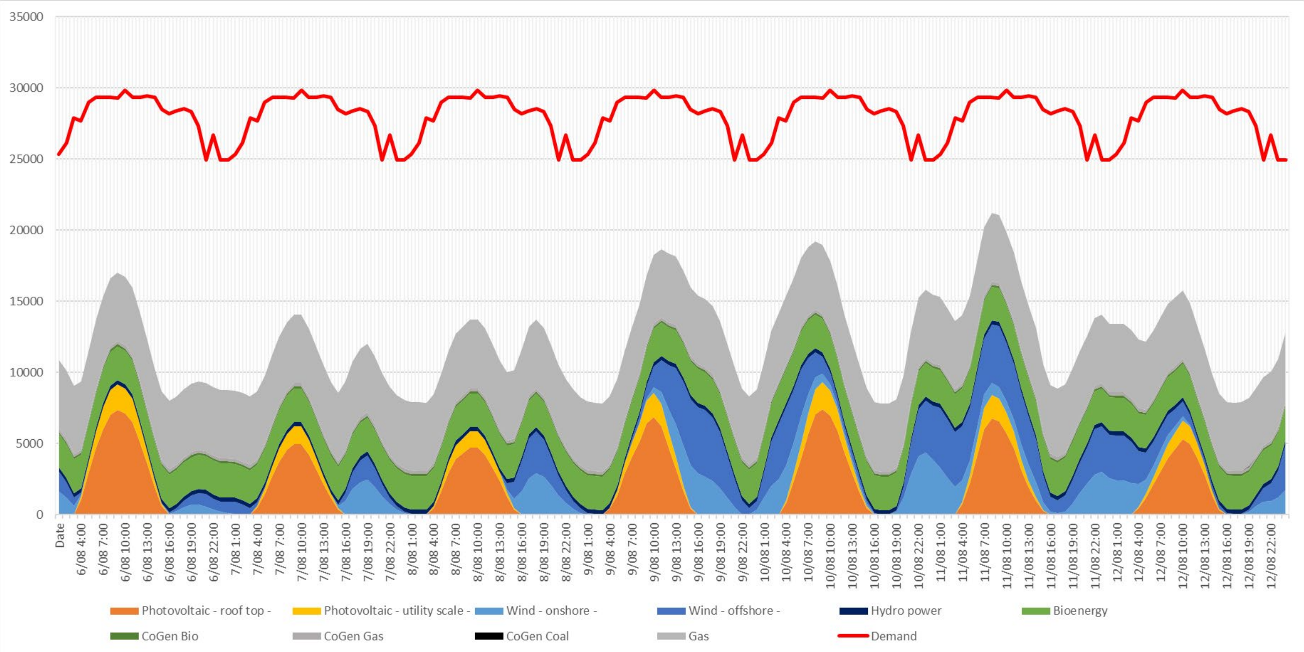


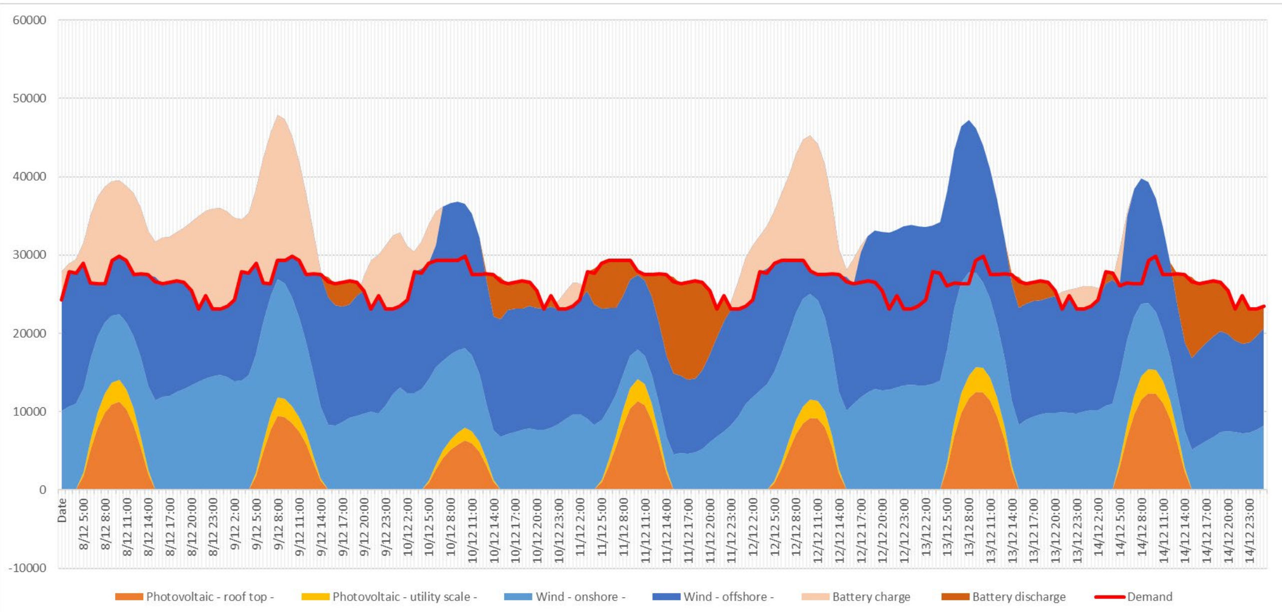
Figure 38 shows the RE2 scenario in 2050 for the Red River Delta region during one week in August, 20 years after the power supply situation shown in Figure 36. Solar photovoltaic, wind, and gas power generation is able to supply the demand in 2030, but due to a significant increase in demand, more than half the electricity must be imported from a neighbouring cluster. Therefore, the exchange capacity must increase between 2030 and 2050. As shown in Figure 33, the maximum import capacity must be 15 GW.

Figure 38: Red River Delta—example of very low renewable electricity production (6th to 13th August 2050)



Finally, a high-renewable electricity generation situation for 2050 is shown in Figure 39 for same week as shown for 2030 on the previous page. Solar photovoltaic and wind supply the entire demand, with some storage requirements (see dark orange fields). Both solar photovoltaic and wind power generate significantly more electricity than is required within the region. Both storage and interconnection capacity are required in this situation. Quantifying the shares of interconnection and storage is beyond the scope of this analysis. However, the future development of storage costs will influence the extent to which interconnections increase. Further optimization of the solar and wind sites—to increase or reduce variable power generation within a region—and demand-side management will also affect the interconnection and storage requirements.

Figure 39: Red River Delta—example of very high renewable electricity production (16th to 23th May 2050)



5.7 SUMMARY: POWER SECTOR ANALYSIS FOR VIET NAM

Both RENEWABLES scenarios prioritize the use of Viet Nam's renewable energy resources to reduce its dependence on energy importation and to utilize local resources. Viet Nam will significantly increase its power demand under each power generation scenario. Therefore, power grids must expand, and power generation must increase as the load increases, under both a conventional power generation pathway and a renewable-power-dominated pathway.

However, renewable-energy-dominated power generation requires a different infrastructural design than a fossil- and nuclear-power-dominated future. To harvest Viet Nam's offshore wind and solar resources, the power grid must be able to transport large loads from the coast further north and inland, whereas decentralized power will shoulder a significant part of the residential sector demand. Offshore wind requires transmission lines to the load centres of Viet Nam. UTS-ISF suggests that an offshore wind link along the coastline of Viet Nam be designed, which would also function in long-distance transmission from and towards the load centres at the northern and southern ends of the country.

In 2050, the majority of dispatch power will come from gas power, which may be operated with hydrogen and/or synthetic fuels after 2040. Viet Nam has abundant renewable energy resources, which could supply, with the currently available technologies, all the renewable electricity required to produce fuels, and even to export renewable fuels. However, more research is required to assess how existing gas pipelines in Viet Nam can be converted to renewable fuel pipelines and to identify the optimal locations for the production of renewable fuels.

6 VIET NAM: SENSITIVITY ANALYSIS

The scenarios documented in Chapter 5 were developed with the Long-Term Energy (2.2) and [R]E 24/7 models (2.3). Neither methodology is a cost optimization models. Instead, the long-term energy model computes holistic energy scenarios for countries and/or regions and analyses the interactions between the power sector and the transport, building, and industry sectors—including heating. The [R]E 24/7 model is a power sector analysis and simulates the demand and supply with 1 hour resolution within the interactions of up to eight sub-regions.

6.1 SENSITIVITY ANALYSIS—GENERATION AND CAPACITY

The open-source model *OSeMOSYS* (Howells et al., 2011[72]; section 4.5) was used to undertake a sensitivity analysis of the power generation mix. This analysis focuses on power generation and does not include heating or transport. The demand, in terawatt hours per year, is the exogenous input. The three coal pathways *OLD PLAN* (a), *NEW NORMAL* (b), and *FACTOR THREE* (c) are used in three of the six OSeMOSYS scenarios.

The following scenarios were calculated:

1. REFERENCE OSeMOSYS (REF OS):

   The coal pathway and electricity demand are the same as in the REFERENCE Long-Term scenario (REF LT), but the renewable and gas capacities are cost optimized, and further investment costs for various technologies are assumed. The cost assumptions are documented in 3.6.

2. RENEWABLES 1 OSeMOSYS (RE1 OS):

   The coal pathway and electricity demand are similar to those in RENEWABLES 1 Long Term (RE1 LT), but the renewable and gas capacities are cost optimized with the open-source model.

3. RENEWABLES 2 OSeMOSYS (RE2 OS):
   The coal pathway and electricity demand are similar to those in RENEWABLES 2 Long Term (RE2 LT), but the renewable and gas capacities are cost optimized with the open-source model.

4. OSeMOSYS $10 ($10CP):
   The installed coal capacity in 2020 and the electricity demand over the entire modelling period are the same as in REFERENCE Long Term (REF LT). The only constraint in this scenario is a carbon price of US$10 per ton CO_2.

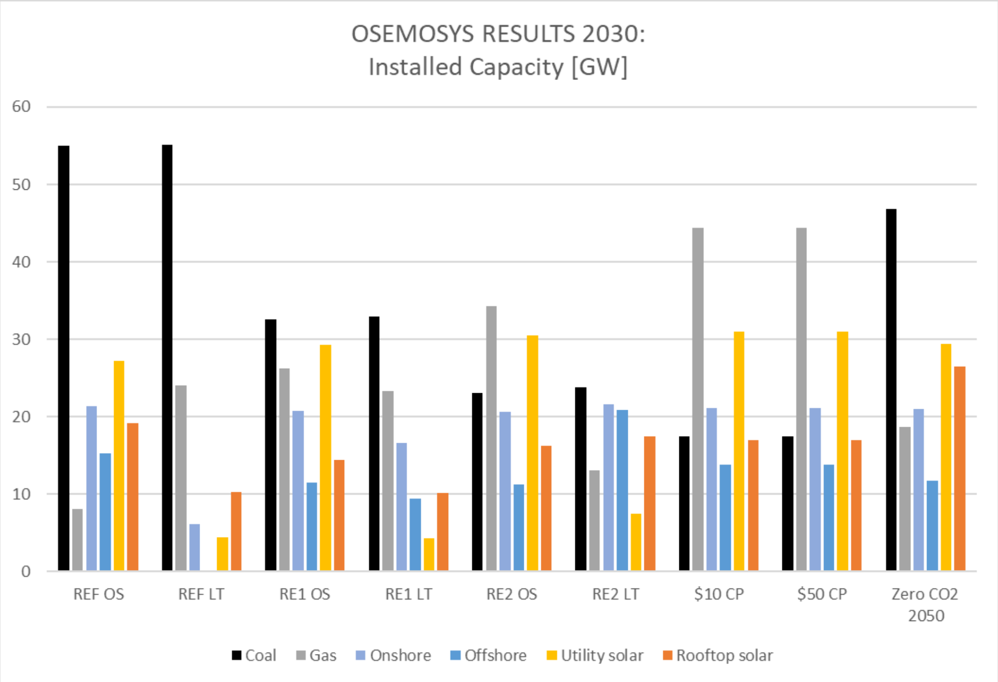
5. OSeMOSYS $50 ($50CP):
   The installed coal capacity in 2020 and the electricity demand over the entire modelling period are the same as in REFERENCE Long Term (REF LT). The only constraint in this scenario is a carbon price of US$50 per ton CO_2.

6. Zero CO_2:

   The installed coal capacity in 2020 and the electricity demand over the entire modelling period are the same as in REFERENCE Long Term (REF LT scenario). The only constraint in this scenario is to achieve zero CO_2 in 2050.

[72] Howells et al., 2011. OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. Energy Policy, 39 (10), pp. 5850-5870.

Figure 40: Viet Nam—Installed capacity under various scenarios (2030)



Differences between Long-Term/[R]E 24/7 and OSeMOSYS calculations
[R]E 24/7 generates a load curve with a resolution of 8760 hours per year based on bottom-up demand analyses. The OSeMOSYS mode uses a simplified load curve based on an actual load curve from Viet Nam (2018) for three seasons (winter, summer, shoulder) for 12 hours a day (3 h in the morning, noon, afternoon, and night). This leads to a minor difference in the calculated total annual demand of plus 7% for the OSeMOSYS results.

The construction rates for wind and solar generation technologies are significantly more rapid in the OS scenarios than in the LT scenarios. This reflects the deliberate staged construction process incorporated into the LT modelling. To avoid boom and bust cycles and encourage a sustainable construction industry for renewables, construction is staged over decades, resulting in similar levels throughout the whole modelling period, and without early periods of rapid growth and periods of industrial stagnation in later years. The OS model lacks this level of sophistication and simply detects the most cost-effective approach, without taking into account externalities such as market design considerations.

At first glance, the zero CO_2 scenario provides counterintuitive results and is instructive from a policy design perspective. Therefore, it was included in this report for the lessons it provides. The only constraint applied in this scenario is the requirement for carbon emissions to be zero in 2050. In the intervening years, the model seeks only the most cost-effective solution, with no constraints. This leads to the use of large amounts of coal in the year 2030 because coal is still the cheapest option between the reference year and that year if the infrastructure requirements (such as coal ports and more transmission capacity) arising from centralized power generation are not taken into account. Later in the modelling period, coal starts to drop and by 2050, the energy mix consists entirely of renewable energy technologies. Should policy makers incorporate an emissions limit, something progressive with incremental targets is recommended.

As can be seen in Figure 33, coal tends to be maximized within the given constraints. This is attributable to the aforementioned cost competitiveness of coal relative to other generation technologies. Beyond 2030, with the drop in solar and wind prices, renewable energy will start to become more dominant. Gas will play a major role in the lead up to 2030 when constraints are imposed on coal, such as in the carbon price scenarios. In the carbon price scenarios, the greater carbon efficiency of gas will lead to a far greater proportion of gas over coal because the inefficiency of coal will entail a large financial penalty. As one would expect, renewables will play a large role in these scenarios.

The installed capacities for the nine different scenarios vary significantly, as shown in Figure 33. Whereas the coal capacity is an exogenous input based on the current situation in Viet Nam (described in section

5.7), all other capacities in the OSEMOSYS scenarios have been cost optimized. The cost projections for the investment costs in power generation are shown in Table 16 and the fuel costs are shown in Table 18.

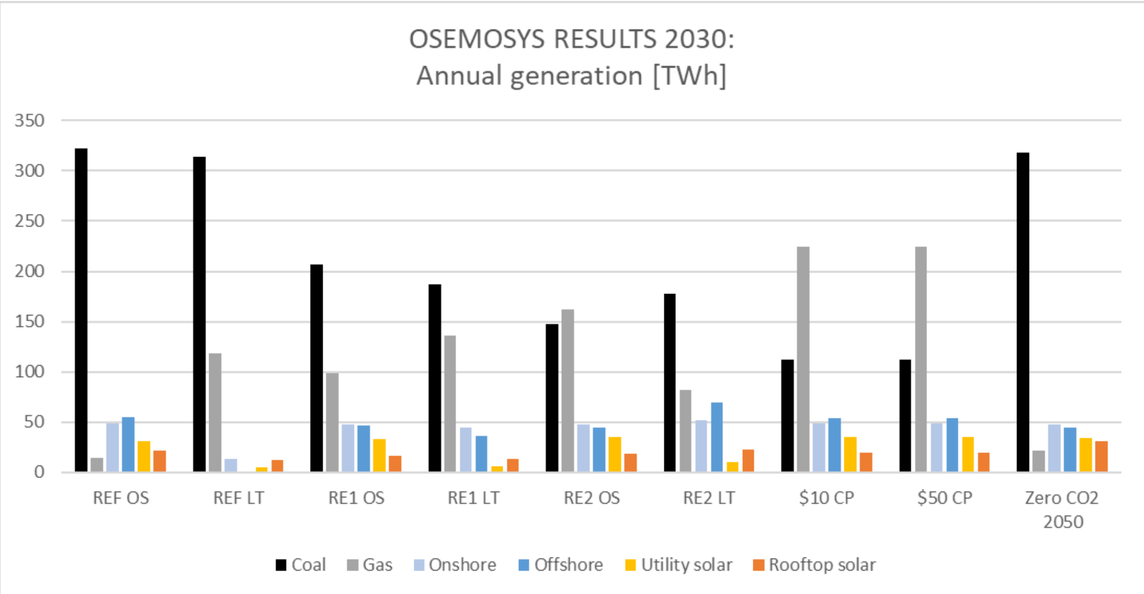
The comparison of the REF scenario, the RE1 and RE2 scenarios calculated with OSeMOSYS, and the [R]E 24/7 LT scenario model shows that:

- total solar and wind capacities for RE1 and RE2 are 33% and 49%, respectively of the total installed capacity by 2030;
- gas capacities in the OSEMOSYS results are significantly lower than in the [R]E 24/7 LT model.

In terms of annual generation, as shown in Figure 30, the key observations are:

- the minimum annual generation from solar photovoltaics will be 17 TWh/a, whereas the average across all scenarios will be 44 TW/a. The highest generation shares (55 TWh per year) appear in both carbon price scenarios ($10 CP and $50 CP) and in Zero CO_2 OS (57 TWh/a), which are all calculated with OSeMOSYS.
- average wind electricity generation across all scenarios will be 89 TWh/a in 2030, with the lowest amount in the REF LT scenario (17 TWh/a) and one of the highest in the REF OS scenario (104 TWh/a).

Figure 41: Viet Nam: Annual generation under various scenarios (2030)



The 2030 analysis shows two key trends:

- Solar photovoltaic and wind power will represent around 40% of the total capacity and provide about one quarter of Viet Nam's electricity in all nine scenarios, including the REF scenarios with enforced high shares of coal.
- Gas capacities will differ significantly across all scenarios and will be dependent on the coal capacity (see section 3.7.1). This indicates that gas will compete predominantly with coal and to a lesser extent with renewables under cost constrains. This does not include infrastructural costs, such as coal loading facilities, harbours, and pipelines.

The 2030 trends continue and accelerate to 2050:

- Total solar and wind capacities for RE1 and RE2 in both models will be around 80% (81% and 76%, respectively) of the total installed capacity by 2030.
- Average share of the total generation capacity for solar photovoltaics and wind combined across all scenarios will be 77% (Figure 42).

Figure 42: Viet Nam: Installed capacity under various scenarios (2050)

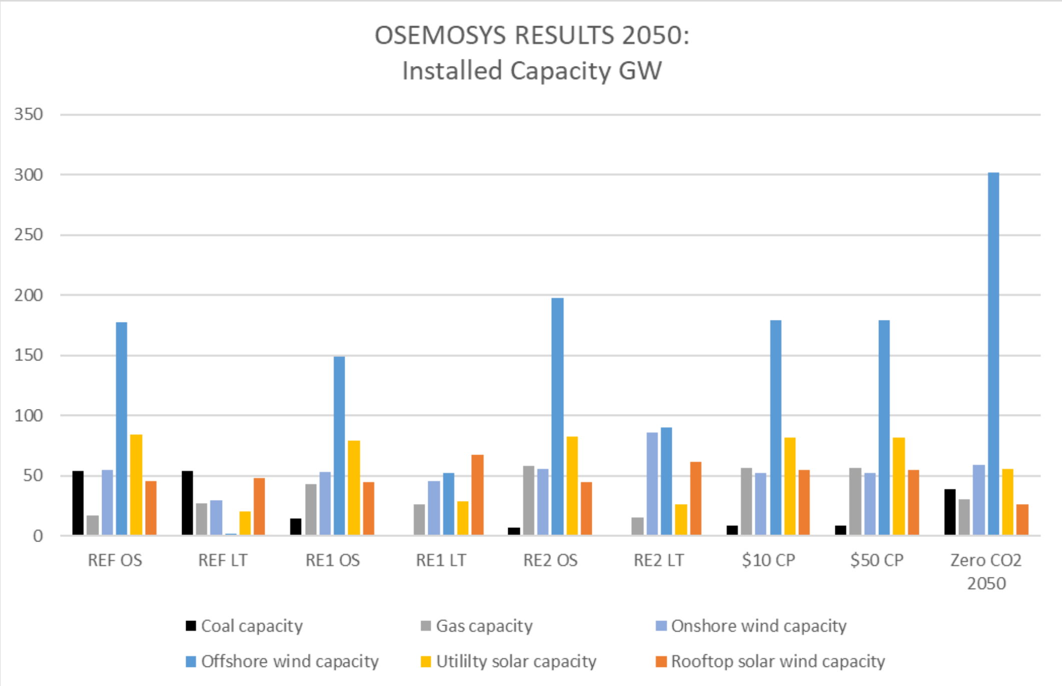
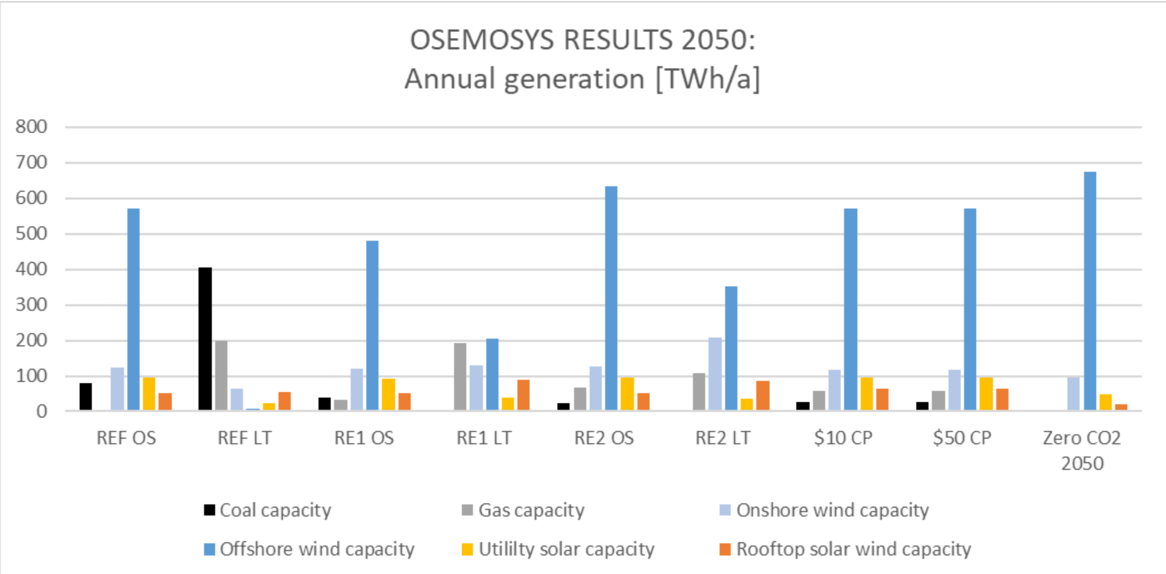


Figure 43: Viet Nam: Annual electricity generation under various scenarios (2050)

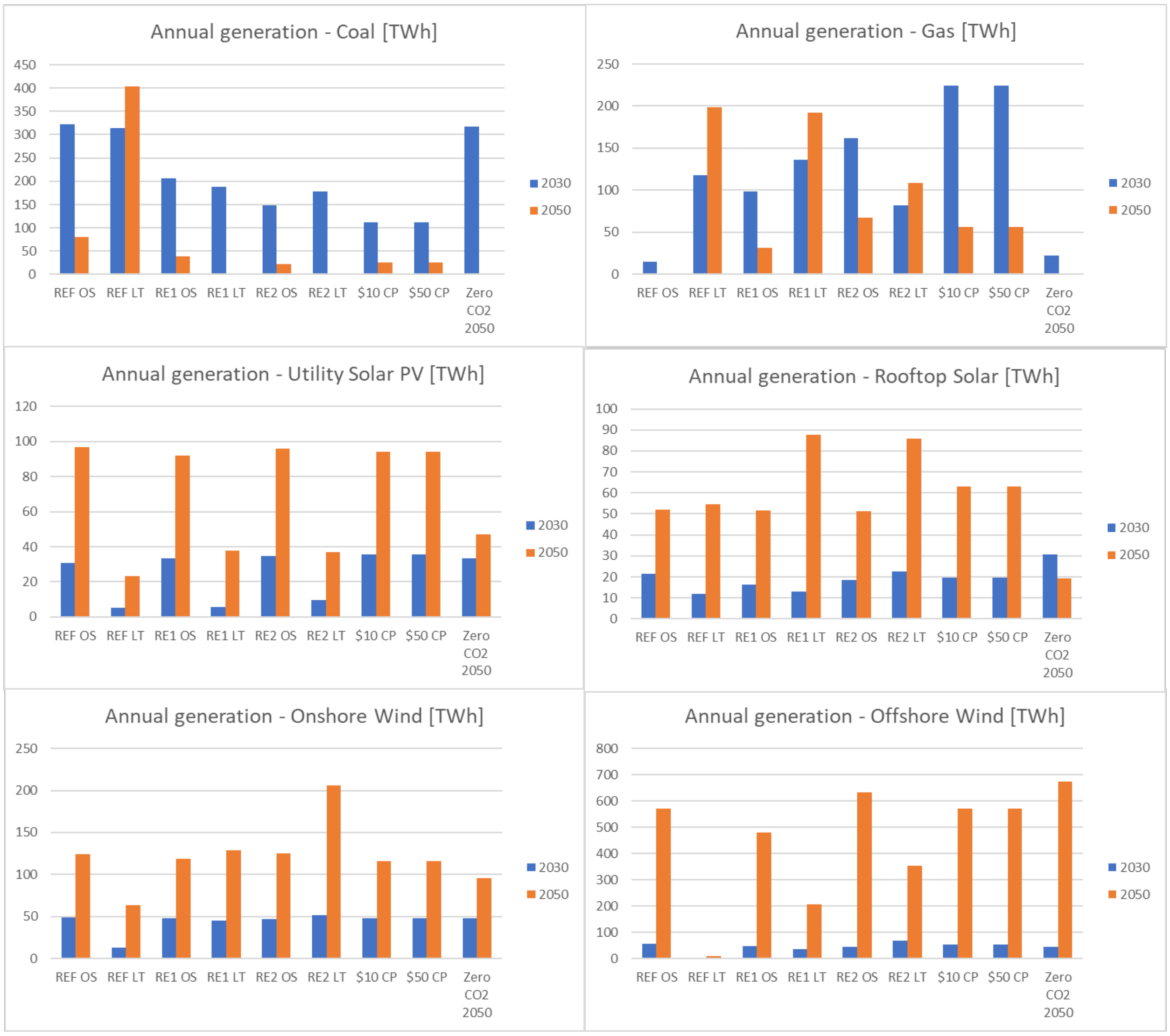


In terms of annual electricity generation, our results show that wind generation—especially offshore wind—will dominate (as shown in Figure 43).

The average wind electricity generation across all scenarios will be 202 TWh/a in 2030, with the lowest amount in the REF LT scenario (71 TWh/a) and the highest in the REF OS scenario (695 TWh/a). The reason for this lies mainly in the different calculation methodologies for both models. Whereas [R]E 24/7 LT develops the scenario across the entire time period, the cost-optimization model OSeMOSYS tries to find the generation mix with the lowest costs. Therefore, the main result is not the actual amount of calculated generation for the year, but that under cost optimization proposes, wind energy.

In summary, Figure 44 compares the annual power generation for each technology across the nine scenarios. The results clearly show that offshore wind is by far the predominant technology, followed by onshore wind and solar photovoltaics, across all scenarios. This confirms the generation mix calculated with [R]E 24/7 LT and the results presented in Chapter 4and 5. However, the results do not show a clear result for gas. The amount of gas in each scenario is significantly dependent upon the carbon price, the reliability of the fuel supply, fuel prices, and whether gas will be used for dispatch generation (to be later operated with synthetic gas and/or hydrogen infrastructure) or as a leading supply technology with a high capacity factor. If the latter is the case, gas has economic disadvantages, whereas gas power plants used as dispatch plants and to reduce storage requirements show better economic results. If gas power plants are increasingly utilized as dispatch power plants, the market framework must move away from generation-based tariffs to service-based tariffs, making a quick reaction time as valid as the generation itself.

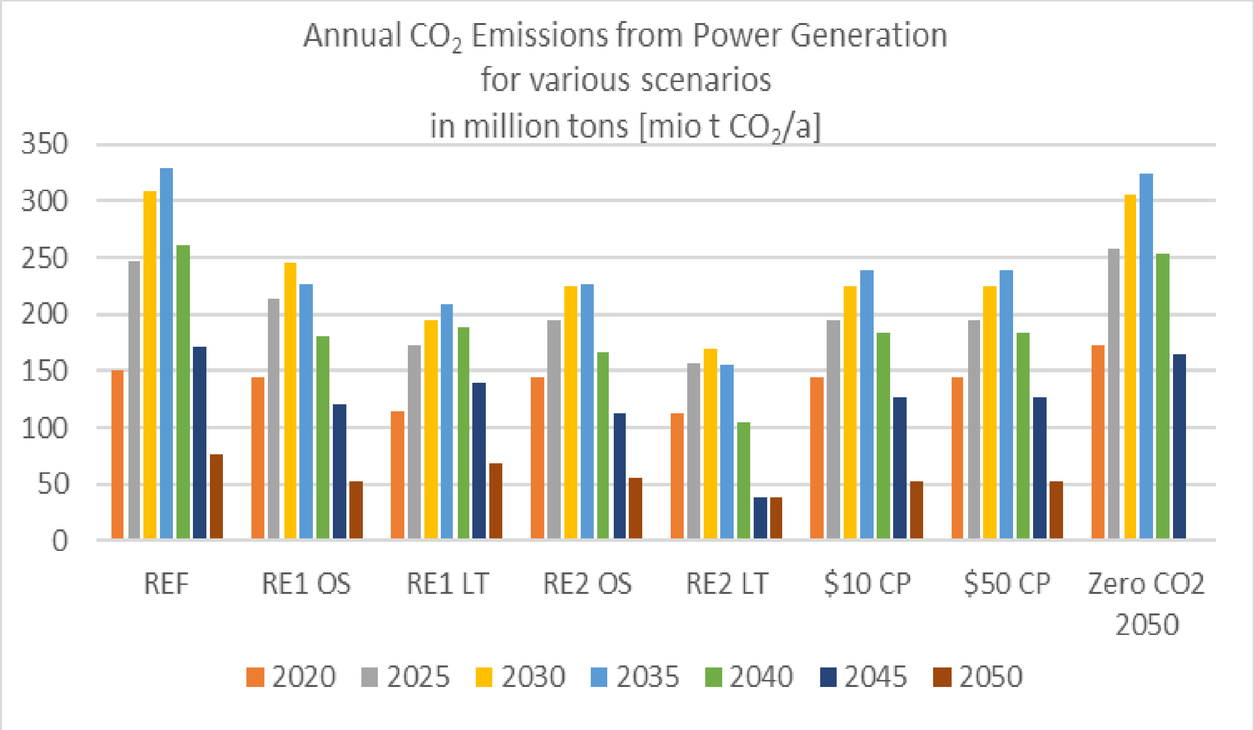
Figure 44: Viet Nam: Comparison of annual generation in 2030 versus 2050 under various scenarios



6.2 VIET NAM: POWER SECTOR EMISSIONS

The CO_2, SO_x, NO_x, and CH_4 emissions across all scenarios were compared. The LT/[R]E 24/7 model does not include calculations for SO_x, NO_x, or CH_4 emissions, so the LT scenarios are not included in Figure 46. The OSeMOSYS model only calculates CO_2 emissions for the power sector and not for any other sector—transport, heating, or industry. Thus, the CO_2 emissions shown in Figure 45 are for the power sector only. The total energy-related CO_2 emissions for Viet Nam are provided in section 4.6 and Figure 23.

Figure 45: Viet Nam: Comparison of annual CO_2 emissions from power generation under various scenarios



SO_x, NO_x, and CH_4 emissions
SO_x, NOx, and CH_4 emissions are directly linked to the chosen generation technologies. Therefore, those scenarios with the highest shares of renewables—excluding bio energy—will have the lowest emissions, not just for energy-related CO_2, but also for air pollutants. These data are from the Australian National Pollution Inventory database (ANPI 2019)[73].

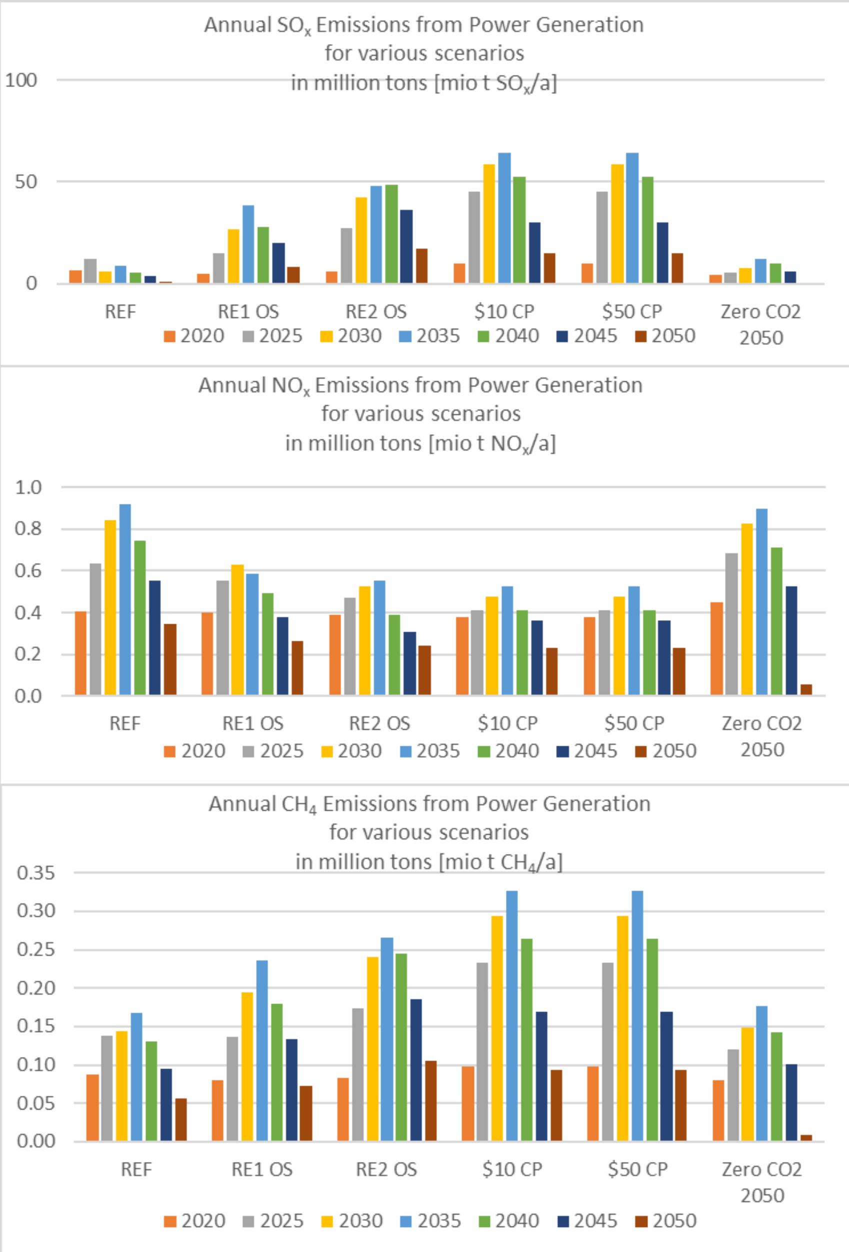
Table 36: Emission factors for SO_x, NO_x, and CH_4

	CO_2		CH_4		N_2O		SO_x	
	kg/GJ	mt/PJ	kg/GJ	mt/PJ	kg/GJ	mt/PJ	kg/GJ	mt/PJ
Coal	90	0.09	0.03	0.00003	0.2	0.0002	0.63333	0.0006333
Oil	73.6	0.0736	0.04	0.00004	0.2	0.0002		
Gas (LNG)	51.4	0.0514	0.1	0.0001	0.03	0.00003	25	0.025
Biomass	0	0	0.2	0.0002	1.2	0.0012		

Notably, the scenarios with the highest gas shares have the highest SO_x and methane (CH_4) emissions. Methane is a high-impact green house gas.

[73] A NPV (2019), page 39, http://www.npi.gov.au/system/files/resources/d3fd3837-b931-e3e4-e105-98a9f7048ac6/files/elec-supply.pdf

Figure 46: Viet Nam: Comparison of annual SO_x, NO_x, and CH_4 emissions from power generation under various scenarios



6.3 VIET NAM: INVESTMENT COSTS FOR POWER GENERATION—A COMPARISON

The OSeMOSYS and LT/[R]E 24/7 models operate with different methodologies, so the comparability of their results should only be considered in terms of the resulting electricity generation mix. However, the input values for the technology-specific investment costs and fuel costs are identical (see Table 8 and Table 10). Furthermore, the assumed cost of capital is the same. In all cases, the weighted average cost of capital (WACC) is been assumed to be 10%. Therefore, a comparison of the results provides interesting insights.

Figure 47 provides an overview of the total investment costs for 2020, 2030, 2040, and 2050. It is important to note that the costs for all years (2015–2050) cannot be added up to a total value for the OSeMOSYS model, because optimization is applied to each individual year. In the case of *Zero CO_2 2050*, optimization with the constraint 'no energy-related CO_2 emissions' is for the year 2050. Therefore, the power generation mix changes significantly from 2040 to 2050 and all fossil-fuel-based generation is replaced with the most economic form of electricity generation, which is offshore wind and solar photovoltaics in 2050.

Figure 47: Viet Nam—Investment costs in power generation under various scenarios

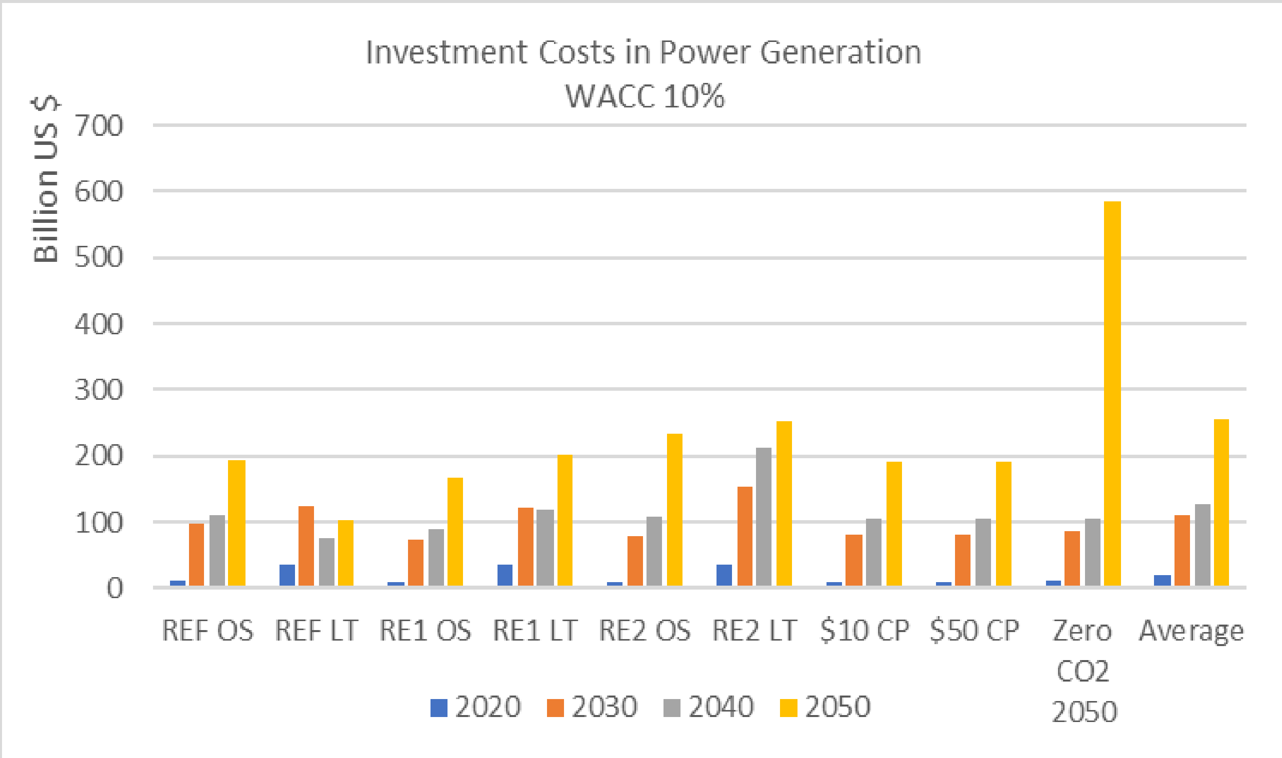


Table 37 shows the calculated values for the investment costs in all scenarios and the average costs across all scenarios. There are significant differences between all the scenarios, but a common trend is also apparent. The differences are mainly attributable to the time of investment in new (mainly renewable) power capacities. The LT takes a holistic approach, including a more sustainable development market for the local solar and wind industry in terms of annual new installations over the whole time period. Therefore, large variations from one year to the next are avoided. The aim is to build up an industry with stable and annually increasing market volumes rather than “boom and bust” cycles. The aim of cost optimization is to achieve the most cost-efficient electricity generation for each individual year. However, the average investment costs will increase over time and most scenarios are within the range of the average.

Table 37: Investment costs in US$ million for 2020, 2030, 2040, and 2050

Capital Costs in US$ million	2020	2030	2040	2050
REF OS	11,995	98,169	109,931	193,651
REF LT	36,900	124,200	74,700	102,700
RE1 OS	9,347	74,634	90,192	166,235
RE1 LT	34,800	121,500	117,600	203,000
RE2 OS	8,901	77,626	108,379	233,272
RE2 LT	36,800	154,500	213,800	252,100
$10 CP	9,194	81,845	105,677	190,674
$50 CP	9,194	81,845	105,677	190,674
Zero CO_2 2050	12,983	87,980	105,475	583,598
Average	20,344	110,029	126,303	256,389

Furthermore, the different overall investment costs for each scenario are a function of the total power generation and the three different demand projections, and do not take into account the fuel cost savings for gas and coal or oil, especially in the transport sector when electric mobility replaces oil for gasoline.

7 EMPLOYMENT ANALYSIS

7.1 METHODOLOGY: EMPLOYMENT ANALYSIS

The methodology outlined in this section has two dimensions: total employment in the energy sector and occupational breakdown. The methodology used to analyse the total employment in the energy sector was first developed in 2009 for the Greenpeace Energy [R]evolution study (see Rutovitz et al., 2015; Rutovitz and Atherton, 2009). This methodology has been updated for a global energy scenario project by UTS-ISF, in partnership with the German Aerospace Centre (DLR), Institute for Engineering Thermodynamics, Department of Systems Analysis and Technology Assessment (STB), and funded by the Leonardo DiCaprio Foundation (Teske, 2019) and the German Greenpeace Foundation (Greenpeace Umweltstiftung).

This study projects the total employment in the energy sector against three scenarios: the RENEWABLES 1, RENEWABLES 2, and REFERENCE scenarios.
Employment is projected for each scenario from 2015 until 2050 for Viet Nam. The calculations are based on a series of employment multipliers and the projections for energy use and capacity. Only direct employment is included—jobs in construction, manufacturing, operations and maintenance, fuel supply associated with electricity generation, and direct heat provision. An overview of the total employment methodology is given in Figure 48.

Figure 48: Total employment calculation: methodological overview

Manufacturing (for local use) = MW installed per year in region x Manufacturing employment factor X Regional job multiplier for year x % local manufacturing

Manufacturing (for export) = MW exported per year x Manufacturing employment factor X Regional job multiplier for year

Construction = MW installed per year x Construction employment factor X Regional job multiplier for year

Operation and maintenance = Cumulative capacity x O&M employment factor X Regional job multiplier for year

Fuel supply (nuclear) = Electricity generation x Fuel employment factor X Regional job multiplier for year

Fuel supply (coal, gas and biomass) = Primary energy demand plus exports x Fuel employment factor (always regional for coal) X Regional job multiplier for year x % of local production

Heat supply = MW installed per year x Employment factor for heat X Regional job multiplier for year

Jobs in region = Manufacturing + Construction + Operation and maintenance (O&M) + Fuel + Heat

Employment factors at 2020, 2030, or 2050 = 2015 employment factor x Technology decline factor [number of years after 2015]

The main inputs for the quantitative employment calculations are outlined below.

7.1.1 FOR EACH SCENARIO (REF, RE1, AND RE2):

- the electrical and heating capacity that will be installed each year for each technology;
- the primary energy demand for coal, gas, and biomass fuels in the electricity and heating sectors;
- the amount of electricity generated per year from nuclear power, oil, and diesel.

7.1.2 FOR EACH TECHNOLOGY:

- 'employment factors', or the number of jobs per unit of capacity, separated into manufacturing, construction, operation, and maintenance, and per unit of primary energy for fuel supply;
- for the 2020, 2030, and 2050 calculations, a 'decline factor' for each technology, which reduces the employment factor by a certain percentage per year. This reflects the fact that employment per unit decreases as technology efficiencies improve.

7.1.3 FOR VIET NAM—COMPARED WITH OECD:

- the percentage of local manufacturing and domestic fuel production in each region, to calculate the proportions of jobs in manufacturing and fuel production that occur in that region;
- the percentage of world trade in coal and gas fuels, and the traded renewable components that originates in each region;
- a 'regional job multiplier', which indicates how labour-intensive the economic activity is in that region compared with the OECD, which is used to adjust the OECD employment factors because local data are not available;
- a set of 'decline factors' for each technology, based on the projected costs for that region in the REF scenario.

The figures for the increase in electrical capacity and energy use for each scenario are multiplied by the employment factors for each of the technologies, and then adjusted for the regional labour intensity and the proportion of fuel or manufacturing that occurs locally.

A range of data sources were used for the model inputs, including the International Energy Agency, US Energy Information Administration, BP Statistical Review of World Energy, US National Renewable Energy Laboratory, International Labour Organization, World Bank, industry associations, national statistics, company reports, academic literature, and the UTS-ISF's own research.

These calculations only take into account direct employment; for example, the construction team required to build a new wind farm. They do not include indirect employment; for example, the extra services provided in a town to accommodate the construction team.

The calculations do not include jobs in energy efficiency because this is beyond the scope of this research. The large number of assumptions required to make these calculations means that the employment numbers are only estimates, especially for regions where few data exist. However, within the limits of data availability, the figures presented are representative of employment levels under the given scenarios.

7.1.4 EMPLOYMENT FACTORS

Employment factors were used to calculate the number of jobs required per unit of electrical or heating capacity, or per unit of fuel. The employment factors differ depending on whether they involve manufacturing, construction, operation and maintenance, or fuel supply. Information about these factors usually comes from OECD countries because that is where most data are collected, although local data were used wherever possible. For the job calculations in non-OECD regions, regional adjustments were made when a local factor was not available. The employment factor for China was used for Viet Nam in our calculations, as shown in Table 38.

Table 38: Summary of employment factors

	Construction/ installation	Manufacturing	Operations & maintenance	Fuel—Primary energy demand
	Job years/ MW	Job years/ MW	Jobs/MW	
Coal	11.4	5.1	0.14	Regional
Gas	1.8	2.9	0.14	Regional
Nuclear	11.8	1.3	0.6	0.001 jobs per GWh final energy demand
Biomass	14.0	2.9	1.5	29.9 Jobs/PJ
Hydro, large	7.5	3.9	0.2	
Hydro, small	15.8	11.1	4.9	
Wind onshore	3.0	3.4	0.3	
Wind offshore	6.5	13.6	0.15	
Photovoltaic	13.0	6.7	0.7	
Geothermal	6.8	3.9	0.4	
Solar thermal	8.9	4.0	0.7	
Ocean	10.3	10.3	0.6	
Geothermal—heat	6.9 jobs/MW (construction and manufacturing)			
Solar—heat	8.4 jobs/MW (construction and manufacturing)			
Nuclear decommissioning	0.95 jobs per MW decommissioned			
Combined heat and power	CHP technologies use the factor for the technology, i.e., coal, gas, biomass, geothermal, etc., increased by a factor of 1.5 for O&M only.			

7.1.5 COAL FUEL SUPPLY

The employment factors for coal are particularly important at the regional level, because employment per ton varies significantly across world regions and because coal plays a significant role in energy production in many countries. In Australia and the USA, coal is extracted at an average rate of more than 9,000 tonnes per person per year, whereas in Europe, the average coal miner is responsible for less than 1,000 tonnes per year. China has relatively low per capita productivity at present, with 650 tonnes per worker per year, but the annual increases in productivity are very high. India and Eurasia have significantly increased their productivity since a similar analysis was performed in 2015. Local data were also used for gas extraction in every region except India, the Middle East, and non-OECD Asia. The calculation of coal and gas employment per petajoule (PJ) was based on data from national statistics and company reports, combined with production figures from the BP Statistical Review of World Energy 2018 (BP-SR 2018) or other sources. Data were collected for as many major coal-producing countries as possible, and coverage was obtained for 90% of the world coal production.

Table 39: Employment factors used for coal fuel supply (mining and associated jobs)

	Employment factor Jobs per PJ	Tonnes per person per year (coal equivalent)
World average	36.2	943
China	52.9	645

7.1.6 REGIONAL ADJUSTMENTS

The employment factors used in this model for energy technologies other than coal mining were usually for OECD regions, which are typically wealthier than other regions. A regional multiplier was applied to make the jobs per MW more realistic for other parts of the world. In developing countries, there are generally more jobs per unit of electricity because those countries have more labour-intensive practices. The multipliers change over the study period, consistent with the projections for GDP per worker. This reflects the fact that as prosperity increases, labour intensity tends to fall. The multipliers are shown in Table 40.

Table 40: Regional multipliers used for the quantitative calculation of employment

	2015	2020	2030	2040	2050
OECD (North America, Europe, Pacific)	1.0	1.0	1.0	1.0	1.0
Latin America	3.4	3.4	3.4	3.1	2.8
Africa	5.7	5.7	5.5	5.2	4.8
Middle East	1.4	1.5	1.4	1.4	1.2
Eastern Europe/Eurasia	2.4	2.4	2.2	2.0	1.8
India	7.0	5.5	3.7	2.7	2.2
Developing Asia	6.1	5.2	4.1	3.5	3.1
China	2.6	2.2	1.6	1.3	1.2

Source: Derived from ILO (2013) Key Indicators of the Labour Market, eighth edition software, with growth in GDP per capita derived from IEA World Energy Outlook 2018 and World Bank data.

For this analysis, the regional factors and multipliers for China were used for Viet Nam because no local data were available.

7.2 RESULTS: EMPLOYMENT ANALYSIS

Employment development has been calculated based on the methodology described and the results for the long-term energy scenario documented in Chapter 4. The figures represent quantitative estimates and have been compared with the current workforces in Viet Nam when information was available.

Table 41 shows the projected development of employment in the energy sector of Viet Nam. Under the REF scenario, while employment in the coal sector will increase by about 100,000 jobs, employment in the renewables sector will decrease. The total number of jobs in the energy sector will increase from around 250,000 to almost 380,000 jobs.

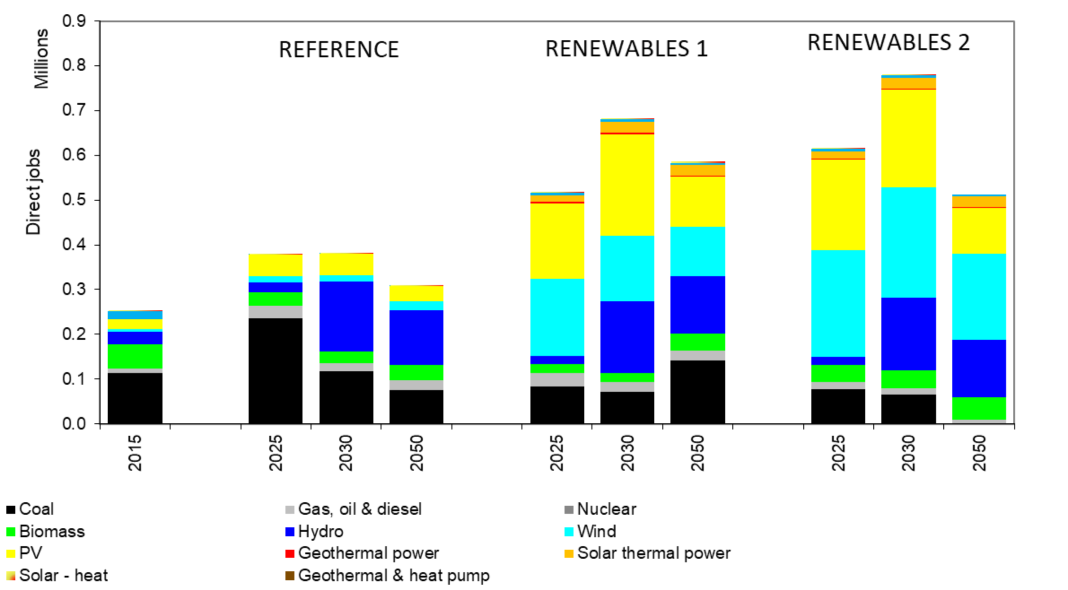
Table 41: Viet Nam: Development of employment in the energy sector

Viet Nam: Development of Employment under Three Scenarios										
		REFERENCE			RENEWABLES 1			RENEWABLES 2		
Thousand jobs	2015	2025	2030	2050	2025	2030	2050	2025	2030	2050
Coal	113	236	117	76	84	71	141	78	65	0
Gas, oil & diesel	10	28	18	21	28	23	23	17	15	10
Nuclear	-	-	-	-	-	-	-	-	-	-
Renewable	129	115	245	210	406	587	423	522	699	501
Total jobs	251	378	380	308	519	681	587	616	780	511
Construction and installation	79	146	132	99	81	194	218	122	220	144
Manufacturing	51	82	78	56	308	352	248	352	407	243
Operations and maintenance	18	38	53	77	32	47	72	39	60	95
Fuel supply (domestic)	103	113	118	75	98	87	44	100	92	30
Coal and gas export	-	-	-	-	-	-	-	-	-	-
Total jobs (thousands)	251	378	380	308	519	681	587	616	780	511

Figure 49 shows the changes in job numbers under all scenarios for each technology between 2015 and 2050. Jobs in the REF scenario will increase by 150% and remain at this level throughout 2030, with a slight reduction by 2050.
However, both alternative energy pathways will lead to strong growth in the renewable sector, significantly overcompensating for the losses in the coal industry. The RE1 scenario will double overall employment in the energy sector from 250,000 today to 520,000 by 2025, with a further increase of 130,000 jobs by 2030. Only 14% of the jobs in 2030 will be in the fossil fuel industry, whereas the remaining 86% will be in the renewables industry.

Our analysis shows similar developments under the RE2 scenario: the overall number of jobs in 2025 and 2030 will 100,000 more than under the RE1 scenario. As the development of renewables accelerates under the RE2 scenario, the construction rates will decrease after 2030, so by 2050, there will be around 75,000 fewer jobs than under the RE1 scenario, but still approximately 200,000 more than under the REF scenario.

Figure 49: Total employment in Viet Nam's energy sector in 20205, 2030, and 2050



8 ANNEX

8.1 CONTEXT: REVISION OF VIET NAM'S POWER DEVELOPMENT PLAN

This section provides the context for the collaborative analysis by the Vietnam Initiative for Energy Transition (VIET), a think tank based in Hanoi; the University of Technology Sydney, Institute for Sustainable Futures and the European Climate Foundation.

100% RENEWABLE ENERGY FOR VIET NAM is a proposal for an economically and environmentally sustainable 8th Power Development Plan of the government of Viet Nam.

The Viet Nam Government regularly develops power development plans to ensure a reliable and affordable electricity supply. The 8th iteration is ongoing during the time of writing of this analysis (2019).

The 7th Power Development Plan has been reviewed and the progress has been documented in a paper that we cite in excerpts and summarize in the following section (PDP7rev 2019)[74]:

8.2 ON THE PROGRESS OF POWER PROJECTS IN REVISED POWER DEVELOPMENT PLAN 7

The following text is taken from the original publication.

I. Update on power supply and demand in 2018

> *- The total yield of power generated and purchased in 2018 was 212.9 billion kWh, an increasing of 10.36% compared with 2017.*
>
> *- The total yield of commercial power in 2018 was 192.93 billion kWh, an increase of 10.47% compared with 2017.*
>
> *- The total installed capacity in 2018 was 48,563 MW, including 17,031 MW of hydropower (35.1%), 3,466 MW of renewable energy (7.1%), 18,51 6MW of coal-fired thermal power (38.1%), 8,978 MW of gas and oil power (18.5%), and 572 MW of imported power (1.2%).*
>
> *- The power supply in 2018 remained stable, adequate, and reliable for the local economy.*

II. Power capacity and structure of power sources as per revised Power Development Plan 7 (revised PDP7)

According to the revised PDP7, a total of 116 power projects will be operationalized in the period 2016–2030 (not including renewable energy sources, on which the project has not had its name specified or not been planned), i.e., 43 hydropower, 57 thermal power, 11 renewable energy, three pumped storage hydropower, and two nuclear power projects.

1. The period until 2020

By 2020, the total capacity of power plants will have reached about 60,000 MW, among which large hydropower and pumped storage hydropower will account for about 30.1%, coal-fired thermal power and gas power will make up about 57.6%, renewable power (small hydropower, wind power, solar power, and biomass energy) will represent about 9.9%, and imported power will constitute about 2.4%.

Between 2016 and 2020, a total capacity of 21,651 MW will be operationalized, in which the total capacity of thermal power projects will be 13,845 MW (63.95%), hydropower 4,084 MW (16.86%), and renewable energy 3,722 MW (17.19%).

2. The period until 2025

By 2025, the total capacity of power plants will have reached about 96,500 MW, in which large hydropower and pumped storage hydropower will account for about 21.1%, coal-fired thermal power and gas power will make up about 64.9%, renewable energy (small hydropower, wind power, solar power, and biomass power) will represent about 12.5%, and imported power will constitute about 1.5%.

Between 2021 and 2025, a total capacity of 38,010 MW will be operationalized, in which the total capacity of thermal power projects will be 29,365 MW (77.3%), hydropower and pumped storage hydropower 2,355 MW (6.2%), and renewable energy 6,290 MW (16.5%).

[74] PDP 7rev 2019

3. The period until 2030

By 2030, the total capacity of power plants will have reached about 129,500 MW, in which large hydropower and pumped storage hydropower will account for about 16.9%, coal-fired thermal power and gas power will make up about 57.3%, renewable power (small hydropower, wind power, solar power, and biomass power) will represent about 21%, and imported power will constitute about 1.2%.

Between 2026 and 2030, a total capacity of 36,192 MW will be operationalized, in which the total capacity of thermal power projects will be 14,350 MW (39.6%), hydropower and pumped storage hydropower 2,052 MW (5.7%), renewable power 15,190 MW (42.0%), and nuclear power 4,600 MW (12.7%).

III. Implementation progress of power projects in the revised PDP7

1. Status of load and power supply

*- According to the revised PDP7, the yield of commercial power by 2020 is forecast to be **235 billion kWh** in the base scenario and **245 billion kWh** in the high scenario, with average annual growth rates of commercial power of 10.34% and 11.26%, respectively, in the period 2016–2020 (…)*

- Between 2019 and 2020, about 6,900 MW is expected to be operationalized, in which coal-fired thermal power plants will account for 2,488 MW, hydropower plants (above 30 MW) for 592 MW, and renewable energy projects for about 3,800 MW (solar power about 2,500 MW and wind power 350 MW). The nationwide power demand is likely to be met. However, it will be important to mobilize oil-fired thermal generation of ~1.7 billion kWh in 2019 and 5.2 billion kWh in 2020. Should generating units perform unreliably or the fuel (coal or gas) supply fall short, Viet Nam may encounter power shortages in 2020.

- Between 2021 and 2025, despite the maximization of oil-fired generation, the power network will eventually fail to meet the load demand, and power shortages will occur in the south. The power shortages will increase from 3.7 billion kWh (2021) to 10 billion kWh (2022), peak at about 12 billion kWh (2023), and gradually decline to 7 billion kWh (2024) and 3.5 billion (2025).

- The total capacity of all power sources is likely to be operationalized over the course of 15 years (2016–2030) and is expected to reach about 80,500 MW, over 15,200 MW less than the capacity forecast in the revised PDP7. Power shortages will be primarily observed between 2018 and 2022 (with a total capacity of 17,000 MW). In this period, many power supply projects (mostly thermal power ones) in the south will be postponed to the period 2026–2030. Consequently, in contrast to the 20%–30% backup in the period 2015–2016 and almost no backup in 2018–2019, the power network will suffer from a supply deficiency in the period 2021–2025.

- The total capacity of power sources operationalized in the period 2021–2030 is expected to be about 64,200 MW, which is 10,000 MW less than that provided in the revised PDP7 (72,202 MW).

- The main explanations for the escalation of the power shortage in the south compared with previous calculations are that: (i) the progress of the Lot B and Blue Whale gas projects is delayed by 9–12 months; (ii) the progress of the Kien Giang 1 and 2 thermal power projects is delayed beyond 2030, and they will not be completed in the period 2021–2025 as scheduled; and (iii) the O Mon III project is delayed until 2025. If the Long Phu 1 thermal power project fails to be completed in 2023, as planned, power shortages in the south will be exacerbated between 2024 and 2025.

Table 42: Expected capacities of power sources completed between 2019 and 2030

Year/Period	Total capacity operationalized (MW)		Difference (MW)
	As per the revised PDP7	Post review	
2019	6,230	3,650	-2,580
2020	4,571	3,230	-1,341
Period of 2021–2025	**38,010**	**30,485**	**-7,525**
2021	9,435	4,520	-4,915
2022	10,290	3,890	-6,400
2023	7,185	6,635	-550
2024	5,250	8,170	2,920
2025	5,850	7,270	1,420
Period of 2025–2030	**36,192**	**34,382**	**-1,810**
2026	6,482	7,792	1,310
2027	5,660	6,270	610
2028	7,890	8,340	450
2029	8,950	7,310	-1,640
2030	7,210	4,670	-2,540

2. Investment in power supply development

According to the revised PDP7, the total capacity of operationalized power sources is expected to be 21,650 MW in the period 2016–2020 across the network, 7,185 MW (33.2%) of which will be invested in by EVN and 14,465 MW (66.8%) by other businesses.

There are three types of investment in power supply projects: state-owned enterprises (EVN, PVN, and TKV) as project owners, BOT, and IPP. A review of the progress of 62 projects with a capacity of more than 200 MW showed that 15 projects are on track, whereas the remaining 47 projects are behind schedule or their progress has not been benchmarked against the revised PDP7, as follows: (…)

2.7. Development of renewable energy

As far as renewable energy is concerned, the Prime Minister and MOIT have so far approved the inclusion of 130 solar power projects with a total capacity of about 10,600 MW (more than 8,500 MW) and wind power projects with a total capacity of about 2,000 MW into the plan. What wind power and solar power projects have in common is that they are primarily concentrated at locations of low on-site load demand. Therefore, where utility-scale wind power and solar power projects have been added into the plan, most of their generation capacity must be collected, grid-connected, and transmitted to areas of high load demand. However, the 110–500 kV grid infrastructures in these areas do not meet the requirements for transmitting this capacity from the new projects that have been added into the plan, despite recent upgrades.

Based on EVN's calculation, MOIT submitted a number of projects for 220–500 kV transmission lines in Binh Thuan and Ninh Thuan to the Prime Minister, who approved the incorporation of these projects into the Plan to help relieve the capacity of renewable power projects. EVN is undertaking further research to propose new projects.

3. Power Grids

In the period 2016–2018, EVN completed 117 projects involving 500–220 kV power grids.

EVN is now deploying power grid projects in accordance with the approved Plan to improve the performance of transmission lines and meet the subnational power demand, including the Vung Ang–

Quang Trach–Doc Soi–Pleiku 2,500 kV transmission line expected to be operationalized by Quarter II/2020 to improve the power supply to the south.

EVN has also directed its member units to accelerate grid projects that serve the power supply projects, especially solar power projects, recently added into the plan as an additional national power supply (…)

IV. Factors influencing power supply in the period until 2030

(…)

2. Potential risks for the adequacy of fuel supply for power generation

- Coal supply: TKV is reported to have ceased work on the coal trans-shipment port in the Mekong Delta because it has failed to negotiate a project location or to find any solution to going forward. The Long Phu 1 and Hau River 1 thermal power plants are expected to supply coal via the Go Da port via trans-shipment. Options for coal transportation have not been specified for the Long Phu 2 and Hau River 2 thermal power plants. The coal supply has not met the demands of the power plants in terms of quantity and the type of coal. Although the yield of coal-fired thermal power was lower than planned in 2018, the last months of 2018 experienced a coal shortage.

- Gas supply: The gas supply to the Phu My thermal power cluster in the south-eastern region is likely to decrease after 2020, and experience an annual shortage of about 2–3 billion m³ between 2023 and 2024 and an annual shortage of over 10 billion m³ in 2030. Therefore, if the Son My port is not operationalized by 2023, the Phu My–Ba Ria thermal power cluster will suffer from a gas supply shortage equivalent to about 13 billion kWh in 2023. There will also be a shortage of gas supply (0.5–1 billion m³) to the Ca Mau thermal power cluster in the south-western region from 2019. PVN is now negotiating with a Malaysian counterpart to purchase additional gas.

- The O Mon thermal power cluster is facing the issue of high gas prices, leading to a high electricity tariff. These are crucial power supply projects in the South until 2025. The use of gas or LNG in power generation is inevitable after 2023. Therefore, it is important to find a solution to improve the efficiency of the O Mon 3 and 4 thermal power plants to lower the electricity price.

- LNG-fuelled thermal power plants, such as Nhon Trach 3 and 4: there is a gas supply shortage in the south east, which must be compensated by LNG after 2022. Therefore, it will be necessary to use the Thi Vai and Son My LNG ports in 2023 to supply additional gas to the Phu My thermal power cluster and to the Nhon Trach 3 and 4 thermal power plants. An LNG port at Cai Mep is under construction, with a capacity of about 2–3 million tons/year. If the development of the Thi Vai and Son My ports is delayed, Cai Mep port may offer an alternative site to supply additional gas to the south-eastern region, or the construction of new LNG-fuelled power plants in the area could be considered.

3. Other factors influencing operation and power supply

- The 500 kV triple-circuit transmission line (Vung Ang–Quang Trach–Doc Soi–Pleiku 2 line), which was hoped to strengthen the north–south transmission performance, has been delayed by almost 1 year. Failure to complete this transmission line by early 2020 will pose a threat of power shortage to the southern region.

- Because there will also be no backup across the network between 2021 and 2025, any unreliable performance of thermal-power-generating units or a coal supply shortage will also jeopardize the power supply.

V. Key difficulties and bottlenecks

(…)

6. Other difficulties and bottlenecks

- Projects affecting natural forests and the protection of forests must comply with the procedures stipulated by Directive 13 of the Secretariat and Notice 191 of the Prime Minister, so many projects suffer from delayed EIA approval or failure in construction (e.g., 500 kV triple-circuit transmission line, Nghia Lo 220 kV substation, Nghia Lo–Viet Tri 220 kV transmission line, and Thuong Kon Tum–Quang Ngai 220 kV triple-circuit transmission line). In accordance with the request of MONRE, the project owner (EVNNPT) is the agency that submits EIA reports (previously Board A was the agency to directly submit EIA reports).

That the procedure involves multiple levels of authority makes it difficult to get control of EIA submission and approval.

- The transmission of the capacities of renewable energy projects in areas of high potential (i.e., Ninh Thuan, Binh Thuan, Khanh Hoa, etc.) faces challenges in the coming years because transmission grid projects in the revised PDP7 and the 110 kV grid projects in the subnational PDPs have not taken into account the feed-in capacities of the newly included renewable energy projects. Most decisions approving the inclusion of renewable energy projects into the plan have only included additional grid projects that connect individual projects and have made no mention of supplementing grid projects as a whole, in a consistent manner. Therefore, it is impossible to meet the demand to feed in the capacities of renewable energy projects.

- The 2017 Law on Planning, which takes force on January 1, 2019, will have a significant impact on the planning, appraisal, and supplementation of power projects. Should there be no specific and feasible guidelines, the execution and progress of power projects will be prolonged, affecting the power supply to national socio-economic development.

- Since 2016, as directed by the Prime Minister, MOIT has developed an exclusive mechanism to ensure investment in and the construction of power projects under the PDP ('exclusive mechanism' for short). However, after many revisions, the exclusive mechanism has not been promulgated; and if it is refined in a way that eliminates exclusive provisions, the mechanism will make little difference.

- Local leaders do not support the idea of coal-fired thermal power development in their localities, although these projects are listed in the revised PDP7. Such conflicts have caused delays in project implementation, negative public responses, and consequences for the power supply for socio-economic development, especially in the south.

VI. Solutions to power supply

- Accelerate the exploitation of smaller mines in the south-western region as an additional source for the Ca Mau thermal power cluster between 2019 and 2021, when the Lot B gas project has not been operationalized; prioritize the gas supply for power generation in the period 2018–2021; and develop and select the most rational option for LNG importation in the south-western region, when the Kien Giang gas-fired power project begins construction. Concurrently, consider the supplementation of the LNG-fuelled power plants proposed by several provincial People's Committees and investors, i.e., Long Son (Ba Ria-Vung Tau) and Ca Na (Ninh Thuan), as alternative power supplies to the delayed or at-risk supplies (several coal-fired thermal power plants).

- To install appropriate mechanisms (gas and power off-take) to accelerate the progress of the Nhon Trach III and IV LNG-fuelled power plants and Thi Vai port, allowing them to be operationalized in 2022 and 2023; to accelerate the progress of the Son My gas-fired power plants; and to consider the use of the LNG port in Cai Mep (under construction, with a capacity of about 2 million tons/year) as a supplementary source of gas supply to the south-eastern region in case of any delay in the LNG-importing port, and the construction of a new power plant in this area if the gas supply is adequate, reliable, and reasonably priced.

- To encourage and maintain on schedule the Blue Whale gas project and the thermal power cluster in the central region to be operationalized in 2023 and 2024; to closely track the progress of a series of projects; to facilitate the functioning of gas-fired power plants using gas from the Blue Whale basin; to encourage and put mechanisms in place to ensure the progress of bringing the Lot B gas onshore as a reliable supply for the O Mon II and IV gas-fired thermal power plants, which are expected to be operational in 2023.

- To explore the option and feasibility of purchasing power from Laos and China as supplementary capacities for the local power network, providing a secure and reliable power supply to the economy; to allow EVN to negotiate with CSG to increase power importation from China via the existing 220 kV transmission lines, and coordinate with CSG to invest in a back-to-back network to improve power purchase from 2022, without the need for grid segregation; to study the feasibility of buying electricity through the 500 kV transmission line system to allow power purchase from 2025, and to approve the policy of further importing power from China in future times; and to assign EVN to negotiate and reach a consensus with CSG on the phase-by-phase importation plan, commercial terms, and tariffs (…)

8.3 RESULTS

Table 43: Results for the Long-Term Energy scenario in all sectors—REFERENCE

Viet Nam — Reference

Electricity generation [TWh/a]	2012	2015	2020	2030	2040	2050
Power plants	118	162	268	568	821	884
- Hard coal (& non-renewable waste)	25	59	134	314	422	404
- Lignite	0	0	0	0	0	0
- Gas	39	46	49	118	183	199
of which from H2	0	0	0	0	0	0
- Oil	0	1	1	1	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	3	12	18	30
- Hydro	53	56	78	94	102	102
- Wind	0	0	2	13	48	71
of which wind offshore	0	0	0	1	4	8
- PV	0	0	2	17	48	78
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Combined heat and power plants	0	0	1	3	4	6
- Hard coal (& non-renewable waste)	0	0	0	1	1	1
- Lignite	0	0	0	0	0	0
- Gas	0	0	1	2	3	4
of which from H2	0	0	0	0	0	0
- Oil	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
CHP by producer						
- Main activity producers	0	0	0	0	0	1
- Autoproducers	0	0	1	3	4	5
Total generation	118	162	269	571	825	890
- Fossil	65	105	185	435	609	610
- Hard coal (& non-renewable waste)	25	59	134	314	423	406
- Lignite	0	0	0	0	0	0
- Gas	39	46	50	120	186	203
- Oil	0	1	1	1	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
- of which renewable H2	0	0	0	0	0	0
- Renewables (w/o renewable hydrogen)	53	56	84	136	215	280
- Hydro	53	56	78	94	102	102
- Wind	0	0	2	13	48	71
- PV	0	0	2	17	48	78
- Biomass (& renewable waste)	0	0	3	12	18	30
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Distribution losses	11	16	24	51	75	81
Own consumption electricity	3	4	11	12	16	16
Electricity for hydrogen production	0	0	0	0	0	0
Electricity for synfuel production	0	0	0	0	0	0
Final energy consumption (electricity)	105	143	234	505	737	795
Variable RES (PV, Wind, Ocean)	0	0	4	30	95	149
Share of variable RES	0%	0%	1%	5%	12%	17%
RES share (domestic generation)	45%	35%	31%	24%	26%	31%

Transport - Final Energy [PJ/a]	2012	2015	2020	2030	2040	2050
road	404	435	673	1,239	1,759	2,071
- fossil fuels	404	435	583	1,031	1,377	1,520
- biofuels	0	0	1	50	112	140
- synfuels	0	0	0	0	0	0
- natural gas	0	0	88	152	228	342
- hydrogen	0	0	0	0	0	0
- electricity	0	0	1	7	42	68
rail	13	13	13	13	14	15
- fossil fuels	13	13	13	12	12	11
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
- electricity	0	0	1	1	2	3
navigation	2	2	2	2	3	4
- fossil fuels	2	2	2	2	3	4
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
aviation	7	10	12	20	29	35
- fossil fuels	7	10	12	20	29	35
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
total (incl. pipelines)	425	459	709	1,283	1,812	2,130
- fossil fuels	425	459	610	1,066	1,421	1,570
- biofuels (incl. biogas)	0	0	1	50	112	140
- synfuels	0	0	0	0	0	0
- natural gas	0	0	96	159	235	348
- hydrogen	0	0	0	0	0	0
- electricity	0	0	2	8	44	72
total RES	0	0	1	52	123	163
RES share	0%	0%	0%	4%	7%	8%

Heat supply and air conditioning [PJ/a]	2012	2015	2020	2030	2040	2050
District heating plants	0	0	112	200	268	357
- Fossil fuels	0	0	112	200	268	357
- Biomass	0	0	0	0	0	0
- Solar collectors	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
Heat from CHP 1)	0	0	3	9	14	25
- Fossil fuels	0	0	3	9	14	25
- Biomass	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
Direct heating (incl. traditional cooking)	919	1,106	1,068	1,421	1,611	1,707
- Fossil fuels	489	577	673	948	917	785
- Biomass	429	429	291	155	213	303
- Solar collectors	0	0	0	0	3	0
- Geothermal	0	0	0	0	0	0
- Heat pumps 2)	0	0	14	42	68	104
- Electric direct heating	0	100	90	276	410	515
- Hydrogen	0	0	0	0	0	0
Total heat supply3)	919	1,106	1,183	1,629	1,893	2,089
- Fossil fuels	489	577	788	1,156	1,198	1,167
- Biomass	429	429	291	155	213	303
- Solar collectors	0	0	0	0	3	0
- Geothermal	0	0	0	0	0	0
- Heat pumps 2)	0	0	14	42	68	104
- Electric direct heating	0	100	90	276	410	515
- Hydrogen	0	0	0	0	0	0
RES share (including RES electricity)	47%	42%	27%	14%	17%	22%
electricity consumption heat pumps (TWh/a)	0.0	0.0	4.0	11.6	18.9	28.9

Installed Capacity [GW]	2012	2015	2020	2030	2040	2050
Total generation	28	41	54	131	178	218
- Fossil	13	23	30	80	82	82
- Hard coal (& non-renewable waste)	4	14	21	55	56	54
- Lignite	0	0	0	0	0	0
- Gas (w/o H2)	9	8	8	24	25	27
- Oil	0	1	1	1	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants	0	0	0	0	0	0
- Renewables	15	19	25	51	96	136
- Hydro	15	18	22	28	29	29
- Wind	0	0	1	6	22	32
of which wind offshore	0	0	0	0	1	2
- PV	0	0	2	15	42	69
- Biomass (& renewable waste)	0	0	1	2	3	6
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	3	21	64	101
Share of variable RES	0%	1%	5%	16%	36%	46%
RES share (domestic generation)	54%	45%	45%	39%	54%	62%

Final Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total (incl. non-Energy use)	2,049	2,502	2,978	4,789	6,210	6,701
Total Energy use 1)	1,981	2,352	2,884	4,669	6,083	6,611
Transport	412	447	709	1,284	1,809	2,126
- Oil products	412	447	611	1,068	1,418	1,566
- Natural gas	0	0	96	159	235	348
- Biofuels	0	0	1	49	112	140
- Synfuels	0	0	0	0	0	0
- Electricity	0	0	1	8	44	72
RES electricity	0	0	0	2	12	23
- Hydrogen	0	0	0	0	0	0
RES share Transport	0%	0%	0%	4%	7%	8%
Industry	784	1,059	1,303	2,193	2,699	2,726
- Electricity	199	277	397	747	1,201	1,232
RES electricity	90	97	124	178	314	388
- Public district heat	0	100	110	196	263	351
RES district heat	0	16	16	25	38	67
- Hard coal & lignite	347	429	428	731	644	458
- Oil products	67	68	144	122	119	113
- Gas	60	70	92	218	220	222
- Solar	0	0	0	0	3	0
- Biomass	111	114	121	148	199	272
- Geothermal	0	0	10	30	50	78
- Hydrogen	0	0	0	0	0	0
RES share Industry	26%	21%	21%	17%	22%	30%
Other Sectors	785	847	873	1,192	1,575	1,760
- Electricity	180	239	443	1,063	1,406	1,557
RES electricity	81	83	139	253	367	490
- Public district heat	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0
- Hard coal & lignite	58	63	64	18	18	18
- Oil products	84	86	99	52	51	62
- Gas	0	0	0	0	27	33
- Solar	0	0	0	0	0	0
- Biomass	462	459	266	59	73	89
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
RES share Other Sectors	69%	64%	46%	26%	28%	33%
Total RES	744	769	678	744	1,166	1,547
RES share	38%	33%	23%	16%	19%	23%
Non energy use	68	150	94	119	127	90
- Oil	68	150	94	119	126	89
- Gas	0	0	0	1	1	1
- Coal	0	0	0	0	0	0

Energy-Releated CO2 Emissions [Million tons/a]	2012	2015	2020	2030	2040	2050
Condensation power plants	33	62	123	287	395	385
- Hard coal (& non-renewable waste)	19	46	104	244	328	315
- Lignite	0	0	0	0	0	0
- Gas	14	16	18	43	66	69
- Oil + Diesel	0	1	1	1	1	1
Combined heat and power plants	0	0	1	2	3	4
- Hard coal (& non-renewable waste)	0	0	0	1	1	2
- Lignite	0	0	0	0	0	0
- Gas	0	0	0	1	1	2
- Oil	0	0	0	0	0	0
CO2 emissions power and CHP plants	33	62	123	289	398	388
- Hard coal (& non-renewable waste)	19	46	105	245	329	317
- Lignite	0	0	0	0	0	0
- Gas	14	16	18	44	67	71
- Oil + Diesel	0	1	1	1	1	1
CO2 intensity (g/kWh)	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	516	592	667	664	652	637
- CO2 intensity total electr. generation	284	386	458	506	482	437
CO2 emissions by sector	121	163	265	511	655	657
- % of 1990 emissions (Mill t)	466%	627%	1020%	1965%	2519%	2527%
- Industry 1)	41	49	62	101	97	84
- Other sectors 1)	12	12	20	17	22	29
- Transport	32	34	51	89	119	137
- Power generation 2)	33	62	123	288	395	385
- Other conversion 3)	3	5	10	16	21	22
Population (Mill.)	90	94	98	106	111	115
CO2 emissions per capita (t/capita)	1	2	3	5	6	6

Primary Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total	2,399	3,067	4,072	7,250	9,620	10,006
- Fossil	1,617	2,233	3,338	6,355	8,211	8,157
- Hard coal	607	965	1,744	3,611	4,509	4,286
- Lignite	6	22	0	0	0	0
- Natural gas	318	368	565	1,283	1,894	1,939
- Crude oil	687	879	1,029	1,461	1,808	1,932
- Nuclear	0	0	0	0	0	0
- Renewables	782	834	733	895	1,409	1,849
- Hydro	190	202	279	337	366	366
- Wind	0	0	7	48	171	256
- Solar	0	1	6	61	175	280
- Biomass (& renewable waste)	592	631	430	419	647	869
- Geothermal	0	0	10	30	50	78
- Ocean energy	0	0	0	0	0	0
- of which non-energy use	68	150	94	119	127	90
Total RES	785	836	733	893	1,411	1,851
RES share	33%	27%	18%	12%	15%	18%

Table 44: Results for the Long-Term Energy scenario in all sectors—RENEWABLES 1

Viet Nam — Renewables 1

Electricity generation [TWh/a]	2012	2015	2020	2030	2040	2050
Power plants	118	162	257	523	704	780
- Hard coal (& non-renewable waste)	25	59	121	187	159	0
- Lignite	0	0	0	0	0	0
- Gas	39	46	50	136	180	192
of which from H2	0	0	0	0	0	0
- Oil	0	1	1	1	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	1	4	8	18
- Hydro	53	56	78	96	108	110
- Wind	0	0	2	81	174	334
of which wind offshore	0	0	0	36	83	205
- PV	0	0	5	19	73	125
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Combined heat and power plants	0	0	1	3	4	6
- Hard coal (& non-renewable waste)	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0
- Gas	0	0	1	2	2	2
of which from H2	0	0	0	0	0	0
- Oil	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	1	2	3
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
CHP by producer						
- Main activity producers	0	0	0	0	0	1
- Autoproducers	0	0	1	3	4	5
Total generation	118	162	258	526	708	786
- Fossil	65	105	172	326	342	196
- Hard coal (& non-renewable waste)	25	59	121	188	159	0
- Lignite	0	0	0	0	0	0
- Gas	39	46	50	138	182	195
- Oil	0	1	1	1	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
- of which renewable H2	0	0	0	0	0	0
- Renewables (w/o renewable hydrogen)	53	56	86	200	366	590
- Hydro	53	56	78	96	108	110
- Wind	0	0	2	81	174	334
- PV	0	0	5	19	73	125
- Biomass (& renewable waste)	0	0	1	4	10	21
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Distribution losses	11	16	24	48	66	73
Own consumption electricity	3	4	4	3	2	2
Electricity for hydrogen production	0	0	0	0	0	0
Electricity for synfuel production	0	0	0	0	0	0
Final energy consumption (electricity)	105	143	230	476	649	720
Variable RES (PV, Wind, Ocean)	0	0	7	100	248	459
Share of variable RES	0%	0%	3%	19%	35%	58%
RES share (domestic generation)	45%	35%	33%	38%	52%	75%

Transport - Final Energy [PJ/a]	2012	2015	2020	2030	2040	2050
road	404	387	664	1,197	1,687	1,852
- fossil fuels	404	385	570	1,005	1,363	1,290
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
- natural gas	0	2	88	152	228	342
- hydrogen	0	0	0	0	0	0
- electricity	0	0	6	40	95	219
rail	0	0	13	14	16	19
- fossil fuels	0	0	13	11	6	2
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
- electricity	0	0	0	4	10	17
navigation	2	2	2	2	3	4
- fossil fuels	2	2	2	2	3	3
- biofuels	0	0	0	0	0	1
- synfuels	0	0	0	0	0	0
aviation	7	10	12	20	29	35
- fossil fuels	7	10	12	20	27	26
- biofuels	0	0	0	1	2	9
- synfuels	0	0	0	0	0	0
total (incl. pipelines)	412	400	709	1,251	1,751	1,923
- fossil fuels	412	397	598	1,038	1,399	1,321
- biofuels (incl. biogas)	0	0	0	1	2	9
- synfuels	0	0	0	0	0	0
- natural gas	0	2	96	160	236	349
- hydrogen	0	0	0	0	0	0
- electricity	0	0	6	44	106	236
total RES	0	0	2	17	57	187
RES share	0%	0%	0%	1%	3%	10%

Heat supply and air conditioning [PJ/a]	2012	2015	2020	2030	2040	2050
District heating plants	0	0	112	187	255	347
- Fossil fuels	0	0	112	140	110	35
- Biomass	0	0	0	33	94	225
- Solar collectors	0	0	0	14	51	87
- Geothermal	0	0	0	0	0	0
Heat from CHP 1)	0	0	3	9	16	31
- Fossil fuels	0	0	3	5	2	0
- Biomass	0	0	0	4	14	30
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
Direct heating	919	1,106	1,071	1,275	1,436	1,507
- Fossil fuels	489	577	658	827	766	644
- Biomass	429	429	300	141	183	205
- Solar collectors	0	0	6	8	24	50
- Geothermal	0	0	0	0	0	0
- Heat pumps 2)	0	0	17	40	72	116
- Electric direct heating	0	100	90	259	391	492
- Hydrogen	0	0	0	0	0	0
Total heat supply3)	919	1,106	1,186	1,470	1,707	1,884
- Fossil fuels	489	577	773	972	877	679
- Biomass	429	429	300	177	292	461
- Solar collectors	0	0	6	22	75	137
- Geothermal	0	0	0	0	0	0
- Heat pumps 2)	0	0	17	40	72	116
- Electric direct heating 2)	0	100	90	259	391	492
- Hydrogen	0	0	0	0	0	0
RES share (including RES electricity)	47%	42%	30%	23%	38%	57%
electricity consumption heat pumps (TWh/a)	0.0	0.0	4.0	10.5	17.0	25.9

Installed Capacity [GW]	2012	2015	2020	2030	2040	2050
Total generation	28	41	55	123	187	255
- Fossil	13	23	29	57	46	27
- Hard coal (& non-renewable waste)	4	14	20	33	21	0
- Lignite	0	0	0	0	0	0
- Gas (w/o H2)	9	8	8	23	25	26
- Oil	0	1	0	0	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants,	0	0	0	0	0	0
- Renewables	15	19	26	67	141	228
- Hydro	15	18	21	25	29	29
- Wind	0	0	1	26	54	98
of which wind offshore	0	0	0	9	21	53
- PV	0	0	5	14	56	96
- Biomass (& renewable waste)	0	0	0	1	2	4
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	5	41	110	195
Share of variable RES	0%	1%	10%	33%	59%	76%
RES share (domestic generation)	54%	45%	48%	54%	75%	89%

Final Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total (incl. non-energy use)	2,046	2,503	2,985	4,422	5,539	5,831
Total energy use 1)	1,978	2,354	2,865	4,318	5,440	5,736
Transport	412	449	705	1,244	1,745	1,918
- Oil products	412	447	600	1,041	1,402	1,324
- Natural gas	0	2	96	159	235	348
- Biofuels	0	0	0	1	2	9
- Synfuels	0	0	0	0	0	0
- Electricity	0	0	6	44	106	236
RES electricity	0	0	2	17	55	177
- Hydrogen	0	0	4	0	0	0
RES share Transport	0%	0%	0%	1%	3%	10%
Industry	781	1,058	1,295	2,003	2,426	2,411
- Electricity	199	277	390	703	1,080	1,073
RES electricity	90	97	130	267	559	806
- Public district heat	0	100	110	177	236	315
RES district heat	0	16	16	23	34	60
- Hard coal & lignite	347	429	428	658	579	411
- Oil products	64	68	143	109	106	99
- Gas	60	70	92	196	198	199
- Solar	0	0	0	0	3	0
- Biomass	111	114	121	133	179	244
- Geothermal	0	0	10	27	45	70
- Hydrogen	0	0	0	0	0	0
RES share Industry	26%	21%	21%	22%	34%	49%
Other Sectors	785	847	865	1,070	1,269	1,407
- Electricity	180	239	437	968	1,150	1,282
RES electricity	81	83	146	368	595	963
- Public district heat	0	0	0	7	15	27
RES district heat	0	0	0	5	13	24
- Hard coal & lignite	58	63	1	0	0	21
- Oil products	84	86	48	16	12	10
- Gas	0	0	93	14	8	0
- Solar	0	0	6	8	22	50
- Biomass	462	459	278	55	54	1
- Geothermal	0	0	2	2	8	17
- Hydrogen	0	0	0	0	0	0
RES share Other Sectors	69%	64%	50%	41%	55%	75%
Total RES	744	769	713	906	1,570	2,423
RES share	38%	33%	25%	21%	29%	42%
Non energy use	68	150	120	104	99	95
- Oil	68	150	120	104	99	94
- Gas	0	0	0	0	0	0
- Coal	0	0	0	0	0	1

Energy-Releated CO2 Emissions [Million tons/a]	2012	2015	2020	2030	2040	2050
Condensation power plants	33	62	112	195	189	68
- Hard coal (& non-renewable waste)	19	46	94	146	124	0
- Lignite	0	0	0	0	0	0
- Gas	14	16	18	49	65	67
- Oil + Diesel	0	1	1	0	1	1
Combined heat and power plants	0	0	1	1	1	1
- Hard coal (& non-renewable waste)	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0
- Gas	0	0	0	1	1	1
- Oil	0	0	0	0	0	0
CO2 emissions power and CHP plants	33	62	113	196	190	69
- Hard coal (& non-renewable waste)	19	46	94	146	124	0
- Lignite	0	0	0	0	0	0
- Gas	14	16	18	50	66	68
- Oil & diesel	0	1	1	0	1	1
CO2 intensity (g/kWh)	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	516	592	657	603	557	352
- CO2 intensity total electr. generation	516	592	657	603	557	352
CO2 emissions by sector	120	163	249	396	414	269
- % of 1990 emissions (Mill t)	462%	628%	959%	1525%	1591%	1035%
- Industry 1)	41	49	62	88	78	58
- Other sectors 1)	12	12	15	10	7	4
- Transport	31	34	50	87	118	119
- Power generation 2)	33	62	112	195	189	68
- Other conversion 3)	3	5	10	16	21	20
Population (Mill.)	90	94	98	106	111	115
CO2 emissions per capita (t/capita)	1.3	1.7	2.5	3.7	3.7	2.3

Primary Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total	2,386	3,069	3,954	6,166	7,375	6,836
- Fossil	1,604	2,235	3,221	5,152	5,559	3,910
- Hard coal (& non-renewable waste)	607	965	1,569	2,368	2,007	435
- Lignite	6	22	1	0	0	0
- Natural gas	318	370	670	1,426	1,853	1,872
- Crude oil	673	879	981	1,358	1,700	1,603
- Nuclear	0	0	0	0	0	0
- Renewables	782	834	733	1,014	1,816	2,926
- Hydro	190	202	280	345	390	396
- Wind	0	0	8	291	628	1,202
- Solar	0	1	24	76	288	501
- Biomass (& renewable waste)	592	631	408	274	456	740
- Geothermal	0	0	12	29	53	87
- Ocean energy	0	0	0	0	0	0
- of which non-energy use	68	150	120	104	99	95
Total RES	782	834	733	1,014	1,816	2,926
RES share	33%	27%	19%	16%	25%	43%

Table 45: Results for the Long-Term Energy scenario in all sectors—RENEWABLES 2

Viet Nam Renewables 2

Electricity generation [TWh/a]	2012	2015	2020	2030	2040	2050
Power plants	118	162	258	529	756	946
- Hard coal (& non-renewable waste)	25	59	117	178	86	0
- Lignite	0	0	0	0	0	0
- Gas	39	46	52	82	102	109
of which from H2	0	0	0	0	0	0
- Oil	0	1	1	1	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	3	19	31	45
- Hydro	53	56	78	96	108	110
- Wind	0	0	2	121	345	558
of which wind offshore	0	0	0	69	196	352
- PV	0	0	6	32	83	123
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Combined heat and power plants	0	0	1	3	4	6
- Hard coal (& non-renewable waste)	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0
- Gas	0	0	1	2	2	2
of which from H2	0	0	0	0	0	0
- Oil	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	1	2	3
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
CHP by producer						
- Main activity producers	0	0	0	0	0	1
- Autoproducers	0	0	1	3	4	5
Total generation	118	162	259	532	760	952
- Fossil	65	105	170	262	191	112
- Hard coal (& non-renewable waste)	25	59	117	178	87	0
- Lignite	0	0	0	0	0	0
- Gas	39	46	52	83	103	111
- Oil	0	1	1	1	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
- of which renewable H2	0	0	0	0	0	0
- Renewables (w/o renewable hydrogen)	53	56	89	269	569	839
- Hydro	53	56	78	96	108	110
- Wind	0	0	2	121	345	558
- PV	0	0	6	32	83	123
- Biomass (& renewable waste)	0	0	3	20	33	48
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Distribution losses	11	16	24	49	71	88
Own consumption electricity	3	4	4	3	2	2
Electricity for hydrogen production	0	0	0	0	0	0
Electricity for synfuel production	0	0	0	0	0	0
Final energy consumption (electricity)	105	143	232	481	696	870
Variable RES (PV, Wind, Ocean)	0	0	8	153	428	681
Share of variable RES	0%	0%	3%	29%	56%	72%
RES share (domestic generation)	45%	35%	34%	51%	75%	88%

Transport - Final Energy [PJ/a]	2012	2015	2020	2030	2040	2050
road	404	387	661	1,138	1,383	950
- fossil fuels	404	385	567	878	861	1
- biofuels	0	0	0	50	112	140
- synfuels	0	0	0	0	0	0
- natural gas	0	2	88	152	148	55
- hydrogen	0	0	0	0	0	0
- electricity	0	0	6	58	262	755
rail	13	13	13	15	19	25
- fossil fuels	13	13	13	11	7	2
- biofuels	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0
- electricity	0	0	0	4	13	23
navigation	2	2	2	2	3	4
- fossil fuels	2	2	2	2	2	0
- biofuels	0	0	0	0	1	4
- synfuels	0	0	0	0	0	0
aviation	7	10	8	15	22	26
- fossil fuels	7	10	8	14	15	0
- biofuels	0	0	0	1	7	26
- synfuels	0	0	0	0	0	0
total (incl. pipelines)	425	412	701	1,187	1,443	1,019
- fossil fuels	425	410	590	906	885	3
- biofuels (incl. biogas)	0	0	0	51	121	170
- synfuels	0	0	0	0	0	0
- natural gas	0	2	96	160	156	62
- hydrogen	0	0	0	0	0	0
- electricity	0	0	7	62	274	778
total RES	0	0	2	82	326	855
RES share	0%	0%	0%	7%	23%	85%

Heat supply and air conditioning [PJ/a]	2012	2015	2020	2030	2040	2050
District heating plants	0	0	114	187	255	347
- Fossil fuels	0	0	114	140	97	0
- Biomass	0	0	0	33	107	260
- Solar collectors	0	0	0	14	51	87
- Geothermal	0	0	0	0	0	0
Heat from CHP [1]	0	0	3	9	16	31
- Fossil fuels	0	0	3	5	2	0
- Biomass	0	0	0	4	14	30
- Geothermal	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0
Direct heating	919	1,106	1,071	1,275	1,436	1,507
- Fossil fuels	489	577	658	827	389	4
- Biomass	429	429	300	141	559	844
- Solar collectors	0	0	6	8	24	50
- Geothermal	0	0	0	0	0	0
- Heat pumps [2]	0	0	17	40	72	116
- Electric direct heating	0	100	90	259	391	492
- Hydrogen	0	0	0	0	0	95
Total heat supply[3]	919	1,106	1,187	1,470	1,707	1,980
- Fossil fuels	489	577	774	972	488	5
- Biomass	429	429	300	177	681	1,135
- Solar collectors	0	0	6	22	75	137
- Geothermal	0	0	0	0	0	0
- Heat pumps [2]	0	0	17	40	72	116
- Electric direct heating	0	100	90	259	391	492
- Hydrogen	0	0	0	0	0	95
RES share (including RES electricity)	47%	42%	30%	25%	66%	92%
electricity consumption heat pumps (TWh/a)	0.0	0.0	4.0	10.5	17.0	25.9

Installed Capacity [GW]	2012	2015	2020	2030	2040	2050
Total generation	28	41	56	134	241	318
- Fossil	13	23	29	37	26	16
- Hard coal (& non-renewable waste)	4	14	20	24	12	0
- Lignite	0	0	0	0	0	0
- Gas (w/o H2)	9	8	8	13	14	15
- Oil	0	1	0	0	1	1
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants,	0	0	0	0	0	0
- Renewables	15	19	27	96	215	302
- Hydro	15	18	21	25	29	29
- Wind	0	0	1	43	117	176
of which wind offshore	0	0	0	21	54	90
- PV	0	0	5	25	64	88
- Biomass (& renewable waste)	0	0	1	4	6	9
- Geothermal	0	0	0	0	0	0
- Solar thermal power plants	0	0	0	0	0	0
- Ocean energy	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	6	67	181	264
Share of variable RES	0%	1%	11%	50%	75%	83%
RES share (domestic generation)	54%	45%	49%	72%	89%	95%

Final Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total (incl. non-energy use)	2,046	2,503	2,973	4,356	5,271	4,958
Total energy use [1]	1,978	2,354	2,854	4,252	5,172	4,864
Transport	412	449	694	1,180	1,436	1,011
- Oil products	412	447	592	908	887	3
- Natural gas/biogas	0	2	96	159	155	61
- Biofuels	0	0	0	51	121	170
- Synfuels	0	0	0	0	0	0
- Electricity	0	0	7	62	274	778
RES electricity	0	0	2	31	205	686
- Hydrogen	0	0	0	0	0	0
RES share Transport	0%	0%	0%	7%	23%	85%
Industry	781	1,058	1,295	2,003	2,468	2,443
- Electricity	199	277	390	703	1,080	1,073
RES electricity	90	97	134	356	809	947
- Public district heat	0	100	110	177	236	315
RES district heat	0	16	16	23	54	194
- Hard coal & lignite	347	429	428	658	314	5
- Oil products	64	68	143	109	47	0
- Gas	60	70	92	196	85	0
- Solar	0	0	0	0	3	0
- Biomass	111	114	121	133	659	980
- Geothermal	0	0	10	27	45	70
- Hydrogen	0	0	0	0	0	0
RES share Industry	26%	21%	22%	27%	64%	90%
Other Sectors	785	847	865	1,069	1,268	1,410
- Electricity	180	239	437	968	1,150	1,282
RES electricity	81	83	150	490	862	1,130
- Public district heat	0	0	0	7	15	27
RES district heat	0	0	0	5	13	28
- Hard coal & lignite	58	63	1	0	0	0
- Oil products	84	86	48	15	11	9
- Gas	0	0	93	14	8	0
- Solar	0	0	6	8	22	50
- Biomass	462	459	278	55	54	25
- Geothermal	0	0	2	2	8	17
- Hydrogen	0	0	0	0	0	0
RES share Other Sectors	69%	64%	50%	52%	76%	89%
Total RES	744	769	721	1,181	2,854	4,303
RES share	38%	33%	25%	28%	55%	88%
Non energy use	68	150	120	104	99	95
- Oil	68	150	120	104	99	94
- Gas	0	0	0	0	0	0
- Coal	0	0	0	0	0	1

Energy-Releated CO2 Emissions [Million tons/a]	2012	2015	2020	2030	2040	2050
Condensation power plants	33	62	110	168	104	38
- Hard coal (& non-renewable waste)	19	46	91	139	67	0
- Lignite	0	0	0	0	0	0
- Gas	14	16	19	29	37	38
- Oil + Diesel	0	1	1	0	1	1
Combined heat and power plants	0	0	1	1	1	1
- Hard coal (& non-renewable waste)	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0
- Gas	0	0	0	1	1	1
- Oil	0	0	0	0	0	0
CO2 emissions power and CHP plants	33	62	111	170	105	40
- Hard coal (& non-renewable waste)	19	46	91	139	67	0
- Lignite	0	0	0	0	0	0
- Gas	14	16	19	30	37	39
- Oil & diesel	0	1	1	0	1	1
CO2 intensity (g/kWh)	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	516	592	644	521	309	203
- CO2 intensity total electr. generation	516	592	644	521	309	203
CO2 emissions by sector	121	163	247	357	241	49
- % of 1990 emissions (Mill t)	466%	628%	949%	1371%	927%	189%
- Industry [1]	41	49	62	88	43	1
- Other sectors [1]	12	12	15	10	7	1
- Transport	32	34	50	77	75	4
- Power generation [2]	33	62	110	169	104	39
- Other conversion [3]	3	5	9	13	12	5
Population (Mill.)	90	94	98	106	111	115
CO2 emissions per capita (t/capita)	1	2	3	3	2	0

Primary Energy Demand [PJ/a]	2012	2015	2020	2030	2040	2050
Total	2,399	3,069	3,958	5,991	6,655	5,931
- Fossil	1,617	2,235	3,196	4,546	3,284	911
- Hard coal (& non-renewable waste)	607	965	1,540	2,289	1,135	6
- Lignite	6	22	1	0	0	0
- Natural gas	318	370	683	1,041	1,053	797
- Crude oil	687	879	973	1,215	1,095	107
- Nuclear	0	0	0	0	0	0
- Renewables	782	834	761	1,444	3,372	5,020
- Hydro	190	202	280	345	390	396
- Wind	0	0	8	435	1,242	2,010
- Solar	0	1	27	124	324	492
- Biomass (& renewable waste)	592	631	434	511	1,363	2,035
- Geothermal	0	0	12	29	53	87
- Ocean energy	0	0	0	0	0	0
- of which non-energy use	68	150	120	104	99	95
Total RES	782	834	761	1,444	3,372	5,020
RES share	33%	27%	19%	24%	50%	84%

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