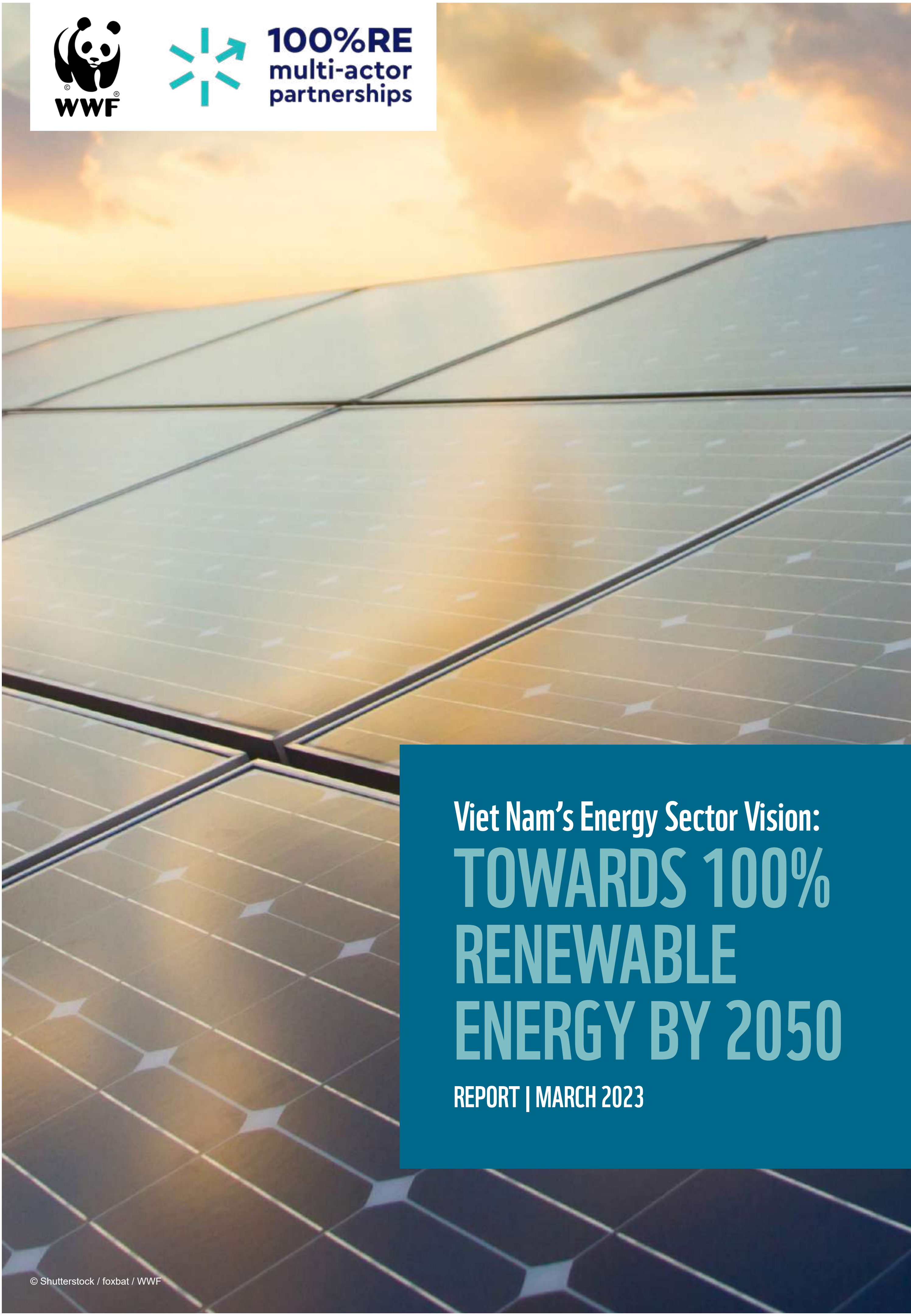

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100%RE multi-actor partnerships

Viet Nam's Energy Sector Vision:

TOWARDS 100% RENEWABLE ENERGY BY 2050

REPORT | MARCH 2023

ABOUT THE AUTHORS

Intelligent Energy Systems (IES) is an Australian consulting firm established in 1983 to provide advisory services and software solutions to organizations working in the energy industry. IES specializes in taking a systematic approach to solving problems in energy markets that require consideration of energy policy, legislation, economics, finance, and engineering. IES has a proven track record in advising government departments, regulators, system and market operators, transmission companies, generators, and retailers in the Asia Pacific region, including Australia, the Greater Mekong Sub-region, Philippines, Singapore, and elsewhere.

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The work would not have been possible without the tremendous help and engagement of Anna Skowron, Lena Dente, Dr. Joachim Fünfgelt, Jaime Medina Fernandez, Fentje Jacobsen, Corinne Kowalski, Sebastian Akermann.

DISCLAIMER

ABOUT THE 100% RE MAP PROJECT

The scale of the transformation ahead calls for collaboration and collective action. Inclusive alliances must be built that include people from all sectors, regions, and walks of life. We need a positive vision for our future, one that empowers change-makers and builds capacities across all sectors. By focusing on the opportunities related to 100% RE, rather than focusing on the fear related to the looming climate crisis, we can unlock the transformative power of renewables.

The Multi-Actor Partnership for Implementing Nationally Determined Contributions with 100% Renewable Energy for All in the Global South (100% RE MAP) is a project to facilitate positive changes and advance the transformation necessary to ensure economic and social development in line with the Paris Agreement's climate target of 1.5 °C. By strengthening MAPs, we enable inclusive decision-making and unlock disruptive innovations for scalability. The project ensures strategic buy-in from opinion leaders, academia, civil society, government and think tanks, and is being implemented simultaneously in Nepal, Uganda and Vietnam. The 100% RE scenario covers state-of-the-art modelling technologies that highlight possible transition pathways towards 100% RE and enable comparisons to business-as-usual pathways.

PROJECT'S CONSORTIUM

WWF

WWF-Viet Nam is recognised as the leading conservation organisation in the country, with a mission to stop the degradation of the country's natural environment and build a future in which humans live in harmony with nature. Its objective is to reduce environmental footprint and secure a sustainable future for the next generations. Ecological integrity and biodiversity conservation and restoration are cornerstones for WWF-Viet Nam's strategy.

WWF Germany is an independent, non-profit, non-partisan foundation, and part of the WWF network, which operates in over 100 countries and consists of national organizations and program offices.

GreenID

The **Green Innovation and Development Centre** (GreenID) works to achieve fundamental change in the approach to sustainable development by promoting the transition to a sustainable energy system, good environmental governance and inclusive decision processes.

Vietnam Business Council for Sustainable Development (VBCSD)

The **Vietnam Business Council for Sustainable Development** (VBCSD) is a business-led organization with the mandate to promote the business community's active role and strong advocate on the implementation of the Strategic Orientations for Sustainable Development in Viet Nam, to facilitate the dialogue among business community, the Government and civil organizations for sustainable development.

Brot für die Welt is the globally active development and relief agency of the Protestant Churches in Germany. In more than 90 countries all across the globe, we empower the poor and marginalized and closely and continuously cooperate with local, often church-related partner organizations. Through lobbying, public relations and education we seek to influence political decisions in favor of the poor and to raise awareness for the necessity of a sustainable way of life.

The **World Future Council** is a foundation based in Hamburg, Germany. Against the background of ever-increasing global problems that affect all areas of human life, a global group of experts have set up the World Future Council as a politically neutral and independent body. It brings the interests of future generations to the centre of policy making and addresses challenges to our common future and provides decision makers with effective policy solutions.

The project is supported by the German Federal Ministry for Economic Cooperation and Development (BMZ)

Federal Ministry for Economic Cooperation and Development

FORWORD BY WWF-VIET NAM

Vietnam has the fastest increase in greenhouse gas (GHG) emissions in the Greater Mekong Sub-region. According to the emission scenario, the GHG emissions of Viet Nam are forecasted to reach up to 1,495.4 million tons of CO2eq by 2050, in which the energy sector accounts for 81% of the total GHG emissions. In this context, Viet Nam has made great efforts to reduce GHG emissions which are highly praised by the international community such as the commitment to reaching net-zero carbon emissions by 2050 at the COP26 and the Updated National Determined Contributions (NDC 2022) at the COP27, in which the country's 2030 unconditional and conditional GHG emissions reduction targets have been increased from 9% and 27% to 15.8% and 43.5% compared to BAU, respectively. To achieve this goal, it is critical for Viet Nam to accelerate the energy transition towards Renewable Energy (RE) in all sectors.

The report "Energy Sector Vision: Towards 100% Renewable Energy for Viet Nam by 2050" was implemented under the "Multi-Actor Partnership (MAP) for Implementing Nationally Determined Contributions with 100% Renewable Energy (RE) for All in the Global South" project (100% RE MAP). The study has developed 03 scenarios for the Energy Sector of Viet Nam: BAU Scenario, 80% RE Scenario (80RE), and 100% RE Scenario (100RE) by 2050, based on the current power generation mix and energy plans and master plan of the Government, in order to build a feasible energy transition roadmap.

We hope this study will provide policymakers and stakeholders with useful and science-based information for promoting renewable energy development, contributing to delivering on emissions reduction commitments in the national NDC as well as achieving the Net Zero target.

This report is a product of 100% RE MAP project prepared by WWF-Viet Nam and our partners. We sincerely thank the MAP members, individual experts and project partners who helped shape this report.

Dr. Van Ngoc Thinh

CEO, WWF-Viet Nam

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Executive Summary

The aim of the project is to produce scenarios for transforming Vietnam's energy system to 100% renewable energy over the 2020 to 2050 horizon. Three scenarios were developed:

- BAU in line with the Draft Energy Master Plan (EMP) preferred Scenario A1 updated to reflect the higher level of renewable electricity resource in the November 2022 version of the draft PDP8,
- 80RE, a scenario to achieve 80% renewable energy by 2050, and
- 100RE, a scenario to achieve 100% renewable energy by 2050.

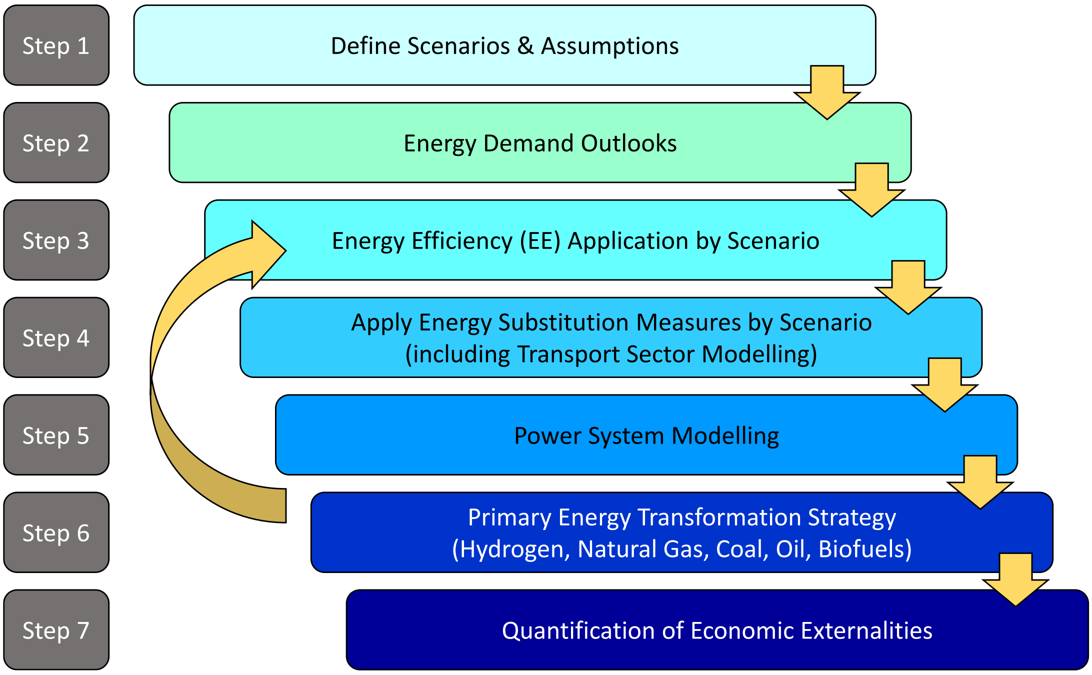
Scope and methodology

The scope includes taking account of key existing policies and regulations that impact the energy system, developing assumptions relevant to the scenarios, conduct modelling and recommend policies, consistent with the results, to support achieving the 100% RE vision of WWF. The non-energy use of primary energy sources, currently representing around 5% of total final energy, is out-of-scope. There are five main sectors in Vietnam listed in order of decreasing energy consumption:

- Industrial sector,
- Transport sector,
- Household sector,
- Commercial sector, and
- Agricultural, forestry and fishery sector.

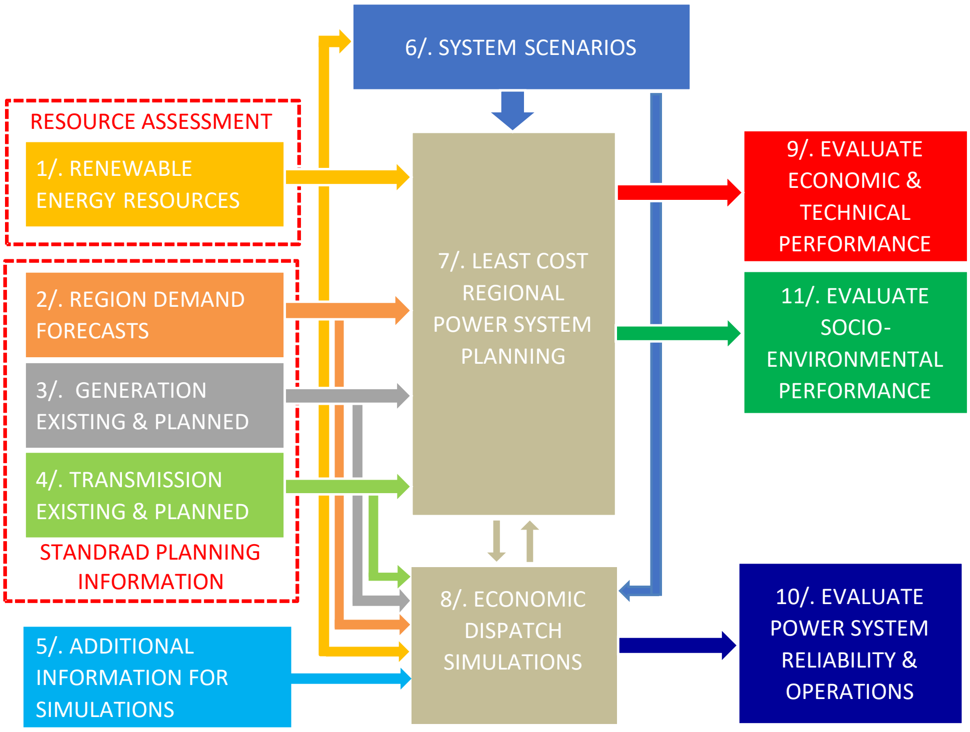
The power sector supplies electricity to all the above sectors and is also modelled in this study.

The EMP is the first national energy master plan that is inclusive of component energy plans, including those for coal, oil and gas, electricity, and renewable energy. It also includes the Vietnam energy efficiency program VNEEP3. Vietnam pledged to reach net zero CO2 emissions by 2050 at the United Nations Climate Change Conference (COP26) in Glasgow in 2021. The modelling methodology is depicted in the figure below. Externalities are quantified as a final step and includes CO2, SO2, NOx and particulate emissions.



Demand forecasts were developed for each sector. Non-renewable energy consumption (in the form of electricity or heat) was replaced either by direct electrification or conversion to renewable fuels. Energy efficiency (EE) in the BAU was limited to what is already included in the EMP Scenario A1. Additional EE savings were included in the 80RE and 100Re scenarios. The non-electricity industrial sector energy demand was either electrified or converted to renewable fuel based on an assumed trajectory. The electricity demand of the sector was supplied from an expanding renewable energy generation fleet. The transport sector was modelled across both tasks, passenger and freight traffic. The modelling estimated the energy used by mode of transport (and by type of energy carrier including electricity for EV) for the modelled vehicle types. The transport fleet was transformed to EV or renewable fuel, where direct electrification was judged infeasible. The household sector has a high share of households electrified but still uses biomass and LPG for cooking. It was modelled to transform these to renewable alternatives. Water heating is a major consumer of energy in that sector and was also converted to renewable alternatives. The modelling differentiated between urban and rural households. The commercial and agriculture sectors are small relative to the big three sectors accounting for approximately 7% of the national energy demand in Vietnam. Electricity's share of total energy consumption in the commercial sector is expected to grow. The agriculture section in Vietnam includes fishery and aquaculture. The sector accounts for 3% of the country's final energy consumption. Electricity accounts for approximately 50% of the energy used in this sector and is modelled to be supplied by electricity from renewable resources. In the high renewable energy scenarios current fossil fuel use is displaced by expanding electrification and renewable fuels in this sector. Data was sourced from the General Statistics Office of Vietnam (GSO) while GDP growth projections were based on the EMP.

The power sector supplies electricity to the main sectors and was modelled as part of the study. The generic approach used is shown in the diagram below.



Scenario results

Looking at the results of the modelling across the three scenarios; for snapshot years 2020, 2030, 2040 and 2050; we see that the fossil energy carriers used in the economy – coal; gasoline, oil, and other oil products; and natural gas – increases in the BAU. In the 80RE and 100RE scenarios usage of fossil energy carriers falls and is replaced by renewable alternatives. Direct electrification accounts for most of this conversion and the remainder consists of taken up by renewable fuels and biomass. The 80RE scenario contains a component of energy sourced from fossil sources. The fossil component is across hard to convert transport, industry and the marginal capacity in the power sector that is associated with higher cost to convert to renewables.

Emissions across the scenarios show a pattern consistent with the conversion to renewables. Total emission increase in the BAU. In the other two scenarios, emissions are higher in 2030 compared to 2020 as the conversion to renewables, while underway, has not reached a high enough level. In 100RE, total emissions are significantly lower in 2040 and become zero in 2050. In 80RE emissions are imperceptibly lower in 2040 compared to 2030 but are reduced significantly in 2050. Emissions attributable to electricity account for a higher share in the interim years due to the increase in electrification but fossil-fired generators are still dispatching electricity.

Average power sector costs are about 23% higher in 2050 compared to the BAU while the 80RE cost in 2050 is on par with the BAU. Energy intensity falls from about 7 MMBTU/1,000 USD to below 5. Accounting for economic externalities due to emissions shows that BAU is the highest cost scenario followed by 100RE then 80 RE as the lowest as the latter avoids converting to the highest cost renewable alternatives.

Policy recommendations

Policy recommendations to support electrification as the cornerstone of the path to achieve the 100% RE vision of WWF have been developed. The policy recommendations covering the key areas of policy are summarised below.

Policies in Energy and Energy infrastructure planning

Targeting higher levels of Energy Efficiency (EE) through a mix of incentives, regulation, standardisation of methods, better data collection, strengthening regulation, monitoring and enforcement, and capability building.

Policies targeted at increasing the share of RE in the power system to enable supplying the increased electrification levels from renewable sources. In the high RE scenarios, electricity satisfies more than 50% of the energy consumed by 2040. By 2050 this rises to three quarters of energy consumed in the 100RE scenario and nearly two thirds in the 80RE scenario. This requires integration of RE sources into planning and operation of the power system including the grid which needs to develop to allow power from resource rich areas to reach high demand areas.

Policies to encourage flexibility needed by the power system. This includes encouraging demand-side flexibility, response to system needs (such as primary frequency response) and developing ancillary services markets.

Investment planning

Improve resource mapping and integrating planning requirements across networks, power system requirement, environmental, and health. Offshore wind requires additional attention including in the areas of surveying, evaluation and permitting.

Use auctions, an approach that has already been used successfully in other jurisdictions.

Improving system operations for electricity

Upgrade the grid code, system operation and forecasting to enable the integration of RE in an orderly and robust power dispatch system without unduly constraining RE from being dispatched.

Improve the underlying IT technologies to better integrate BESS and VRE into the power system. Modelling shows the growing share (and importance) of storage. Storage can play an important role in providing energy as well as system services to maintain system security and reliability.

Institutional arrangements

Strengthen governance including in the areas of monitoring and reporting.

Develop standards, methods and reporting systems for carbon accounting.

Develop the workforce to support achievement of the goals set in the policies.

Energy pricing and contracts

Reward flexibility, integrate distributed resources, collect accurate information in a timely manner and reward RE adoption through green certificates in addition to the announced system for carbon credits. The growing importance of EVs is seen by the growing electricity consumption in the transport sector in the high RE scenarios.

Transport sector

Encourage electrification and adoption of EV through financial support for early adopters and providing the necessary infrastructure. Modelling shows that the majority of passenger transport and freight will shift to EV and policies to encourage this shift are needed.

Develop regulation to encourage EV owners to participate in the bidirectional network that will develop.

Enforce the targets in the recently announced policy to phase out ICE.

Climate, health and environment

Develop an overarching planning framework that integrates climate policies, decarbonisation strategies and achievement of NDC targets. These policies will improve health outcomes by reducing pollution, reduce dependence on imported energy and accrue economic benefits to the economy.

1 Introduction

1.1 Project objectives

The overall objective of this project is to produce 100% RE scenarios of Vietnam's energy system and develop transition pathways for decarbonization. As part of the Multi Actor Partnership (MAPs) which endeavours to introduce and consolidate feasible and viable scenarios of full economy-wide renewable energy strategies in three countries (this study concerned with Vietnam). Developing a MAPs for Vietnam that demonstrates a complete energy system-wide shift to 100% RE contributes towards engaging discussion and the formulation/design of more ambitious RE policies. Moreover, the RFP adds that this work under the MAP should be closely aligned (and contribute to) other ongoing engagement endeavours Vietnam has been pursuing as part of the NDCP and in seeking implementation of updated NDCs.

This study is to be based on feasible and scientifically based policy design pathways for transitioning Vietnam's energy sector. The methodology to be used is to consider establishing a set of both technical and economic analysis on modelling results, detailing implications for developing RE transition policies in Vietnam. The results of the study should be used to inform both Vietnam's decarbonization and efforts for deploying higher shares of RE in the energy sector as well as present a model case study for other jurisdictions (and the work of partner institutions such as UNFCCC, IRENA, SDGs, NCAP) to reference in their own future assessments.

1.2 Scope of work

The scope of work defined in the RFP is targeted towards achieving the objectives, and ultimately concerned with setting out three key scenarios. In formulating the three scenarios, the RFP seeks the consultant to undertake the following:

- Determine baseline information and data on renewable energy, energy efficiency, energy demand, socio-economic through desk study and discussion (workshop, bilateral) with stakeholders to ensure quality of data, carry out analysis of energy efficiency and renewable energy potential with Solar PV, Concentrated Solar Power (CSP), On- and Off-shore wind, geothermal, hydro, bioenergy, distributed energy sources, and at the same time considering the following key plans:
    - Sustainable Development Goals (SDGs) to 2030,
    - Vietnam Power Development Plan No. 8 (PDP8),
    - Vietnam's National energy development strategy to 2030 with vision to 2045 ("Resolution 55"),
    - Macroeconomic development (including GDP, population growth, income per capita, industrialisation strategy and plans and other objectives),

- Collect and review related power alternative scenarios for Vietnam including analysis of the strengths and weaknesses of the previous relevant studies/scenarios,
- Model three scenarios to enable comparison:
  - Scenario 1: Business As Usual (BAU) scenario including power sector and energy system-wide plans and showcasing Vietnam's power sector, taking into consideration: PDP8 and Resolution 55. Scenario A1 of the Energy Master Plan was taken as BAU. The BAU has been updated to reflect the higher level of renewable electricity resource in the November 2022 version of the draft PDP8.
  - Scenario 2: 80% electricity and energy (80RE) supplied through the utilization of RE by the year 2050. This scenario is to consider increased e-mobility and heating processes (e.g., electrification of residential, commercial, and industrial processes) and, if feasible, hydrogen production using surplus RE,
  - Scenario 3: An advance scenario which is characterised by the ambition to achieve 100% RE (100RE) by 2050 for electricity and the entire energy supply, with a clear focus towards electrification, which would include, if feasible, increased production of hydrogen from surplus RE.
- The scenarios include (where relevant):
  - Renewable energy resource analysis based on GIS data,
  - The future energy demand per sector and region for Vietnam,
  - Pathways for the electrification of transport and heating processes, residential, commercial, and Industrial sectors,
  - Feasibility study on the loading capacity of the national grid for 100%RE scenarios,
  - Regional linkages for energy transmission, electricity import-export from/to other countries,
  - Calculations and assessments of socio-economic benefits of the transition – covering for example: benefits of carbon emission reductions, job growth per sector and other assessments of benefits of a less carbon intensive energy sector,
  - Hourly and annual load curve calculations/determinations,
  - Assessment of operational reliability of the power system,
  - Energy storage needs (in electrical energy and in terms of other energy sources – e.g. hydrogen or water storages),
  - Financial requirements over time in the three scenarios – in terms of investments, operational costs and variable operation costs,

- Account for the availability of land (e.g., not using conservation areas or agricultural land to develop energy resources),
- Compute and assess the implications for energy prices,
- Account for energy imports/exports (energy trade balances),
- Include (as a minimum) timespan and steps for period from 2020 to 2050, with milestones in five-year interval (2025, 2030, 2035, 2040, 2045) and compare these to the BAU scenario,

▪ Calculate/develop assumptions as inputs into the scenarios, based on a participatory process in collaboration with the project team,

▪ The study is also required to estimate comparisons of renewable energy production costs considering affordability and competitiveness against fossil fuel options, taking into account other costs such as environment, health, and other social impacts,

▪ Recommend 100% RE implementation options (policy, regulatory, institutional, technological, financial) to achieve the RE trajectories,

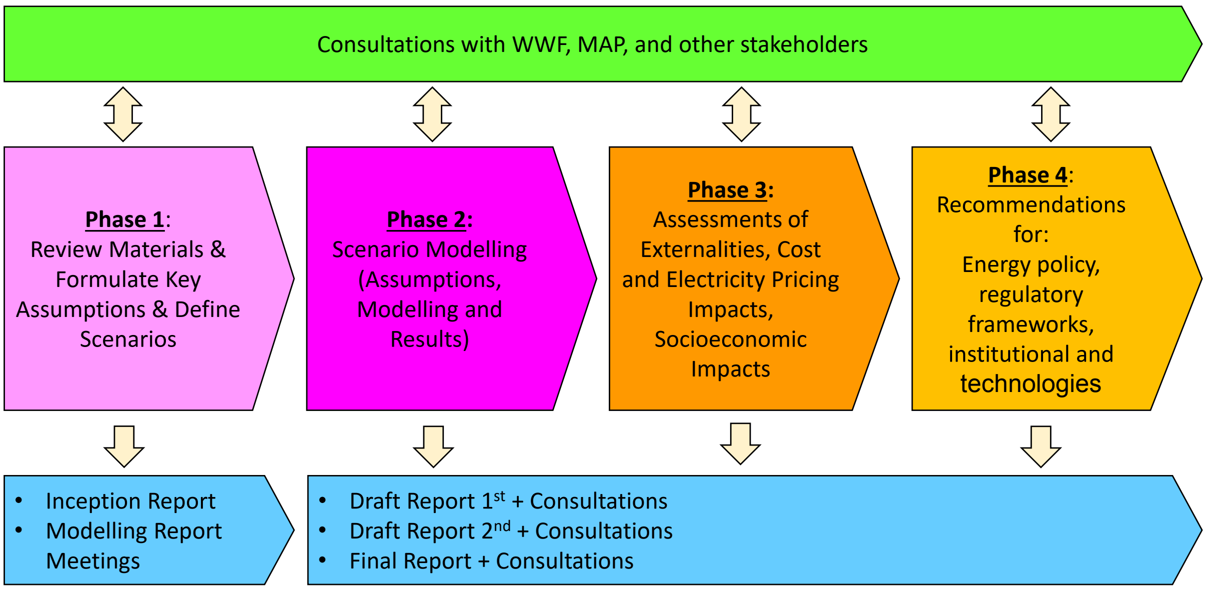
▪ Undertake consultations at all stages of the project:
  - Participate in development of summary for policy makers based on scenarios,
  - Present methodology and outputs to the project teams and in a subsequent workshop to members of the Multi-Actor-Partnership platform,
  - Technical 100% RE scenarios are consulted and validated via participatory workshops with technical working group and stakeholders, and
  - Contribute to the design of workshops, to gather relevant data for the modelling, with workshops that will be conducted primarily by WWF Vietnam and GreenID.

The remainder of the report is organised as follows and covers the project phase 2 through to phase 4 represented in Figure 1.

▪ Section 2 sets out the background and context to the project,
▪ Section 3 defines the scenarios and assumptions,
▪ Section 4 provides a detailed discussion of the modelling methodology,
▪ Section 5 discusses the BAU modelling results,
▪ Section 6 compares the scenarios against the BAU outlook,
▪ Section 7 explains a policy framework related to the study and development outlooks,
▪ Section 8 provides a summary of the key findings and conclusions, and

- The appendix (section 9) contains detailed assumptions relating to the transport sector.

Figure 1 Project phases



1.3 Notes to this report

The basis of figures quoted in this report, unless otherwise stated, is listed in Table 1.

Table 1 Reporting basis

Reference	Basis
Years	Calendar year starting Jan to Dec
Capacity and generation	As generated
Electricity demand	As generated
Dollars	Real, 2021 US dollars
Average prices	Time-weighted
Fuel prices	Delivered

2 Background and context

2.1 Vietnam energy sector policies

Vietnam's energy sector has experienced significant growth over the past decade with coal, oil and gas comprising a majority share of the country's energy supply. However, Vietnam in recent years has implemented a wide range of new domestic renewable energy policies, strategies, resolutions, and energy master plans that are geared towards encouraging the uptake of a higher share of RE. Moreover, Vietnam has actively participated in international climate change frameworks and conventions that promote energy-sector wide transitions towards increasing the deployment of RE to meet abatement targets.

This section provides a summary of the most relevant policies in line with transitioning Vietnam's power sector towards one that promotes low GHG emissions:

- Vietnam's Sustainable Development Goals to 2030,
- Vietnam's Renewable Energy Development Strategy to 2030,
- Vietnam Nationally Determined Contribution (NDC),
- Vietnam National Energy Development Strategy to 2030 with Vision to 2040,
- Vietnam Power Development Plan No. 8, and
- Mekong Delta Master Plan for 2021-2030 with vision to 2050.

Each of these policies has been summarised in the sections that follow. As the ultimate output of this project is a set of policy recommendations to expedite energy sector transformation, these form the basis on which to advance.

2.1.1 Vietnam's Sustainable Development Goals to 2030

The Sustainable Development Goals (SDGs) were established in 2015 by the United Nations General Assembly and offer 17 'global' goals for achieving a more sustainable future. There are many SDGs interlinked with the energy sector, amongst which SDG 7: Ensure Access to sustainable, reliable and affordable energy for all, and SDG 13: Respond in a timely and effective manner to climate change and natural disasters, most explicitly target the energy sector. Adapting to the local context, in 2015 Vietnam has 'nationalized' the SDGs into 115 Vietnam SDG (VSDGs) targets as part of the National Action Plan for Implementation Agenda 2030 for Sustainable Development.

With regards to the VSDGs in the context of the RFP, there are specific sub-targets for VSDG 7 and 13 we highlight below.

- VSDG 7: Ensure Access to sustainable, reliable and affordable energy for all:

- Target 7.1: By 2030, fundamentally 100% households have access to electricity; by 2025, fully 100% households have access to electricity; by 2030, ensure universal access
- Target 7.2: By 2030, substantially increase the share of renewable energies in the total national consumption of primary energies, more specifically to reach 31% by 2020
- Target 7.3: Energy efficiency - by 2030, double the national rate of improvement in energy use efficiency. Reduce the rate of power utilization by 10% compared to the baseline scenario.
- Target 7.4: By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services to all citizens, particularly in less developed regions, isolated and remote regions, mountainous and island regions
- For VSDG 7, Targets 7.2 and 7.3 are most relevant to the contents on the RFP and relate closer to supporting an RE energy sector transition. Prospects for achieving SDG 7.2 was initially considered a challenge from 2016-2017, while the non-hydro renewable energy potential for the country had yet to be developed. However, since 2018, there has been substantial development of both Solar PV and Wind renewable energy resources in the Country. SDG 7.3. is also relevant to this study, as energy efficiency through the economy has become a greater challenge due to the rise in the intensity of energy consumption in Vietnam (KgOE/USD 1,000 of 2005 GDP fixed), which is greater than the ASEAN and Global averages.
- Targets 7.1 has been largely achieved in 2016, when Vietnam reported over 99% household access to electricity. Moreover, Target 7.4 involves improving remote energy access, which is related to this study, however, less at the large economy-wide scale. The primary focus in this area instead will be on VSDG targets 7.2 and 7.3.

▪ VSDG 13: Respond in a timely and effective manner to climate change and natural disasters:

- Target 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and capacity in responding to natural and other disasters.
- Target 13.2: Integrate climate change measures into national development policies, strategies, planning schemes and plans.
- Target 13.3: Improve Educate, raise awareness, and strengthen-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

- Targets 13.1 – 13.3 all involve RE-related measures for mitigation and adaptation in the energy sector, however, each target differs in method of delivery. For example, 13.2 is more concerned with the adaptation of RE uptake measures into policies and planning strategies, whereas 13.3 is targeted at capacity building and expansion of human and institutional capabilities. All three VSDG 13 targets are relevant to the objectives of the RFP. In 2018, Vietnam produced a Voluntary National Review (VNR) on its implementation of the SDG targets that demonstrates multiple interlinkages of energy with other VSGS, so others might be of consideration for this study.

2.1.2 Vietnam's Renewable Energy Development Strategy to 2030 with a Vision to 2050

The government of Vietnam in 2015 implemented the Renewable Energy Development Strategy 2016-2030 with vision to 2050 (REDS). It set out various targets for promoting the use of energy from RE sources in Vietnam over 2020, 2030, and 2050 targets. One of the primary objectives of this strategy is to "Develop and utilize RE sources in such a way that contributes to fulfilling the objectives of sustainable environment and development of green economy." Amongst the most relevant targets (for our RFP involving the modelling of 100% RE scenarios for Vietnam's energy sector) for consideration include:

- Emissions reductions (relative to BAU) by 5% in 2020, 25% in 2030 and 45% by 2050.
- Reductions in Coal and Oil imports by 5% in 2020, 25% by 2030, and 45% by 2050.
- Share of RE in total primary energy consumption to reach 31% by 2020, 32.3% by 2030, and 44% by 2050.
- Share of RE in electricity generation from 38% in 2020, 32% by 2030, and 43% in 2050.
- Deployment of Solar-water heating devices to population for households to reach 12% in 2020, 26% in 2030, and 50% by 2050.
- Other targets for Biomass, Biogas and Renewable fuel consumption (amongst the most relevant is 5% renewable fuels in transport sector by 2020, 15% by 2030, and 25% by 2050).
- Increase of domestically manufactured RE equipment from 30% in 2020, 60% in 2030, and 100% by 2050.

Moreover, the REDS considers a Renewable Portfolio Standard as a policy mechanism to encourage the deployment of renewable energy. Power generation companies are to be mandated to reach 3% renewable power capacity by 2020, 10% by 2030, and 20% by 2050. These policy approaches will be considered as part of the modelling framework and design of a 100% RE strategy for Vietnam. All energy-sector related targets part of the REDS will be considered and evaluated in this project.

2.1.3 Vietnam's Nationally Determined Contributions (NDC) and NDC Partnership (NDCP)

Vietnam is a (Non-Annex 1) member to the United Nations Framework Convention on Climate Change (UNFCCC) and ratified party (as of 2016) to the Paris Agreement. Upon entering the Paris agreement, the Vietnamese government produced its Intended Nationally Determined Contributions (NDC) and issued alongside it the Plan for Implementation of Paris Agreement (PIPA). The purpose of the PIPA is to mobilize Vietnam's commitments in actions, represented by 68 groups of tasks that include both mitigation and adaptation.

In 2020 Vietnam's updated its NDCs, which involved a recalibration for Vietnam's intended contributions to be adjusted according to latest country context and comprised elements of both mitigation and adaptation. It also includes new commitments for GHG reductions from 2021-2030. There is a particular consideration of energy sector but goes beyond to also include carbon abatement in the agriculture, land use, land-use change and forestry (LULUCF) and waste sectors.

Table 2 shows Vietnam's updated NDC by sector. Note that the focus of this study is on the energy sector and as such our considerations for reaching abatement targets will be considered in the context of energy sector contributions. Considering both domestic resources and international support, the energy-sector by far the largest contribution to reductions and is indicated as a key area for decarbonization. By 2030, Vietnam's updated NDC targets a total reduction of 155.8 million Tonnes of CO2eq (or 62% of all NDC reduction commitments). Vietnam's NDC modelling showed that the reductions in energy sector emissions had the second largest positive impact on growth, mainly due to the rise in domestic investment and employment.

Vietnam is also member to the NDC partnership (NDCP), which aims to leverage a large global network to expand opportunities for implementing NDCs at the country level. Some overall goals of the NDCP include providing grass-roots knowledge sharing platforms, bridging gaps in technology and information, and enhancing financial avenues for abatement. The objective of the study is to advance the goals targeted by the NDCP by providing a study to demonstrate the feasibility and viability of deep decarbonization of Vietnam's energy sector overall.

Table 2 Vietnam updated NDC reduction contribution by sector

Sector	Contribution with domestic resources		Contribution with international support		Total Contribution (both domestic and resources and international support)	
	Compared to BAU scenario (%)	Reduction amount (Mil. tonnes of CO2eq)	Compared to BAU scenario (%)	Reduction amount (Mil. tonnes of CO2eq)	Compared to BAU scenario (%)	Reduction amount (Mil. tonnes of CO2eq)
Energy	5.5	51.5	11.2	104.3	16.7	155.8
Agriculture	0.7	6.8	2.8	25.8	3.5	32.6
LULUCF	1.0	9.3	1.3	11.9	2.3	21.2
Waste	1.0	9.1	2.6	24.0	3.6	33.1
IP	0.8	7.2	0.1	0.8	0.9	8.0
Total	9.0	83.9	18.0	166.8	27.0	250.8

2.1.4 Vietnam's Nationally energy development strategy to 2030 with vision to 2045 ("Resolution 55)

In February 2020, the government of Vietnam issued Resolution No.55-NQ/TW on Vietnam's National Energy Development Strategy to 2030, with a vision to 2045. Resolution 55 provides a national strategy for decarbonizing the energy sector while aiming to introduce more private sector competition. There are many targets, objectives and goals set out related to Vietnam's energy sector transition. The most relevant areas of this policy in relation to this study are :

- Increasing the share of renewable energy in total primary energy supply to 15-20% in 2030 and 25-30% by 2045.
- Primary energy intensity to 420-460 kgOE/USD 1,000 GDP by 2030 and 375-410 kgOE/USD 1,000 GPD by 2045.
- Establish regional ASEAN interconnectivity as one of the top 4 in terms of grid reliability.
- Energy-savings in total final energy consumption reduction by 7% in 2030 and 20% by 2045.

- Reduction of GHG emissions form energy sector activities by 15% in 2030 and 20% by 2045.

In addition to energy-sector targets, there are specific renewable energy provisions in Resolution 55 that include the prioritization of Solar and Wind energy potential, promotion of investments in renewable and green energy, and the introduction of preferable tax and financing mechanisms for encouraging the development of Vietnam's renewable energy sector.

Resolution 55 indicates some progress towards decarbonization at the energy sector level in Vietnam. However, the goals of RFP indicate far more ambitious targets to reach and facilitate a much higher share. Resolution 55 provides an indication of government's intention towards decarbonizing the energy sector and transitioning to a clean, renewable, and more long-term secure energy strategy for the country.

2.1.5 Vietnam's Power Development Plan 8 (PDP8)

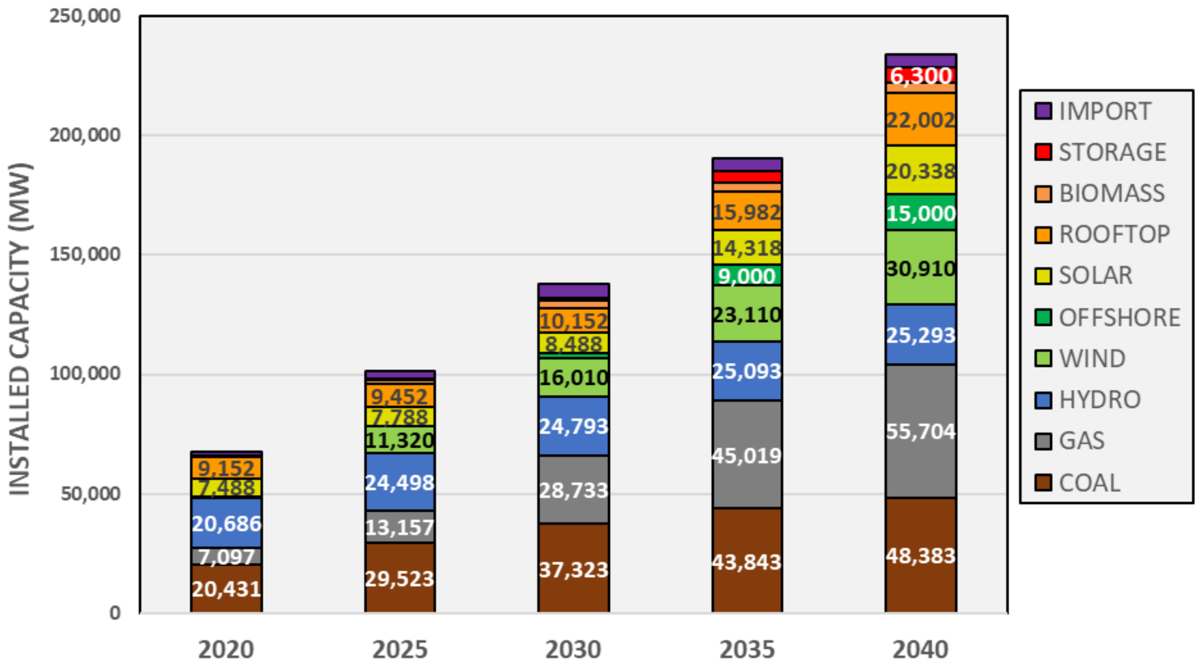
In February 2021, the MOIT released a draft PDP8, 'the draft proposal for the period of 2021-2030, with a vision to 2045 for public consultation'. In Figure 2 we summarize the growth of Vietnam's power system installed capacity in 5-year increments according to PDP8.

According to the PDP8 baseline scenario, the incremental capacity will primarily come from Coal plant to 2030, where after that LNG takes over as marginal supply. Moreover, renewable energy is significantly built out, with 30 GW of on-shore Wind, 15 GW of off-shore Wind, and some 40 GW combined of utility-scale and rooftop Solar PV. There is a small amount of Battery Energy Storage System (BESS) and Pumped Hydro Storage (PHS) amounting to 6.3 GW total supporting RE development. This compares to a much more thermal coal-heavy outlook in the previous revised PDP7 base case.

The PDP8 considers numerous scenarios for the share of RE in electricity generation mix in Vietnam, including:

- Scenario 1 – Renewable Energy Target according to RE development strategy and Resolution 55 (32% by 2030, 37.5% by 2040, and 43% by 2050 – share of RE in electricity generation mix).
- Scenario 2 – High Renewable energy target (39% by 2030, 41% by 2040, and 43% in 2050).
- Scenario 3 – Ambitious RE target scenario (42% by 2030 and 46% by 2040, and 50% by 2050).

Figure 2 PDP8 projected growth of Vietnam's power system



There have been many updates to the draft PDP8. The BAU incorporates the higher level of renewable energy resource included in the November 2022 version.

2.1.6 Mekong Delta Master Plan for 2021-2030, with vision to 2050

A draft master plan for the Mekong Delta (2021-2030 with vision to 2050) was released for public feedback in February 2021. One major policy development driven by this strategy is a "no new Coal in the Mekong Delta region", which is a relevant consideration for the objectives set out in this study, particularly as it pertains to the development of hydro resources.

2.1.7 Vietnam Technology Catalogue for power generation and storage

The Vietnam Technology Catalogue is developed under the Danish-Vietnamese Energy Partnership and contains data that has been scrutinised and discussed by a broad range of relevant stakeholders including the Ministry of Energy and Trade (MOIT) and its research organisations, Vietnam Electricity (EVN) and its subsidiaries, Electricity and Renewable Energy Authority (EREA), independent power producers, and local and international consultants. The Technology Catalogue will assist long-term energy/power modelling in Vietnam through a common and broadly recognised set of data. The latest version of the catalogue which will be referred to in the aim to achieve 100% RE has been updated to include all the technologies that have been reviewed since the last version to include many more RE technologies.

The technologies covered in the catalogue cover both, very mature technologies as well as emerging technologies, such as hydrogen, which could be highly important to be considered to reach the goal of 100% RE. The emerging technologies are expected to improve significantly over the coming decades with respect to both, their costs and their performance. Hence, the details of these technologies were considered in the creation of the assumptions workbook, as there is an admitted level of uncertainty.

2.1.8 Draft Energy Master Plan (EMP) for period 2021-2030 with vision to 2050

The draft EMP is the first national energy master plan that is inclusive of component energy plans, including those for coal, oil and gas, electricity, and renewable energy. The draft report was published by MOIT in December 2020 for stakeholder comments and consultation and subsequent updates released. We summarise below the main points of three component energy plans relevant to out scope.

We have reviewed the contents of the draft EMP that are pertinent to the objectives of our project. In particular, we will be examining the following information:

- National strategies for low carbon development including renewable energy development strategy, strategy for climate change, and green growth strategy
- Definition / formulation of the energy planning scenarios
- Energy demand forecasts, especially for non-electricity sectors
- Supply potential of primary energy sources
- Energy prices forecasts
- Assessment, comparison of the energy planning scenarios and recommendation of the preferred scenario

2.1.8.1 Renewable energy development strategy

- Reduce greenhouse gas (GHG) emissions of energy activities compared to BAU: around by 5% in 2020, around 25% in 2030 and around 45% in 2050.
- Reduce import of fuels: by around 40 million tons of coal and 3.7 million tons of petroleum products in 2030, by around 150 tons of coal and 10.5 tons of petroleum products in 2050.

Table 3 Indicators of RE Development Objectives

Indicator	2015	2020	2030	2050
RE production & consumption, MTOE	25	37	62	138
RE share in the primary energy total, %	31.8%	31.0%	32.3%	44%
Electricity generated from RE, TWh & (%)	58 (35%)	101 (38%)	186 (32%)	452 (43%)

Indicator	2015	2020	2030	2050
Hydropower generation, TWh	56	90	96	
Pumped storage hydropower, MW			2,400	8,000
Biomass for power generation, TOE & (%)	0.3 (1%)	1.8 (3%)	9.0 (6.3%)	20.0 (8.1%)
Biomass for heat production, TOE	13.7	13.6	16.8	23.0
Biomass for bioenergy, TOE	0.2	0.8	6.4	19.5
Wind power generation, TWh & (%)		2.5 (1%)	16 (2.7%)	53 (5%)
Solar power generation, TWh & (%)		1.4 (0.5%)	35.4 (6%)	210 (20%)

2.1.8.2 Strategy for climate change

- Hydropower capacity is in between 20,000 MW – 22,000 MW by 2020
- Increase the share of new and renewable energy sources in the total commercial primary energy to around 5% in 2020 and around 11% in 2050 (excluding conventional hydropower).

2.1.8.3 Green Growth Strategy

- For 2011-2020: Reduce the GHG emission intensity by 8%-10% compared to the 2010 level, reduce the GDP energy intensity by 1% - 1.5% each year; reduce GHG emissions from energy activities by 10% - 20% compared to BAU (including the additional 10% reduction which may be achieved with utilisation of international support). Reduce the energy to GDP elasticity from 2.0 in 2012 to 1.0 in 2020.
- 2030 Outlook: Reduce the level of GHG emissions by at least 1.5% to 2% each year, reduce GHG emissions from energy activities by 20% - 30% compared to BAU (including the additional 10% reduction which may be achieved with utilisation of international support).
- 2050 Outlook: Continue the reduction of the level of GHG emissions by at least 1.5% to 2% each year.
- Definition / formulation of the energy development scenarios

2.1.8.4 Energy planning scenarios

The EMP considered the following factors in defining the energy development scenarios, refer to Table 4.

Table 4 Factors and indicators – EMP scenarios

No.	Factor	Indicator	Remarks
1	Growth	GDP growth scenarios	Average and high growth
2	RE objective	RE share in total primary energy	Decision 55: 15% - 20% in 2030, 25% - 30% in 2045

No.	Factor	Indicator	Remarks
3	GHG emission reduction	GHG emission reduction objective	Decision 55: 15% in 2030, 20% in 2045 NDC: 9% - 27% in 2030
4	Energy efficiency & conservation	Energy efficiency & conservation objective	Decision 55: 7% in 2030, ~14% in 2045 VNEEP3: 8% - 10% in 2030

The results of each scenario were evaluated along the following main criteria set out in Table 5.

Table 5 Main criteria for evaluation of scenarios

Field	Evaluation Criteria
Economy	System costs (including externalities)
Environment – Society	Environment – Society Carbon dioxide emissions Gas emissions into air Other impacts
Energy security	Energy security indicators Energy intensity Imported energy proportion Energy diversity Energy reserves

The EMP stipulates that the component energy plans; including those for coal, oil and gas, electricity, and renewable energy, will be developed consistent with the EMP's preferred scenario.

The six scenarios analysed in the EMP are given in Table 6. The first three use average GDP growth and the other three use High GDP growth.

Table 6 Proposed Energy Development Scenarios

No.	Scenario / Abbreviation	Description
1	A0 – Reference Base Scenario (A0-BASE)	Average GDP growth scenario, low EE-C
2	A1 – Average Objective Base Scenario (A1-C15-E10-RE15)	Average GDP growth scenario, 15% RE share, 15% GHG emission reduction, average EE-C (8%), externalities (CO2, SOx, NOx)
3	A2 – High Objective Base Scenario (A2-C27-E15-RE20)	Average GDP growth scenario, 20% RE share, 27% GHG emission reduction, high EE-C, externalities (CO2, SOx, NOx)

No.	Scenario / Abbreviation	Description
4	A3 – Reference High Scenario (A3-HIGH)	High GDP growth scenario, low EE-C
5	A4 – Average Objective High Scenario (A4-C15-E10-RE15)	High GDP growth scenario, 15% RE share, 15% GHG emission reduction, average EE-C (8%), externalities (CO2, SOx, NOx)
6	A5 – High Objective High Scenario (A5-C27-E15-RE20)	High GDP growth scenario, 20% RE share, 27% GHG emission reduction, high EE-C (12%), externalities (CO2, SOx, NOx)

The EMP only considers average (Base) and high GDP growth scenarios (according to the CPV 13th General Congress Direction).

- Average Growth Scenario:
  - Average GDP growth rate is forecasted at 6.8% per year in the period of 2021 – 2025, 6.4% per year in the period 2026 – 2030, and 6.6% per year for the whole period 2021 - 2030. In the period to 2031 - 2045, the growth rate will decrease to 5.7%/year in the period 2031 - 2045.
- High Growth Scenario:
  - Average GDP growth rate is forecasted at 7.5% per year in the period of 2021 – 2025, 7.2% per year in the period 2026 – 2030, and 7.4% per year for the whole period 2021 - 2030. In the period to 2031 - 2045, the growth rate will decrease to 6.3%/year in the period 2031 - 2045.

The growth targets up to 2030 for some sectors, shown in Table 7, are incorporated into the EMP.

Table 7 Target growth rates in the EMP

No	Sector	Target growth rate		
		2016-2020	2021-2025	2026-2030
1	Paper industry	9.8%	9.5%	
2	Steel	18.8%	3.7%	
3	Cement	4.4%	2.0%	
4	Textile	10%	7%	
5	Transport		~7%	

2.1.8.5 EMP Preferred Scenario

The EMP evaluated the outcome of the six scenarios using a quantitative scoring system that attributed 100 points of negative impact to the worst scenario for each of the criteria considered. Scenario A1 was selected as the preferred scenario as the option that achieves the main policy objective with moderate cost increases which are acceptable for the 2021-2030 period. Scenario A1 has the following main features:

- Average GDP growth scenario
- Renewable energy objective: 15% share in the total primary energy supply in 2030 and 20% in 2050
- GHG emission reduction objective: 15% reduction compared to BAU
- EE-C objective: meeting Vietnam - National Energy Efficiency Program 2019 – 2030 (VNEEP3) - average EE-C (8%)

The main indicators of Scenario A1 are shown in the Table 8 and emissions shown by sector in Table 9.

Table 8 Main indicators of EMP preferred scenario A1

Scenario	Accumulated system costs 2021-2050 (mil. USD)	Main indicators						
		System cost (mil. USD)	Primary energy (MTOE)	CO2 emissions (mil. ton)	RE %	Import dependency %	Supply diversity index HHI	Energy intensity (kgOE/$)
2030	4,937	123	173	459	21%	53%	2295	0.198
2050	4,937	311	354	830	20%	70%	2193	0.084

Table 9 CO2 emissions of the preferred scenario by sector (million tons)

Sector	2020	2030	2040	2050
Agriculture	4.9	7.0	9.4	12.3
Commercial	3.4	9.7	14.4	19.4
Industrial	54.5	108.1	155.3	232.3
Power generation	121.7	234.2	367.8	330.5
Household	5.7	6.6	6.1	19.7
Energy exploitation	24.6	23.0	24.7	43.0
Transport	38.6	70.2	110.6	172.8
Total CO2	253.4	458.6	688.4	830.1

2.1.9 National energy efficiency program

Vietnam implemented VNEEP programs over two periods: 2006 to 2010, which achieved savings equivalent to 4.9 MMTOE, and 2012 to 2015 (VNEEP2), which achieved savings equivalent to 11.2 MMTOE [1]. These were followed in the current period by, Vietnam - National Energy Efficiency Program 2019 – 2030 (VNEEP3), Prime Minister's Decision 280/QD TTg, with a goal of reaching 5% to 7% of total national energy consumption in 2019 to 2025 and 8% to 10% by 2030. The main points in VNEEP3 are [2]:

- Review, develop and complete mechanisms and policies on EE&C

- Provide technical and financial assistance to promote investment, production and business projects on energy efficiency
- Building Vietnam energy data center, databases, applying information technology on energy and energy efficiency
- Strengthening capacity for energy efficiency
- Strengthen inspection, supervision, urge and guide the implementation and evaluation of the results of implementation of law provisions on energy efficiency
- Communication to raise public awareness about energy efficiency
- Strengthening international relations and cooperation in the field of energy efficiency
- Scientific research and technology development on energy efficiency
- Establish a fund to promote energy efficiency

2.1.10 Action Program for Transition to Green Energy

The Action Programme for Transition to Green Energy and Mitigation of carbon dioxide and methane emissions in the transport sector, Decision No. 876/QD-TTg was approved on 22 July 2022. The plan's overall objective is to develop a green transport system that has net zero GHG emissions by 2050. The action plan relates to the various modalities of the transport sector and addresses areas of investment in transport infrastructure such as building charging stations for EV and making rail network investments, encouraging fuel blending in the short term, encouraging consumers to transition to electricity and green energy and encouraging research and international cooperation. The action plan includes specific measures such as phasing out the production, assembly and import of automobiles, motorcycles and mopeds using fossil fuels by 2040.[1] The plan's horizon extends to 2050 and includes targets, including interim targets, for transitioning vehicles and equipment to use electricity and green energy. The vehicle and equipment targets are listed below:[2]

- By 2050 –100% of buses and taxis to use electricity and green energy.
- From 2030 – A minimum of 50% of vehicles and 100% of new taxis to use electricity and green energy.
- From 2025 – 100% of new buses to use electricity and green energy.
- From 2040 – All vehicles operating in airports to use electricity and green energy.

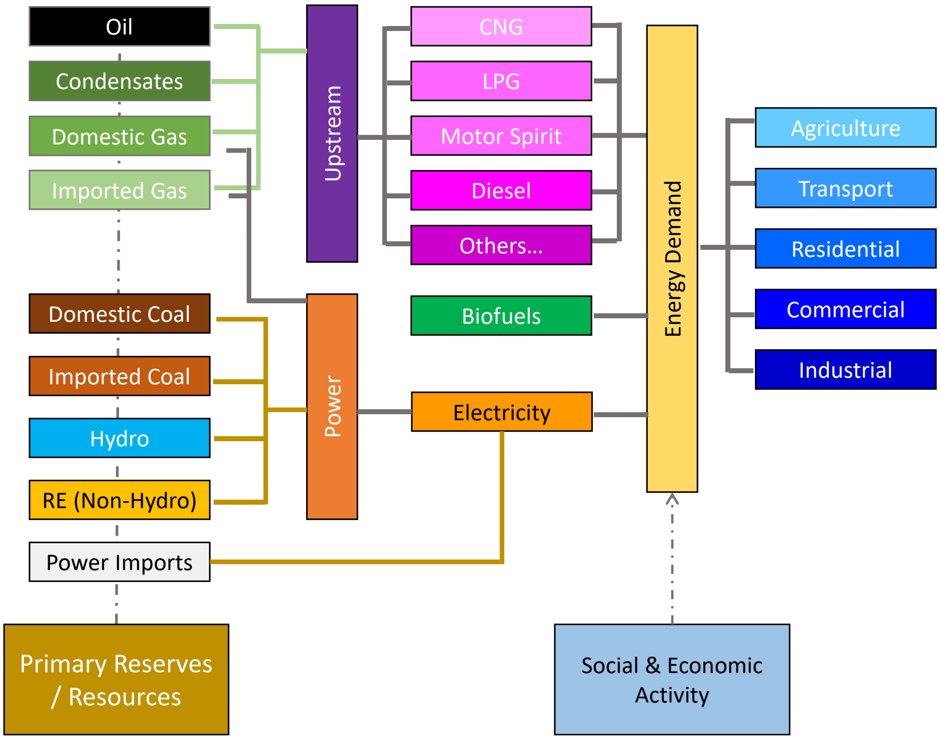
[1] Available at Decision No. 876/QD-TTg dated July 22, 2022 on approving the action program for transition to green energy and mitigation of carbon dioxide and methane emissions from transportation - LawNet. Accessed on 27 January 2023.
[2] Available at https://www.climate-laws.org/geographies/vietnam/policies/decision-no-876-qd-ttg-on-approving-the-action-program-for-transition-to-green-energy-and-mitigation-of-carbon-dioxide-and-methane-emissions-from-transportation. Accessed on 27 January 2023.

- From 2035 – 100% of new passenger vehicles and other vehicles in airports to use electricity and green energy.
- From 2050 – All vehicles and equipment in ports to use electricity and green energy or have equivalent transition measures.
- After 2035 – Ships that are built, converted or imported must use electricity and green energy. Convert all inland waterway ships to use electricity and green energy from 2050.
- By 2050 – Transition 100% of inland railway using fossil fuels and 100% of equipment in inland ports and wharves to use electricity and green energy.
- By 2040 – 100% of new inland waterway vehicles to use electricity and green energy. Apply criteria for green ports to 100% of inland waterway ports.
- By 2050 – 100% of rolling stock to use electricity and green energy. Transition 100% of equipment that uses fossil fuels at stations to electricity and green energy.
- By 2050 – 100% of heavy equipment involved in traffic to use electricity and green energy. Bus stations and rest stops to meet green criteria. Transition all material handling equipment using fossil fuels to electricity and green energy.

2.2 Decarbonisation energy conversion chains

Each scenario projects Vietnam's energy sector for the period from 2021 to 2050. This required modelling the energy conversation chain for Vietnam. The modelling framework reflects the interactions between demand for end use energy consumption and supply of energy consumption – via energy carriers. A framework showing the key elements of the energy conversion chain is set out in Figure 3.

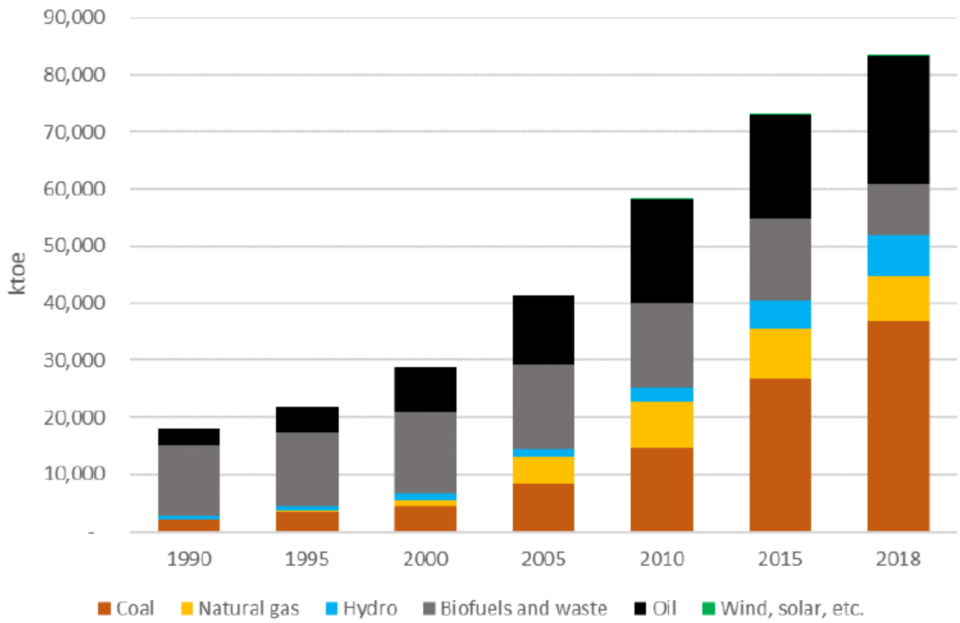
Figure 3 Model of energy conversion



2.2.1 Primary Energy Sector

The primary energy is energy in its natural form as found in nature including raw fuels and other forms of energy received as input to a system. Primary energy includes non-renewable energy such as fossil fuels and renewable energy (RE) forms. The primary energy sector is concerned with the delivery of such energy to a country, and in Vietnam's case, this presently includes the delivery of imported coal and in the future, Liquefied Natural Gas (LNG). As illustrated in Figure 4, Vietnam's primary energy supply is heavily dependent on coal (44%), natural gas (10%), and oil (27%) – based on 2018 data.

Figure 4 Vietnam Total Primary Energy Supply (TPES) (1990-2018)

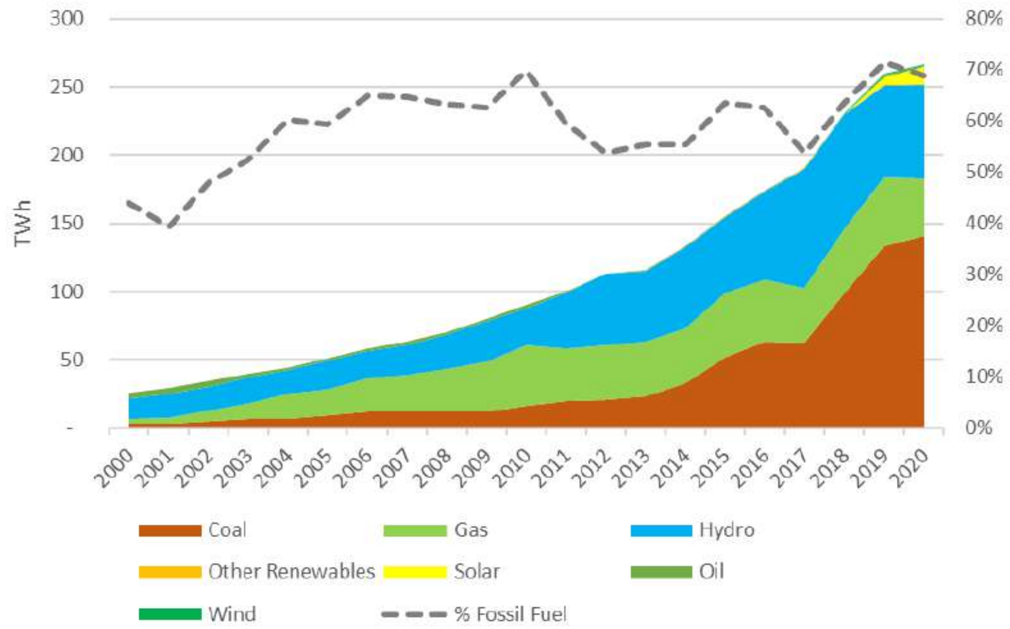


2.2.2 Secondary Energy Sector

Secondary energy is a carrier of energy, with electricity being the most common example, and the other being the petrochemical industry – with the conversion of crude oil into petroleum products by refineries as inputs into industry. Primary energy sources are converted into secondary energy forms. As illustrated in Figure 5, the outputs from secondary energy are in the end used to serve demand for energy services that are in turn driven by economic and societal activities.

Within Vietnam's secondary energy sector, the electricity sector is a very significant component, with oil refineries also playing significant role. As illustrated in Figure 5, some 70% of Vietnam's electricity supply comes from fossil fuels, with coal playing the most significant role.

Figure 5 Vietnam's Electricity Sector by Generation Source and % Fossil Fuel Supply (2000-2020)

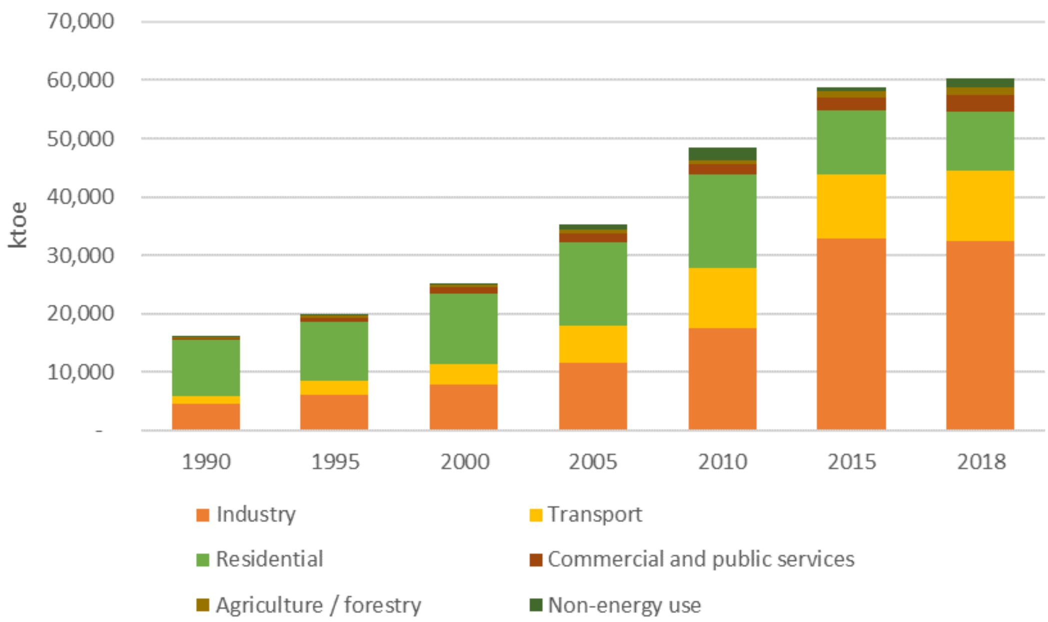


2.2.3 End Use Energy Consumption

End use energy consumption is the total energy consumed by end users of energy services which includes industry, households, commercial, and agriculture subsectors. It excludes any consumption that is used by the energy sector itself and which is absorbed in losses. Different subsectors have different requirements for the energy carriers of electricity and petrochemical products.

Figure 6 shows the total final energy consumption (TFC) for Vietnam to year 2018. The industrial sector consumes approximately 54% of the total energy (as of 2018) with a significant portion of this based on direct consumption of coal [3] which is used as a heat source needed in certain manufacturing process such as steel and cement production. The future energy consumption from the industrial sector, given its high energy consumption, plays a vital role in the electrification of Vietnam. The transport sector comprises some 20% of end use energy consumption as the next most consumption-heavy sector, and its consideration in this project is also very important.

Figure 6 Total Final Consumption in Vietnam (1990-2018)



2.2.4 Towards 100% RE and Decarbonising the Energy Chain

Considering the high penetration of fossil fuels in Vietnam's energy system – almost 70% as shown in Figure 6 – the decarbonisation of Vietnam's energy conversion chain and transitioning it towards the utilisation of only sustainable renewable energy resources is quite challenging. While progress has been made in terms of wind and solar uptake in the very recent past, there are numerous actions that need to be taken across different areas of energy conversion chains to accomplish an 80% RE or 100% RE vision by the year 2050.

2.2.5 Primary energy supply

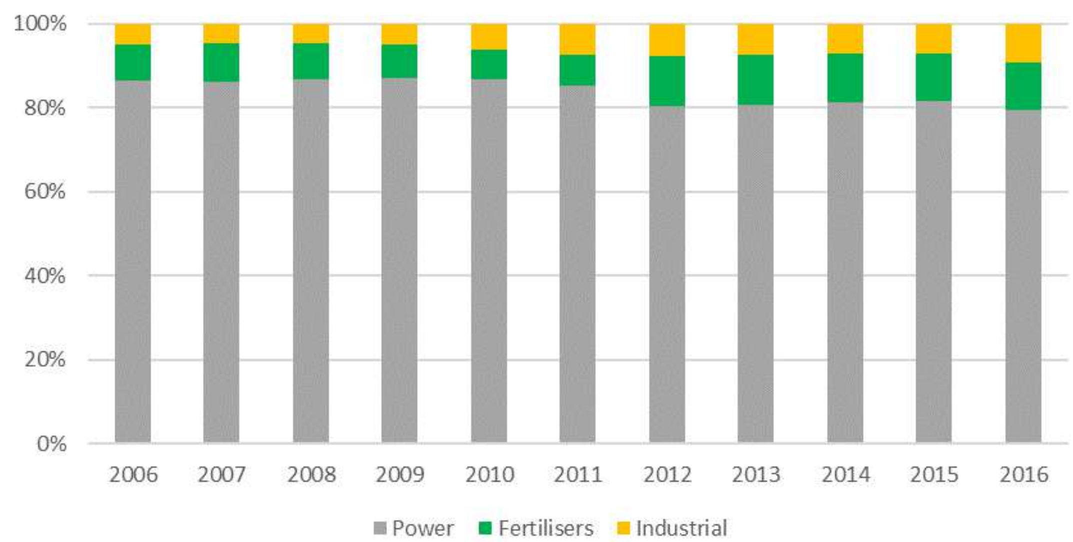
Hydrocarbon industries have long since been a core component of most country's energy sectors and significant investments have been made in infrastructure to support the import or extraction of fossil fuel energy (coal and natural gas) and delivering it to end uses is central to supplying energy to its end-uses. Vietnam has a very high reliance on imported coal, exploitation of domestic coal, and the exploitation of domestic offshore gas reserves. In the near term, there are plans to import liquefied natural gas (LNG) primarily to satisfy electricity demand. The strategy for consideration to decarbonise Vietnam's primary energy sector essentially has three main components:

- Coal sector,
- Gas sector, and
- Oil sector.

The key drivers for coal consumption in Vietnam are the use of coal for power production purposes in Vietnam's electricity sector and the use of coal for heating purposes in Vietnam's industrial sector. In the electricity sector, the strategy for the phase-out of coal is clearly related to increasing use of renewable energy and energy storage in Vietnam's power system and phasing out coal-fired power stations. Considerable challenges include the unwinding of long-term PPAs, finding alternative uses for the coal import facilities, and switching industry heating from the use of coal towards the use of electricity. Other opportunities for coal phase-out include the reduction in coal use in Vietnam's residential sector, where a modest amount of coal is used for cooking and heating purposes.

In terms of Vietnam's gas sector, as illustrated in Figure 7, historically power generation sector has been the main gas user accounting for more than 80% of the total gas demand over the 2006-2016 period. Gas consumption by fertilisers has been stable at 11% while the other industrial gas users (currently only present in the Southeast and Northeast regions) increased their share from 5% in 2006 to more than 9% in 2016. As such the most immediate opportunity for the transition of Vietnam's gas sector towards 100% RE is to also focus on gas consumption in Vietnam's electricity sector.

Figure 7 Gas Demand Composition by End Use (2006-16)



A technology option is the exploitation of renewable-energy hydrogen ("green hydrogen") which is an emerging low-emissions baseload generation technology which has over the past few years, been a significant area of research and development with the promise of net-zero emissions and it is able to utilise existing infrastructure that is already in place to produce and transport the fuel – in particular the conversion of the existing gas sector infrastructure to hydrogen. Additionally, the costs of producing green hydrogen have dropped by almost 50% since 2015 and could be reduced by a further 30% by 2025 due to the benefits of increased scale and standardized manufacturing. However, care should be taken to understand the assumptions and basis when analysing reported costs. In addition to equipment costs, the cost of energy supplying the electrolysers and the utilisation of electrolysers are major cost factors. For example, if an electrolyser is powered by VRE (to reduce the variable cost of energy) then utilisation of the electrolyser can only be increased by incorporating other sources to firm up supply. In high RE scenarios it may not always be optimal to dedicate the RE low cost electricity to the production of hydrogen. Numerous countries (including Australia and Japan in the Asia-Pacific) are working towards making hydrogen a significant export industry with various government led initiatives and pilot projects covering the production, transport and generation based on green hydrogen. Key areas include:

- Hydrogen production can be produced through a process that uses renewable energy only,
- Hydrogen can be transported via existing gas networks, and supply chains – enabling natural gas infrastructure to be "transformed" in line with a low emissions pathway,
- Hydrogen can be used to produce energy with the existing gas turbines of combined cycle gas turbines (CCGTs) or Internal Combustion Engine (ICE) based generation technologies, and
- The technology can play a baseload role or a fast-responding intermediate / peaking role in a power system providing for flexibility and/or the ability to replace baseload coal generation.

However, given that the green hydrogen technology is still relatively young, there are challenges that must be overcome before it can be successfully deployed on a commercial level. Some of the challenges are:

- Green hydrogen production requires electrolysers to be built on a much larger scale than what are readily available,
- Either very high pressures or very low temperatures are required for its transportation and storage, both of which present their own technical difficulties
- Despite the drops in its production cost mentioned earlier, it must reach a benchmark of $2/kg to become competitive with natural gas. The current cost is at $4-$5/kg, but it is believed that the benchmark price of $2/kg is achievable by 2030.

Finally, in Vietnam's oil sector, the greatest source of demand for petroleum products is the transport sector followed by industry. Therefore, the strategy for transitioning Vietnam's oil sector towards renewables is to increase liquid renewable fuels and electrification in the transport and industry sectors. Electrification of the transport sector requires a consideration of the different modes of transportation and transitioning each sector in a stepwise manner to the use of electric vehicles (EVs), which must also be coordinated with investments in appropriate charging infrastructure. In particular:

- Taking measures to support electric cars being phased in and complementing this with the necessary investments in charging infrastructure, and
- Introduction of fuel blending and use of advanced renewable fuels, as well as hydrogen for domestic and international shipping and aviation industries.

2.2.6 Secondary energy sector transformation options

As discussed earlier, Vietnam's secondary energy sectors are:

- electricity subsector, and
- the petrochemical / refinery subsector.

Electricity sector transformation towards the use of renewables requires consideration of the characteristics of the different renewable energy technologies – with solar and wind being characterised by intermittency which needs to be complemented with flexible resources – energy storage options and increased levels of ancillary services. Vietnam's power sector, under the Power Development Plan 8 (PDP8) recognises that energy storage options in the form of large-scale Battery Energy Storage Systems (BESS), Pumped Storage Hydro (PSH) and possible expansions to existing Hydro Reservoirs, will play a crucial role in supporting higher levels of variable renewable energy. As illustrated in previous works, it is technically feasible to transition Vietnam's power sector towards being based on Renewable Energy (RE) without compromising power system reliability. This lays the foundation for the transformation of other subsectors and will be the cornerstone of transformation of Vietnam's energy sector towards 100% RE.

The most significant consumer of energy via Vietnam's petrochemical sector is the transport sector, which as previously discussed can undergo a transformation towards electric vehicles that can be coordinated with charging infrastructure and transformation of the electricity sector. There are other forms of transport – most notably shipping and aviation, as well as industrial end use of petroleum products for which a consideration of bio-refineries and synthetic feedstock used for petrochemicals in industry are an option to transform the petroleum sector towards RE. Fuel blending and use of synthetics is a way of leveraging existing infrastructure, thereby potentially saving capital costs.

2.2.7 End-Use energy consumption transformation options

Vietnam's end use energy consumption can be divided into five categories consisting of:

- Agriculture,
- Transport,
- Commercial,
- Residential, and
- Industry.

Each of these sectors have their own energy consumption requirements which will be a mix of oil, gas and electricity which needs to be understood for different classes of end-use energy consumer. It is understood that of these, the industrial sector is the most complex and presents the most challenges with regards to its decarbonisation. Just three industries – iron and steel, chemicals and plastics, and cement – account to roughly 55% of all industrial emissions, and the top 10 industries are responsible for roughly 90% of industrial emissions. Hence, focusing on a smaller set of product and process improvements can generate more effective results. However, the irony of the situation is that the industry sector itself is responsible for producing technologies like renewable electricity generation facilities, clean vehicles, energy efficient buildings, CO2-free steel, carbon-free cement, and much more. Nevertheless, it is necessary to reduce the industrial emissions even as industries continue to supply transformational technologies. Some of the options that can be adopted to reduce the emissions from the industrial sector are:

- Electrification – Replacing technologies and systems that run on fossil fuels with alternatives like boilers, smelters, heat pumps and induction stoves that run on clean electricity. However, scaling up electrification on am industrial scale requires a multi-faceted approach at the federal, state, and local levels.
- Carbon Pricing – Putting a price on carbon influences energy consumption and investment decisions while also creating a revenue stream that can be reinvested to accelerate the clean energy transition and support programs that reduce pollution.

These broadly represent strategies to substitute carbon intensive energy consumption with less carbon intensive or renewable energy based, or to curtail consumption through energy conservation or energy efficiency measures. In the end, both strategies are essential if 100% RE is to be accomplished, and as noted in the previous section, transformation of the country's national power system to have supply entirely based on RE is a crucial element of substitution.

Key options for transitioning the end-users towards 100% RE include:

- End-use energy efficiency measures to reduce consumption – including improvements to equipment performance, building energy efficiency, improvements to industrial processes, and so on,
- Demand-Response / Demand-Side Management technologies – including smart meters and other technology to remotely control load – which in turn need to be coupled with some form of dynamic pricing of energy / electricity,
- Small scale, distributed energy resources deployed in behind-the-meter contexts – such as rooftop solar PV and distributed energy storage, and

- Capitalising on the potential for Biomass – utilising Vietnam's vast sugar industry's bagasse waste together with other sources of biomass like wood chips, rice straw and rice husks to generate energy in a carbon-neutral manner.

Vietnam is well-positioned to implement such measures over time and they will be considered in this project.

2.3 Vietnam's Renewable Energy Resources

2.3.1 Solar resources

Vietnam is considered to have good potential for the development of solar energy. The country has 13 weather stations to measure radiation, and over 170 weather stations distributed over most of the provinces to measure the number of hours of sunshine. The number of hours of sunshine ranges from 1,300 to 2,900 hours per year which tends to increase gradually from North to South.

The World Bank, in their 2018 report on developing Solar PV in Vietnam, indicated five classes of Solar irradiation in the country. Areas in dark red with PVOUT of over 4.6 kWh/m2/day in South-Central Phan Thiet can yield capacity factors of over 19%, whereas areas in yellow (near Hanoi in the North) with under 3 kWh/m2/day only provide capacity factors under 15%.

They highlight that Ninh Thuan and Binh Thuan are the two provinces most suitable for the development of Solar PV plants (prioritize zones). In addition to having PVOUT of over 4.4 kWh/m2/day, there was enough contiguous land area, proximity to substations and HV network with available hosting capacity, and nearby load demand centres. Areas with 'Very Good' potential (4-4.2 kWh/m2/day) are scattered across 12 provinces amounting to over 135 GW, with large clusters of 47 GW in Binh Phuoc, and 24 GW in Tay Ninh.

'Good Solar PV' potential (4-4.2 kWh/m2/day) in Vietnam totals almost 350 GW across 19 provinces, with Gai Lai (55 GW), Dak Nong (44 GW) and Dak Lak (40 GW) together accounting for a majority share. The criteria for floating Solar PV potential was identified to require a combination of a Solar PVOUT higher than 4 kWh/m2/day, sized greater than 100 MW and cover under 20% of the reservoir area with panels.

As part of the PDP8, a more high-level assessment was conducted and indicated remarkable technical potential through topographic overlays. This study was based on the methodology from IRENA and is calculated using a Solar Resource Map with exclusions based on land use zones, infrastructure and cultural sites and other land conditions which exclude the build-up of solar. The assumptions used in this report are based off the resource potentials as detailed in the PDP8 summarized below in Table 10. The technical potential indicates there is a total of 1,568 GW of technical potential in Vietnam with the most robust potential in terms of output lies in the South, South Central, and Highlands regions, with strong indicated capacity to power output ratios. Despite the

North region having very low potential PVOUT of under 3/ kWh/m2/day and at capacity factors under 15%, there is a remarkable 827 GW of technical Solar PV potential in the North, comprising more than half of Vietnam's total.

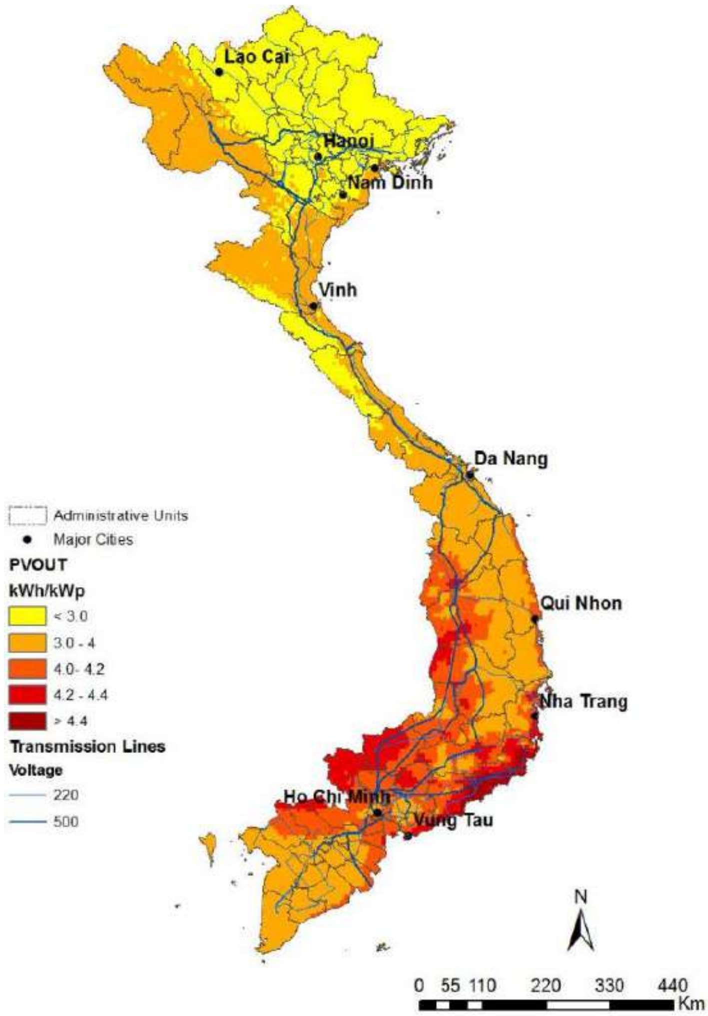
Table 10 Technical potential of terrestrial, rooftop, and floating Solar PV in Vietnam

Region	Capacity (MW)			Power Output (GWh/year)		
	UTILITY	ROOFTOP	FLOATING	UTILITY	ROOFTOP	FLOATING
NORTH	826,800	10,724	16,859	1,046,035	13,626	26,974
NORTH_CENTRAL	103,600	5,542	8,895	136,978	7,351	14,231
MID_CENTRAL	31,459	3,521	11,323	45,371	5,376	18,116
HIGHLANDS	199,763	2,448	8,855	344,600	4,186	14,167
SOUTH_CENTRAL	159,320	4,165	10,871	280,175	7,210	17,394
SOUTH	247,320	22,091	20,373	439,649	38,591	32,596
Total	1,568,551	48,497	77,176	2,292,809	76,342	123,481

Source: PDP 8 [4]

An illustration of Vietnam's solar potential is given in Figure 8. Under 80% and 100% renewable energy scenarios for Vietnam's energy sector, a greater proportion of technical Solar PV capacity will have to be developed.

Figure 8 PVOUT by class in Vietnam (ESMAP 2018)



2.3.2 Wind resources

Figure 9 shows on-shore and off-shore resource potential maps, which were generated by the World Bank's ESMAP program. On-shore areas with wind speeds over 8 m/s are found in various regional clusters, with Highlands, South Central, and the South yielding the most robust potential.

A recent technical assessment conducted as part of the PDP8 process appraised some technical potentials for on-shore and off-shore wind in Vietnam, which were used as inputs to the power development process. Summarized in Table 11, PDP8 indicates a technical potential of 217,305 MW of on-shore wind and 162,200 MW of off-shore wind energy in Vietnam.

As shown in Table 11, the South, South Central, and Highlands regions have the most robust potential for developing on-shore wind in Vietnam, together comprising the majority 182,788 MW (84%) of the 217,305 MW total potential indicated by PDP8. For off-shore wind, South Central alone comprises the greatest technical potential for developing off-shore wind in Vietnam, yielding 118 GW (73%) of the Country's total 162.2 GW of potential.

Figure 9 On-Shore and Off-Shore Wind Resource Map (ESMAP 2018)

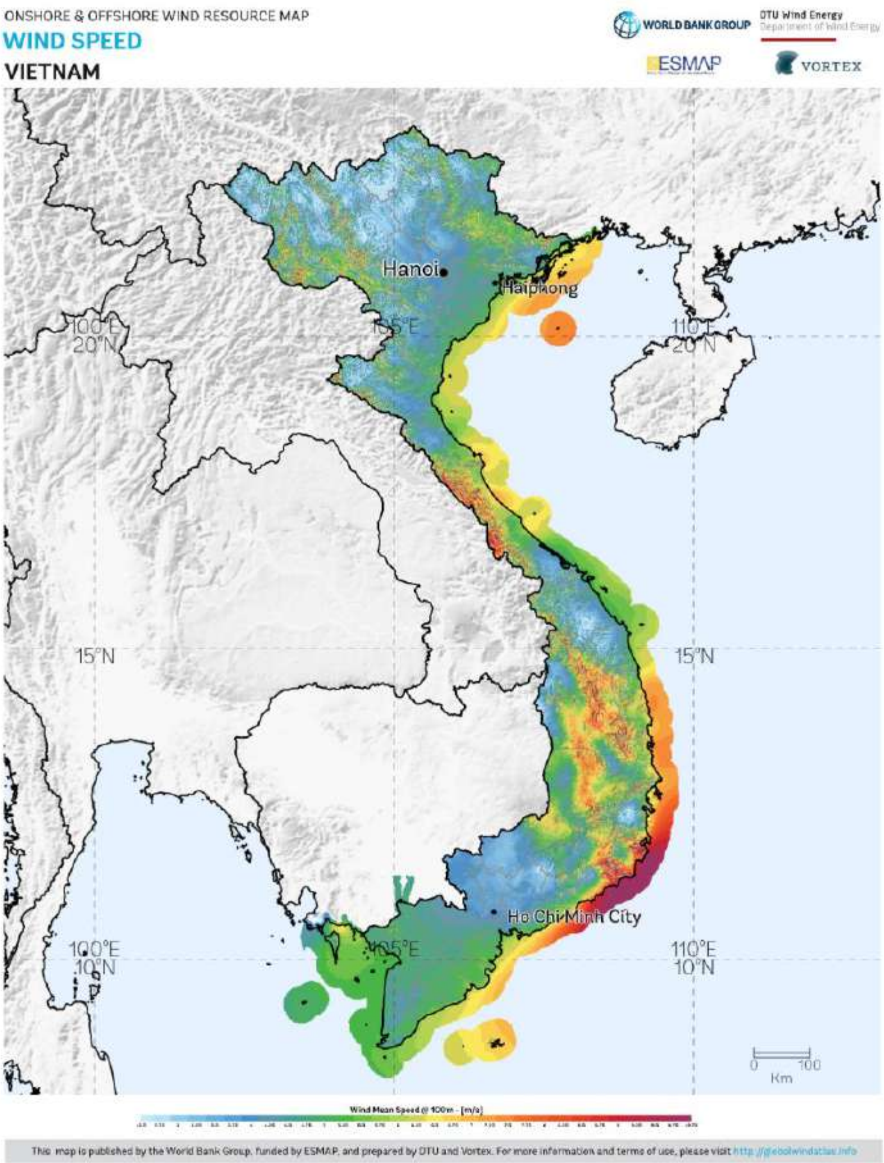


Table 11 Technical potential of On-Shore and Off-Shore Wind in Vietnam

Region	Capacity (MW)	
	Onshore Wind	Off-Shore Wind
NORTH	12,565	13,000
NORTH_CENTRAL	10,717	5,000
MID_CENTRAL	11,235	0
HIGHLANDS	74,386	0
SOUTH_CENTRAL	34,764	118,000
SOUTH	73,638	26,200

Region	Capacity (MW)	
	Onshore Wind	Off-Shore Wind
Total	217,305	162,200

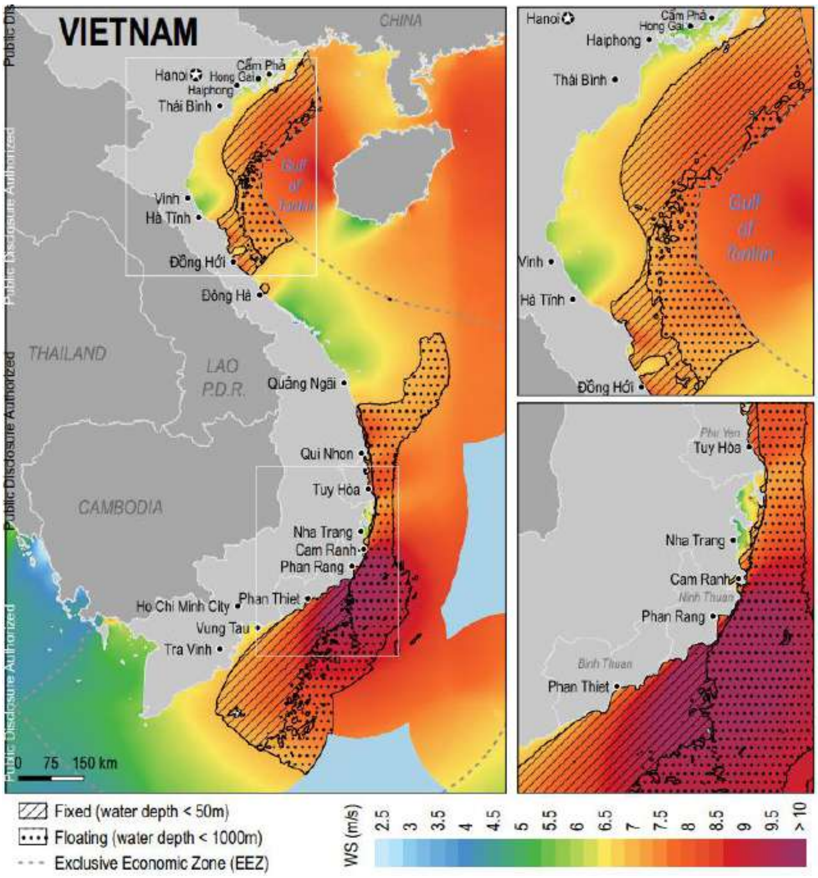
Figure 10 below shows a recent, more detailed appraisal of technical potential for off-shore wind conducted by the World Bank in their 2021 study Offshore Wind Roadmap for Vietnam.

In this report they identify two regions most suitable for the development of off-shore Wind in Vietnam:

- The South-East with remarkable mean wind speeds that exceed 9.5 m/s at 100m height with opportunities for developing both fixed and floating plants in relative proximity to deliver electricity to the Ho Chi Min demand centre.
- The North off the Gulf of Tokin with mean wind speeds between 7.5 to 8.5 m/s at 100m height in reasonable proximity to Hanoi and other load centres.

The World Bank roadmap indicates a total off-shore wind technical potential of 599 GW for Vietnam, of which 261 GW is fixed capacity and 338 GW is floating capacity. The off-shore roadmap report indicates that a high-growth scenario for Vietnam can see the integration of 40 GW of Wind energy by 2040, which would deliver almost 30% of electricity in the Country's energy mix. As detailed in the section that follows, PDP8 indicates Vietnam will build just 15 GW of off-shore Wind capacity by 2040.

Figure 10 Technical Potential of Off-Shore Wind in Vietnam (World Bank 2021)



2.3.3 Other Renewable Energy Options Available to Vietnam

PDP8 provides us with the most up to date applicable estimates on other renewable energy potential options available to Vietnam and are considered where the potentials for solar and wind are unable to meet the electricity demand:

- Biomass – estimated potential to be around 5-6 GW.
- Hydropower – only 2.7 GW of large hydropower and 2.8 GW of small hydropower potential remaining (unexploited).
- Geothermal – 460 MW.
- Tidal & Wave energy – still to be determined for Vietnam.

2.3.4 Role of energy storage and need for flexibility

Transitioning to a 100% RE scenario in Vietnam requires a large share of solar PV and wind energy to be built. Variable renewable energy (VRE) – such as solar and wind – typically require additional needs for system flexibility to ensure and maintain a high degree of grid reliability. The role of energy storage (both battery energy storage systems (BESS) and Pumped Hydro Storage (PSH)) have emerged to play a key role in facilitating the integration of higher shares of RE in Vietnam's energy sector, particularly VRE. As such, this study will closely consider the role of energy storage (as a diverse portfolio of both BESS and PHS) in Vietnam's energy sector transition and achieving 100% RE scenarios. Furthermore, green hydrogen storage has also lately emerged as another source of energy flexibility. The coming decades are crucial for green hydrogen technology to mature as one of the most promising options for the long-duration storage of electricity. As a result of this, green hydrogen technology can be expected to potentially make a significant contribution as part of an energy transition towards 100%RE [5].

2.4 Related alternative scenarios for Vietnam

The scope requires the review of related studies and commenting on their strengths and weaknesses. There are a number of studies dealing with Vietnam. Some are focused on one particular sector such as transport while others take a broad view of the entire economy. Two significant economy-wide studies of comparable scope to the current study are the draft EMP (which incorporates a set of studies to support its conclusions) and the Vietnam Energy Outlook Report 2021 (EOR21). The features of the EMP are discussed in Section 2.1.8 and elaborated upon in this report, particularly in reference to the preferred scenario A1 on which the BAU of this study is based. The Vietnam Energy Outlook Report 2021 is discussed in Section 2.4.1.

2.4.1 Vietnam Energy Outlook Report 2021 (EOR21)

EOR21 examined possible development pathways of the energy sector including reaching net zero emissions by 2050, which corresponds to the pledge at the United Nations Climate Change Conference (COP26) in Glasgow held in November 2021.

2.4.1.1 Scenarios

EOR21 considered five main scenarios and six sensitivity scenarios. The main scenarios are:

Scenario	Description
Baseline (BSL)	Incorporates existing policies. Reduce CO2-emissions by 15% in 2030 and 20 % in 2045. The committed capacity in the power sector follows PDP8 until 2026 and includes no new coal from 2035.
Green Power (GP)	Higher shares of RE, 38% by 2030 and 75% by 2050, compared to BSL

Scenario	Description
Green Transport (GT)	Higher shares of electrification in transport (75%, 90%, and 90% of cars, busses and trucks by 2050; 30% electric motor bikes by 2030; 57% electric passenger train demand by 2050). No new gasoline motorbikes from 2030. Modal shift towards collective means of transport. Higher RE share in the power sector.
Air Pollution (AP)	Included air pollution costs, differentiated by sector, in the optimisation. Pollution unit costs projection assumes a direct relationship with population growth. Pollutants include NOX, SO2 and PM2.5.
Pathway to Net zero (NZ)	Achieves net zero commitment by 2050. Future is carbon constrained.

Modelling used three interlinked models: TIMES covering the energy system, Balmorel representing the power sector and PSS/E represented the transmission grid. The six sensitivity scenarios explored the impact of individual factors:

- (DR) - used a lower socio-economic discount rate,
- (LowEE) - assumed VNEEP3 targets are not achieved,
- (HD) - used a high demand scenario using the high-growth GDP projection of the EMP,
- (HLNG) - used an LNG price higher than BSL by 20%,
- (BC) - was based on the NZ main scenario and used the high-cost estimate for battery reported in the Vietnam Technology Catalogue, and
- (LowPV) - was also based on the NZ scenario but limited utility-scale solar PV to half its technical potential.

2.4.1.2 Main findings

The main findings of EOR21, organised in themes, are summarised below:

Achieving Net Zero

- Electrification powered by renewable energy generation should be the primary substitute for fossil fuels. Direct electrification is the primary path but renewable fuels, indirectly relying on electrification, play a role in the transport areas that cannot be directly electrified. Power generation capacity in 2050 is around 30 times currently installed capacity, dominated by storage (47%) and solar (43%) and production is mainly supplied by Solar (75%) and Wind (21%).
- High RE shares require large investments in transmission and storage.

- Achieving net zero is possible and the NPV of cumulative system costs is 10% higher than in the BSL scenario at the assumed 10% social discount rate. Noting that a high discount rate favours resources that have lower upfront costs and higher running costs, typical of fossil fuel resources.

Energy security

- Electrification, such as in the NZ scenario, significantly improves fuel security and dependence on imports which would rise in the BSL scenario.

Power generation

- Solar and Wind are projected to have high shares of capacity. Electricity production in the NZ scenario is more than double that of BSL and eight times the current level.
- Coal and gas fired generation plant can be replaced by renewable generation. Gas-fired generation could be the technology of choice for backing up renewables.
- RE increases the required capital investment in the power system. Capital's share of total power system costs increases from 50% in other scenarios to 90% in the NZ scenario.
- Revise the regulatory framework to encourage offshore wind.

Power system balancing

- Improve connectivity across the transmission system to connect resource rich areas to high demand areas.
- Storage will play a major role.
- Thermal generation plant needs to be capable of flexible operation.
- Encourage demand-side participation.
- Develop a market for ancillary services.

Transport sector

- Direct electrification is key. 80% of passenger traffic and 50% of freight traffic is expected to be electrified. Road transport is projected to be almost fully electrified. Shifting transport mode toward collective modes is needed to avoid congestion, pollution and energy consumption.
- About one-third of transport demand will be supplied by the more expensive renewable fuels.
- Start phasing out ICE from as early as 2025.

Energy demand

- EE is low-hanging fruit.
- Improve information gathering and modelling to better assess policy impacts.
- Strengthen supervision and enforcement in EE.

Air pollution

- The impact of air pollution in the BSL scenario could triple compared to current levels.
- The transport and power sectors represent opportunities to reduce pollution. Which reduces CO2 emissions at the same time.
- Improve information gathering and modelling in planning.

2.4.1.3 Strengths and limitations

The EOR21 study represents very good work. We discuss here our view of its strengths and limitations as required by the scope of the current study.

Support

The analysis was well supported by governmental agencies of Vietnam and Denmark as well as by reputable research institutions in Vietnam.

Scenarios - Strengths

The BSL scenario incorporates existing policies with other scenarios building up the RE share, firstly through green power then higher electrification through green transport. Air pollution externality costs was included in a separate scenario which enables determining its impact. Net zero is developed as a scenario. The sensitivity scenarios explored the impact of individual issues on the outcomes.

Scenarios – Limitations

The main weakness in the structure of the scenarios is the inclusion of the cost of externalities in a separate scenario which could give the impression that it is an option. The recommendations of the study do establish a link between pollution and GHG emissions and recommend strengthening the representation of pollution in planning. The sensitivity of the analysis to individual factors could well have been accomplished by the more traditional approach to sensitivity analysis. Employing a fully developed scenario to explore the impact of an individual factor may be more elaborate and required more effort than the task required.

Analysis – Strengths

The analysis is based on well gathered data and an interlinked system of models. The study refers to using state-of-the-art atmospheric modelling in the study.

Analysis – Limitations

As with all models, exogenous assumptions introduce limitations and potential bias. For example, Table 7.1 in the EOR21 report lists the exogenous assumption made in the GT scenario, such as percent of vehicles electrified and modal shift target. These assumptions are always open to challenge and opinions about how reasonable they are. This is not a limitation unique to this study and making qualified judgement about exogenous factors is shared by other studies including our present study.

Recommendations – Strengths

The recommendations are structured into themes and consistent with the results of the analysis. It also shows the linkage between different targets such as increasing RE and reducing dependence on fuel imports or the link between reducing GHG emissions and reducing air pollution.

Recommendations - Limitations

The limitations flow from the potential for biases being introduced when defining the scenarios and, within each scenario, setting the exogenous factors.

3 Scenarios and assumptions

3.1 Scenarios

The main high-level features of each of the three scenarios is set out in Table 12.

Table 12 General description of main features of each scenario

Aspect	Business as Usual	80% RE by 2050	100% RE by 2050
Description	Continuation of consumption in line with the preferred EMP scenario, Scenario A1	Accelerated adoption of renewable energy options to reach 80% renewable energy by 2050 and allows for 20% of economy still based on fossil fuels. Economy growth per projections in EMP Scenario A1.	Higher acceleration of adoption of renewable energy options to reach 100% renewable energy (including conversion to renewable fuels) by 2050. Economy growth per projections in EMP Scenario A1.
Industry	Continuation of current trends in energy usage and sources. Includes achievement of VNEEP targets incorporated in EMP Scenario A1.	Accelerated adoption of electrification for heat. Higher share of renewable energy generation in the power system. Renewable fuels used for heat energy that is not electrified.	Higher acceleration of adoption of electrification for heat. Higher share of renewable energy generation in the power system. Renewable fuels used for heat energy that is not electrified.
Commercial	Modest EV penetration.	Very high conversion to EVs or renewable fuels by 2050. EVs are powered by an increasing RE share in the power system. Fossil fuels remain in the sector.	100% conversion to renewables through EVs or renewable fuels by 2050. EVs are powered by an increasing RE share in the power system.

Aspect	Business as Usual	80% RE by 2050	100% RE by 2050
Agriculture, Forestry and Fishery	Continuation of current trends in energy usage and sources in line with EMP Scenario A1.	Accelerated adoption of solar heating, electrification for heating, efficient electrified cooking and efficient lighting. Phasing out of LPG and biomass in cooking. Higher share of renewable energy generation in the power system.	Higher acceleration of adoption of solar heating, electrification for heating, efficient electrified cooking and efficient lighting. Phasing out of LPG and biomass in cooking. Higher share of renewable energy generation in the power system.
Residential	Continuation of current trends in energy usage and sources in line with EMP Scenario A1.	Accelerated adoption of solar heating, electrification for heating and efficient lighting. Higher share of renewable energy generation in the power system.	Higher acceleration of adoption of solar heating, electrification for heating and efficient lighting. Higher share of renewable energy generation in the power system.
Transport	Continuation of current trends in energy usage and sources in line with EMP Scenario A1.	Accelerated adoption of renewable fuels. Higher share of renewable energy generation in the power system.	Higher acceleration of adoption of renewable fuels. Higher share of renewable energy generation in the power system.
Power sector	No new entrant coal from 2037. RE generation share in line with PDP8 base case outlook.	80% RE generation share by 2050. No new entrant coal from 2030. Additional transmission allowed to be built above the BAU transmission plan.	100% RE generation share by 2050. No new entrant coal or gas from 2026. Additional transmission allowed to be built above the BAU transmission plan.

3.2 Assumptions

It is important to have a robust basis for all modelling assumptions. A general approach that will improve modelling buy-in is to align key assumptions with government endorsed assumptions (where possible). The assumptions are based on:

- Macroeconomic / socioeconomic outlooks (population, GDP, transport outlooks),
- Technology cost assumptions (for building different technologies / infrastructure),
- Energy efficiency (leveraging existing work),
- Government formulated scenarios / projections of energy sector,
- Government determined policies / targets, and
- Formulation of baselines which are projected forward (using historical data or benchmarks).

3.2.1 Key documents

The following key documents were considered in this study:

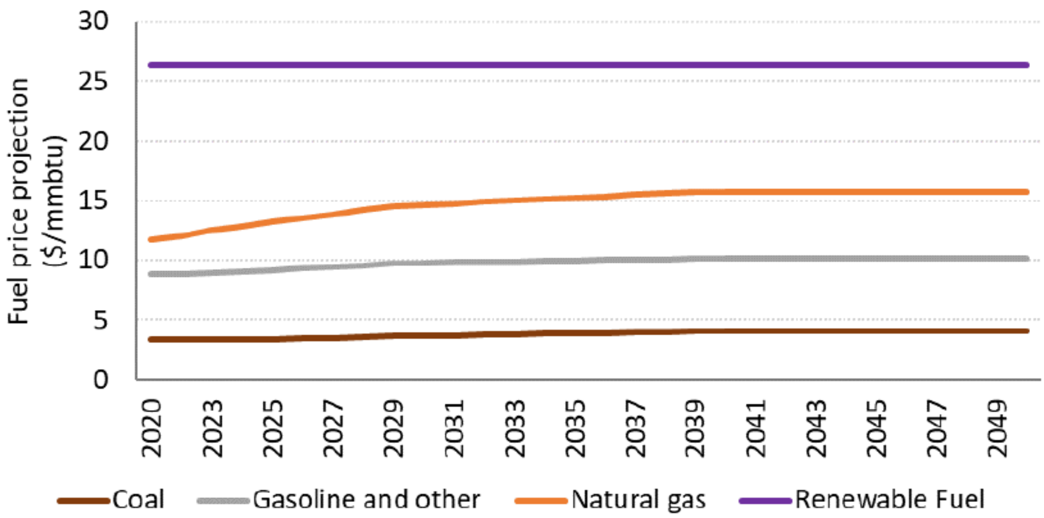
- Vietnam's Sustainable Development Goals to 2030,
- Vietnam's Renewable Energy Development Strategy to 2030,
- Vietnam Nationally Determined Contribution (NDC),
- Vietnam National Energy Development Strategy to 2030 with Vision to 2040,
- Vietnam Power Development Plan No. 8,
- Mekong Delta Master Plan for 2021-2030 with vision to 2050,
- Vietnam Energy Outlook Report 2019 and 2021,
- Vietnam Technology Catalogue, and
- Draft Energy Master Plan (EMP) for period 2021-2030 with vision to 2050.

3.2.2 Fuel prices (economy-wide)

The following fuel price projection was used economy-wide and based on the power sector modelling assumptions of the PDP8 (late 2021 update) [6]. The PDP8 states *"Forecasts of fuel prices for electricity production are referenced according to the fuel price forecast document of 'Vietnam Energy Outlook Report 2019' supported by the Danish Department of Energy with the Department of Electricity and Renewable Energy. At the same time, there are updates on imported fuel prices according to short-term forecasts of the World Bank, IMF, and domestic fuel price forecasts. The base case coal, LNG and world crude oil prices are forecasted according to the new policy scenario in the World Energy Agency's 2018*

World Energy Outlook Report (IEA).” Biomass and coal prices are the lowest per MMBTU while gas and fuel oil are the highest. A key feature of the projection is that fuel prices are assumed to increase over the projection horizon. Cost of renewable fuel, used as an alternative to electrification in the 80RE and 100RE scenarios, is assumed to be $26.4/GJ across the horizon. [7] Based on the recently released World Energy Outlook 2022, the projected coal and gas prices (for Japan) by 2050 under its Stated Policies scenario are $72/MT (approximately $3/mmbtu) and $10.6/mmbtu respectively, which is higher than that assumed in the modelling and, if used, may overstate the relative fuel benefits of the 80RE and 100RE scenarios.[3]

Figure 11 Fuel price assumptions



Source: Draft PDP8, EREA & DEA 2019 - FUEL PRICE PROJECTIONS FOR VIETNAM. Renewable fuel cost assumption from IES.

3.2.3 Technology costs

Technology costs (or investment costs) are a critical assumption that drives economy-wide consumption costs. Technology costs that are accounted for in the modelling are listed below:

- Technology costs relating to the power sector which include costs of investing in generation and transmission capacity, and costs to enable energy efficiency improvements. This is discussed in Section 4.3.2.
- Technology costs relating to non-power sectors are summarised in Table 13. Only the main assumptions across each sector are reported.
  - Road passenger transport cost assumptions show a reduction in the cost of EV vehicles, whereas costs for fossil fuel-based vehicles remain constant in real

[3] See results section for significance of fuel benefits in the 80RE and 100RE scenarios.

terms. In combination with an upward sloping cost curve for fossil fuels (Section 3.2.2), electrification of transport becomes more competitive over time. The current cost of vehicles is based on NDC-TIA. Study of electric mobility development in Vietnam, August 2021. Implied learning rates of fossil-fuel and electric vehicle costs are based on Electric vehicle projections 2021 [8].[4] The non-decreasing cost of ICE is justified given the technology maturity and trend to move away from ICE production by major manufacturers. Electric vehicles also have significantly fewer parts than ICE and is reasonable to assume costs will continue to trend down and reach levels lower than parity compared to ICE over time.

- Technology costs for industry, agriculture and commercial, i.e., investment to convert heating from traditional to renewable fuels, is based on a generic conversion cost assumed to remain constant over the study horizon given that this is a substantially mature technology. Technology cost was based on data published in The Australian Renewable Energy Agency (ARENA) study on Renewable Energy Options for Industrial Process Heat, 2019 [9].

- Household electric cooktop costs are based on Duong, 2022 [10] and Household biomass cooktop costs are based on SNV, 2018 [11].

▪ Technology and investment costs for the power and transport sector is based on a bottoms-up approach of costing, whereas the coverage for the industrial sector is limited (due to data) and likely to understate the costs of the industrial sector even though it comprises a significant share of economy-wide energy consumption.

[4] Current Trajectory scenario which reflects a future energy system based around current government policies and best estimates of all key drivers.

Table 13 Non-power sector technology costs

Sector	Technology	Units	2020	2030	2050	Change (% pa)
Transport	Gasoline 2-wheeler	USD per vehicle	700	700	700	0%
Transport	Gasoline passenger car	USD per vehicle	20,000	20,000	20,000	0%
Transport	Gasoline light commercial	USD per vehicle	30,000	30,000	30,000	0%
Transport	Diesel passenger car	USD per vehicle	21,000	21,000	21,000	0%
Transport	Diesel light commercial	USD per vehicle	20,000	20,000	20,000	0%
Transport	Diesel heavy commercial	USD per vehicle	50,000	50,000	50,000	0%
Transport	Electric 2-wheeler	USD per vehicle	700	560	375	-2.1%
Transport	Electric passenger car	USD per vehicle	20,000	16,000	10,700	-2.1%
Transport	Electric light commercial	USD per vehicle	50,000	40,000	26,700	-2.1%
Industrial, commercial, agriculture	Traditional heating	Annualised cost at 8.86%, expressed in $/mmbtu	5.28	5.28	5.28	0%
	Conversion to electricity		32.46	32.46	32.46	0%
	Conversion to renewable fuel		2.64	2.64	2.64	0%
Household	Electric cooktop	USD per unit	120.89	120.89	120.89	0%
Household	Biomass cooktop	USD per unit	34.8	34.8	34.8	0%

3.2.4 GDP and population assumptions

Underpinning the PDP8 demand projection is the underlying real GDP growth assumption of 6.8% pa through to 2025 followed by a gradual decline to 5.6% pa during the 2036-2040 period, or approximately 6% pa growth over the modelling horizon to 2040. The PDP8 provides a low and high range of 5.2% and 6.7% pa over the 2020 to 2045 period for the high and low demand projections (see Table 14). The demand projection also assumes population growth of 1% pa, or an equivalent population of 130 million by 2050.

Table 14 GDP Growth Assumptions (Real, Local Currency Basis)

Growth	2020	2025	2030	2035	2040	2045
Low	5.90	6.20	5.80	5.20	4.80	4.10
Medium	5.90	6.80	6.40	6.00	5.60	5.50
High	5.90	7.50	7.20	6.60	6.10	6.10

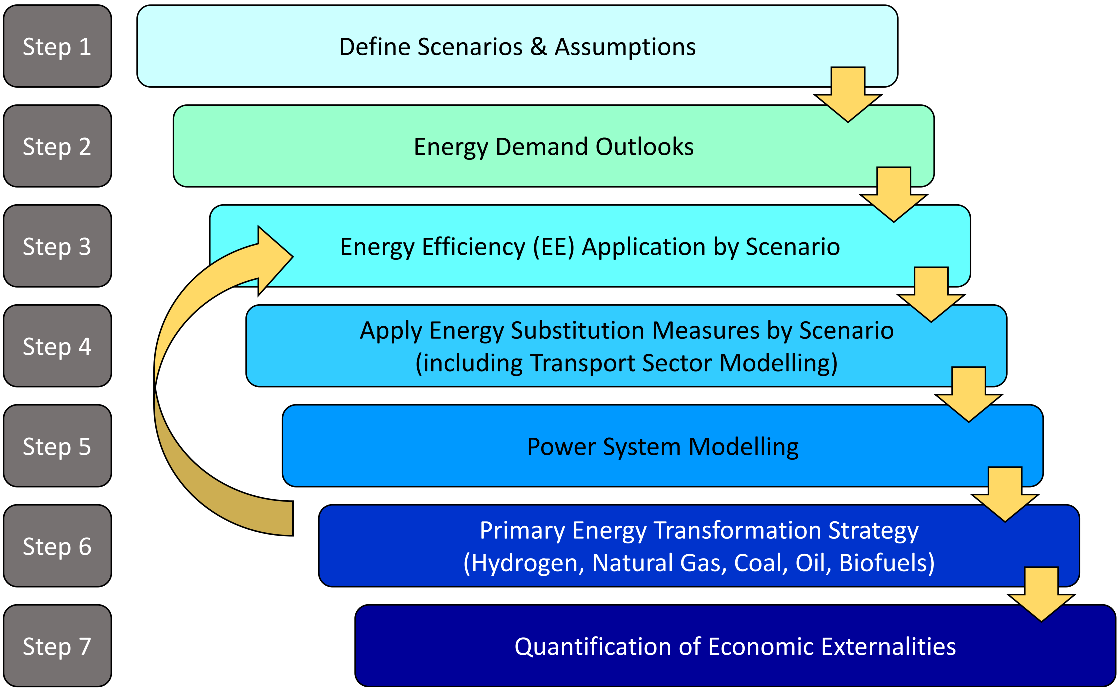
Source: PDP8

4 Modelling methodology

4.1 Overview and framework

The modelling methodology adopted on this project is well-matched to the requirements and reflect the transition options that are possible in Vietnam's context. The broad steps for the energy sector modelling methodology are set out in Figure 12.

Figure 12 Overall modelling methodology



The steps at a high-level are:

- Step 1: Define scenarios and assumptions. Further details are provided in section 5.2;
- Step 2: Develop energy consumption forecasts for each energy demand sector – further details provided in Section 3.2.4 including the transport sector, which requires special treatment;
- Step 3: Model the application of energy efficiency measures in the agriculture, residential, commercial and industry sectors and apply this to the demand outlooks determined in Step 2;
- Step 4: Determine energy substitution opportunities and measures to be applied to the energy demand outlooks as a function of the scenario;

- Step 5: Power System modelling will be conducted, based on detailed modelling of Vietnam's system including the key transmission paths and interconnections with neighbouring power systems. The approach is detailed in section 4.3;
- Step 6: Primary Energy sector transformation strategy in order to make the necessary investments in the primary energy supply systems (for example, charging infrastructure and other infrastructure necessary to enable the transformation of traditional primary energy infrastructure to support renewable energy forms); and
- Step 7: Economic externality quantification based on assessments of the externalities – which is discussed further in section 4.5.

The modelling framework applies cost optimisation to yield a least-cost development plan within the power sector. The least-cost power plan and the plans in the other sectors are brought together to define the least cost development outlooks – this is particularly important in the 80RE scenario where 20% of energy consumption is still based on fossil fuels and the allocation of this is optimised across the sectors, followed by considerations of the cost of electrification or conversion to renewable fuels across each of the sectors. Consideration was also given to electrification and/or renewable fuel conversion feasibility.[5]

It should be noted that non-energy use of primary energy products is beyond the scope of this project. It is also noted that energy consumption that will be highly challenging to replace by readily identifiable RE sources, such as for the aviation and shipping components of transport, will be dependent on introducing assumptions that may require breakthrough technologies. Finally, direct use in households or small businesses (restaurants) of energy for cooking (e.g. LPG or coal for heating) or backup/diesels motors is also challenging area to "enforce" a transition for, although some general policies will be considered and incorporated in the modelling scenarios to handle these energy carriers.

Note that there is some iteration (indicated by the yellow curved arrow in Figure 12) between Steps 3, 4, 5 and 6, as the extent of energy substitution will have implications for the demand of one energy carrier over another.

4.1.1 Energy balance framework

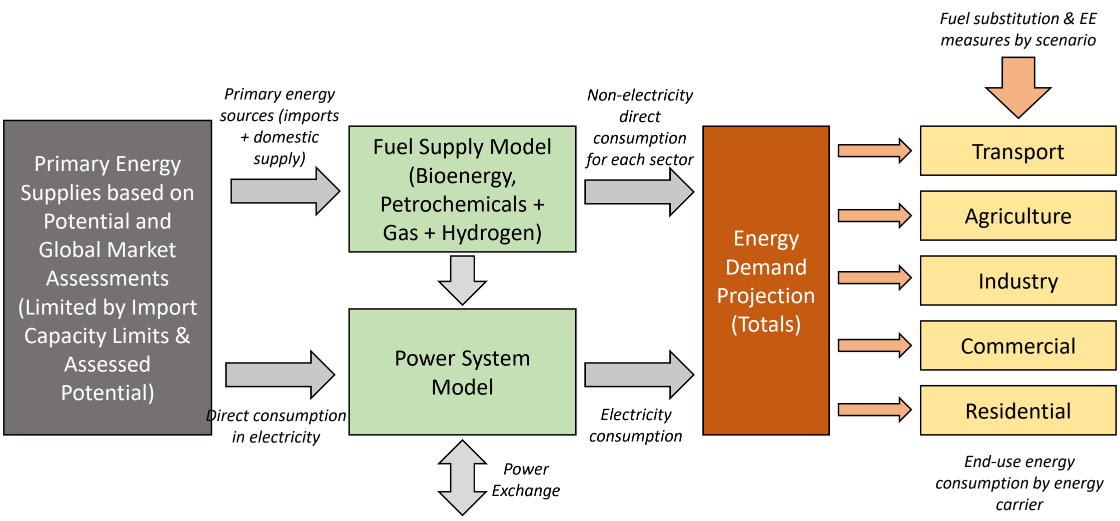
The overall energy balance framework is set out in block diagrams of Figure 12. The blocks are as follows:

[5] See individual sector demand sections in Section 4.2.

- Primary energy supplies: The total primary energy supplies that are available to Vietnam, either through imports (fossil fuels for example) or available as domestic resources (onshore/floating solar, onshore/offshore wind etc.)
- Fuel Supply Model: Includes fuel processing facilities and any constraints inherent in fuel processing systems, and any supply infrastructure constraints – this is set up to meet the demand for energy by carrier for Vietnam and/or supply the electricity industry,
- Power system model: A detailed representation of Vietnam's power system – as this is a key component of energy sector transition it is modelled in some detail,
- Energy demand projections: in total, the energy demands are the aggregate of individual sector components, and
- End-use demand by sector: transport, agriculture, industry, commercial, and residential.
- The more critical blocks are modelled and described in the sections that follow.

The energy balance in the projected years is reconstructed in a bottoms-up approach by starting with the projected energy consumption in each sector and work upwards (to the left) to consolidate into primary energy supply.

Figure 13 Energy balance framework



4.2 Energy demand forecasts (non-electricity)

The BAU was based on the demand projections of the preferred scenario of the EMP, Scenario A1. The projections are published by sector and by fuel-type for the years 2020, 2030 and 2050. Demand projections by fuel-type were taken as the base, allocated to the economic sectors and aligned with the projections by sector given in the EMP. Demand in interim years was estimated by linear interpolation between the demand in the years provided in the EMP. The total demand for each sector was considered to not change between scenarios but what changed was the fuel types that supplied this demand.

Following agreement on a BAU specification of GDP and population, the energy demand outlooks was formulated in line with the preferred scenario of the EMP for each of the following energy carriers:

- Electricity,
- Oil,
- Gas,
- Coal, and
- Biomass.

The overall demand was aligned to the sector consumption forecasts in the EMP for each of the following sectors:

- Agriculture,
- Residential,
- Commercial, and
- Industrial.

The transport sector outlook is significantly more complex and needed a more detailed model to reflect the different categories of vehicle and their phasing over time – this is described further in Section 4.2.5. Where appropriate we also modelled the demand by sector in more detail. The BAU outlook is a projection of energy consumption based on Scenario A1 of the EMP including the incorporated measures for energy efficiency (EE). Additional savings from EE measures are a function of the scenario and will be applied separately for the 80RE and 100RE scenarios.

4.2.1 Industrial sector

4.2.1.1 Energy demand

The non-electricity energy demand for the sector was either electrified or substituted by renewable fuel based on an assumed profile for electrification and fuel substitution. The electrified non-electricity energy took into account the estimated conversion efficiency of the current processes. For demand that is supplied from the power network, the power model has conversion efficiency inputs for each generation fuel-type. For energy supplied by renewable fuels, the amount of new energy considered the efficiency of renewable fuel conversion and added to the electricity demand the amount of energy consumed by the production of the renewable fuel.

Behind the meter generation is netted-off from grid-based electricity supply but is included in the total final energy consumption and primary energy supply figures. Electricity demand is also adjusted for additional electricity demand from the processing of renewable fuels.[6]

4.2.1.2 Cost of electricity

The cost of supplying electricity was determined in the power system model and is discussed in more detail in that section.

4.2.1.3 Cost of thermal energy

Energy is used in the industrial sector in the form of electricity to drive motors and provide process heat or in thermal form to provide heat. To increase the share of renewable energy consumption we have considered two strategies, electrification and fuel switching to renewable fuel. The electrification of heat, where the electricity is supplied by renewable sources, increases RE share and switching to renewable fuel converts the remaining portion of heat that is not practical to electrify. Electric energy is provided by the power system and the cost is optimised through that process as discussed in the power sector section. To project the cost associated with converting process heat to a renewable fuel we calculate the Levelised Cost of Heat (LCOH). The Australian Renewable Energy Agency (ARENA) conducted an analysis of the potential to increase renewable energy use in industry for heat. We use, as a base, the LCOH for selected technologies reported by the ARENA study on Renewable Energy Options for Industrial Process Heat, 2019. The AUD cost is adjusted to account for the biomass cost in our study, indexed for inflation and converted using foreign exchange rate to bring the cost to 2021 terms in USD.

The LCOH was calculated using the following assumptions:

- Cost of equity: Nominal pre-tax return on equity: 10%
- Debt share: 60%, Nominal pre-tax return on debt: 7.78%, term 10 years
- Inflation: 2.5%
- System life: 20 years
- O&M: 2% of capital cost per year

[6] 0.2454 TOE of electricity is required for every 1 TOE of renewable fuel processed.

The LCOH depends on the amount of heat used. A large smelter can use 40,000 TJ/year while a small processing plant can use 20 TJ/year. The average heat used by a manufacturing enterprise is estimated at 15 TJ/year. This is equivalent to a 0.6 MWth boiler at 80% capacity utilisation. For such a plant size a biomass fired boiler has an LCOH of $16.5/GJ for biomass cost of $1.5/GJ when operating at 30% conversion efficiency. An electric resistance boiler with the same capacity factor of 80% and 95% conversion efficiency will have an LCOH of approximately $2.5/GJ after excluding the cost of electricity. The reason for excluding the cost of electricity is to avoid double counting. The cost of electricity is included in the power cost incurred by the system to supply that electricity. For a boiler running on renewable fuel, modelled in the study as biodiesel, the LCOH is estimated at $34.33/GJ for biodiesel cost of $26.4/GJ and efficiency of 80%. The supply of thermal energy for process heat is assumed to be weighted 20% biomass and 80% renewable fuel.

4.2.1.4 Potential and cost of electric efficiency

Energy can be saved by proper selection of electric motors. In this area, the savings can come from many areas such as electric motor components, connecting gear systems, motor control, timers to minimise idle time, etc. Efficiencies can also be gained through the adoption of advanced motor control technologies such as variable speed drives or adjustable speed drives. Savings vary by application (conveyors and belts, pumps, fans, compressors, escalators, grinders, etc) and type of motor (Single phase AC, Synchronous AC, Bushed DC, Brushless DC, etc). Improving engineering and operating practice including appropriate design, sizing and maintenance. Figure 14 provides a good summary of the areas of efficiency in electric motor systems.

Figure 14 Areas of energy efficiency in electric motor systems

	Involved equipment	Improvement possibilities
1 Electric input and conversion	Factory automation	Efficient low-voltage supply, low energy mode during standstill
	Transformation	Use efficient transformers
	Power factor compensation	Use motors with high power factor and use efficient power compensation
	Voltage 3 phases	Balanced voltage
	VFD	Properly sized, programmed and efficient VFD, use active end VFD
	Motor	Efficient, properly sized motor
2 Mechanical transformation	Throttle, damper	Avoid mechanical load management
	Clutch	Try direct drive, avoid worm gear
	Gear	Use efficient gearboxes
	Valves	Use fully open valves with wide gauge
	Transmission	Try direct drive, avoid V-belts and chains, use flat or synchronous belts
	Brake	Use efficient brake, try active braking
3 Application	Low volume	Avoid unnecessary high flow volume and mass
	Low speed	Avoid unnecessary high speed, increase pipe and duct size
	Low pressure	Avoid unnecessary pressure due to bends, use full size heat exchangers, valves, filters, etc.
4 Operation and maintenance	Shorter time	Avoid unnecessary operation time without use: factory automation with automatic load control/off
	No idle time	Avoid idle time: automatic load control/off
	Maintenance	Use regular maintenance for motor and mechanical components
	Rewinding	If not replacement: Try quality rewinding
	Replacement	Preventive maintenance and planned replacement
	Metering	Install and use system operation metering

Source: Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems IEA 2011 [12]

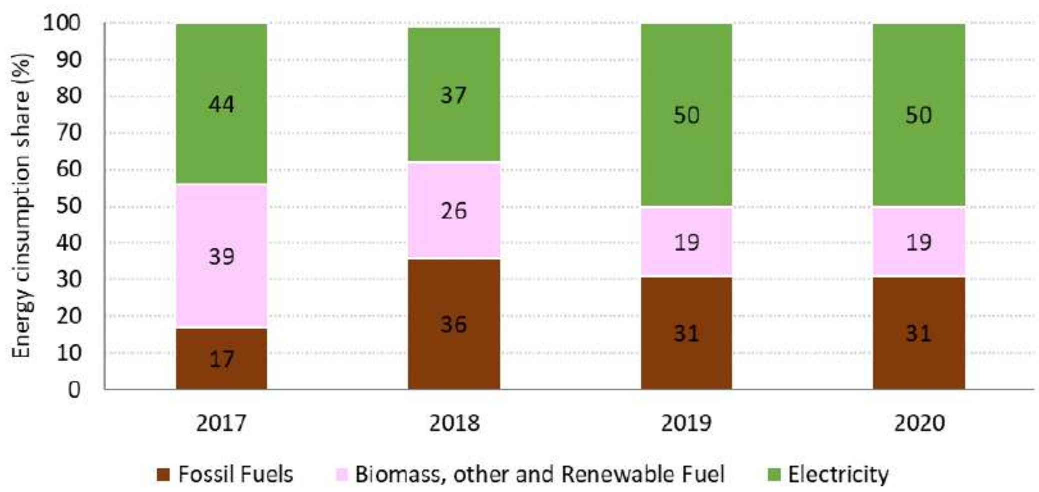
A detailed analysis of specific areas of is beyond the scope of this study and a broad estimate of savings across the sector is used instead. The IEA study 'Energy-efficiency policy opportunities for electric motor-driven systems' undertook a global analysis of energy consumption in electric motor- driven systems (EMDS) and potential energy saving. The study estimated the EMDS electricity consumption to be 69% of total sector electricity consumption and the potential saving to be 25% of the EMDS consumption. The estimated saving is equivalent to 17.25% of the total industrial consumption. The 25% potential is an optimistic assessment and much higher than typical estimates that range from 3% to 14%. For 80RE and 100RE estimates of energy efficiency savings potential of 10% and 14%, respectively, of EMDS is reasonable and equate to approximately 7% and 9%, respectively, of total industrial consumption in each scenario. Payback is typically in the region of three to four years according to the Energy Efficiency

2020 IEA report [13]. We will assume the more conservative payback period of 4 years. While a detailed analysis of the areas of saving is beyond the scope of this study, understanding the areas in which savings can be achieved is helpful as it reveals policy areas that can encourage the attainment of savings.

4.2.2 Agricultural sector

Vietnam, with a traditionally agrarian economy, has been steadily moving towards industrialisation and that has been reflected in both its GDP and energy use. The agricultural sector in Vietnam, which also includes forestry and fishery/aquaculture, has been seeing a steady downward trend over the last decade. Today it accounts for about 12% of the country's GDP and about 3% of the country's total energy consumption [14]. Most of the energy used in this sector in recent years can be attributed to electricity, making up about 50% of the consumption, as seen in Figure 15. Currently biomass and fossil fuels account for the rest of the usage, with fossil fuels having the larger share of 31% in 2020. We also note a reducing share of biomass/renewable fuels over the 2017-2020 period. The agriculture sector is reliant on farm machinery and equipment comprised, in large part, of pumps and vehicles such as tractors and harvesters. The other consumption in this field comes from the use of coal, mainly for heating purposes.

Figure 15: Energy Usage in Agriculture Sector



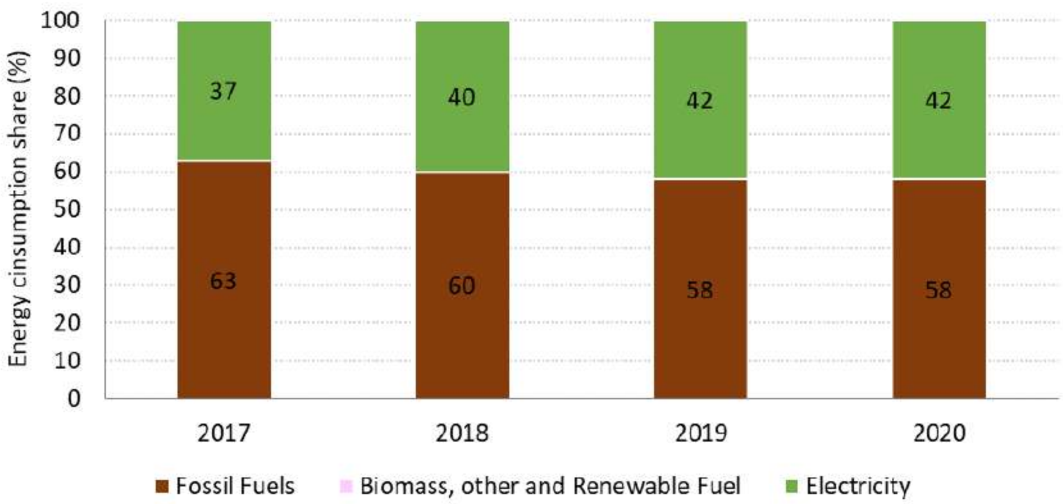
The modelling approach for this sector involves the replacement of fossil fuels, which are mostly gasoline-based products to renewable fuels, and electrification of the heating systems wherever possible.

4.2.3 Commercial Sector

The commercial sector in Vietnam has been growing as the country's economy grows and the share of the commercial sector grows due to factors such as the growth of tourism, and a steady rise in the urban population. The GSO data shows that the number of commercial centres in Vietnam have been increasing at an average rate of 10% over the last decade. However, the size of this sector is still significantly smaller than other three major sectors Industry, Transport, and Household. Most of the energy consumed in this growing sector has come from fossil fuels, with an almost consistent ratio with electricity in the past few years as seen in the Figure 16 below.

The modelling approach for the commercial sector focuses on reducing the dependence on fossil fuels over the coming years, by increasing the use of electricity through electrification of as much of the sector as possible. Furthermore, renewable fuels should be introduced to this sector to replace the fossil fuel-based sources such as gasoline.

Figure 16 Energy Usage in the Commercial Sector

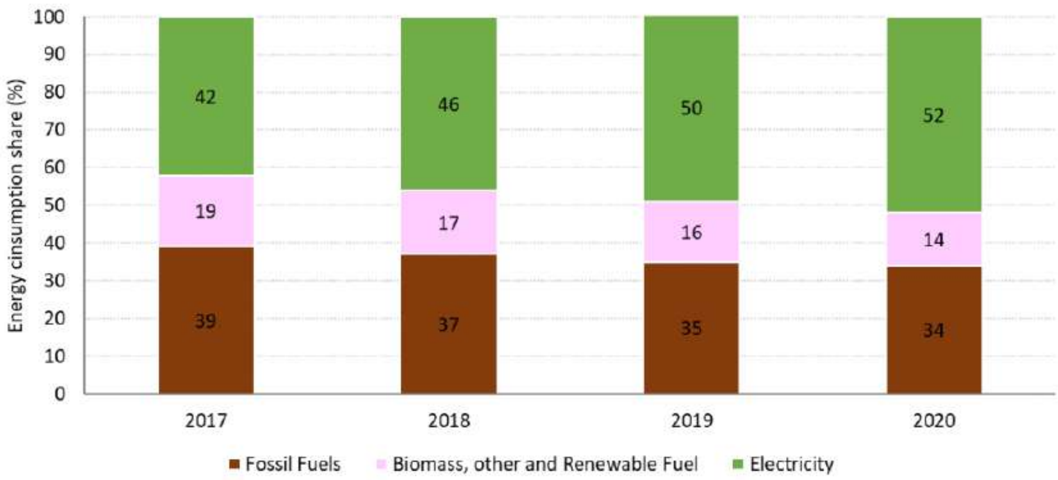


4.2.4 Household sector

The residential/household sector in Vietnam is the third largest consumer of energy, with most of the energy consumed in the form of electricity followed by LPG and biomass. The population of Vietnam is currently growing at about 1% p.a. and is expected to reach 100 million by 2024 [15]. While about two-thirds of this lives in rural areas, the trend shows the urban population is growing faster than its rural counterpart according to GSO data [16]. Figure 17 shows the share of the different types of fuels in the household sector in recent years. Almost all households are electrified. It is seen that the share of electricity has been increasing slightly in the past few years with fossil fuels decreasing marginally.

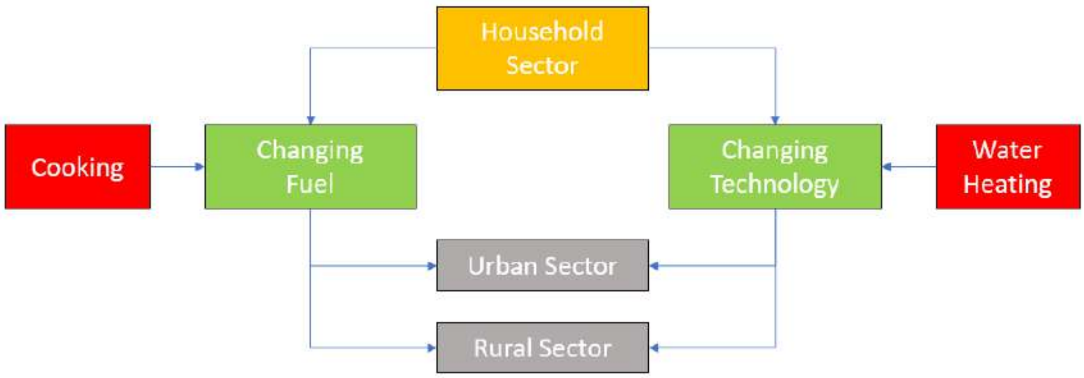
Electricity needs to grow at a much more aggressive rate if the country is to achieve its renewable energy targets in the coming decades.

Figure 17 Energy Usage in the Household Sector



Water heating and cooking consume a large portion of the energy in the household sector, with the other major consumers being appliances and lighting. Upwards of 20% of the electric energy consumed in a household can be attributed to water heating, and between 15% to 20% of the consumption of energy is from cooking. Figure 18 shows the steps taken to model the household sector consumption.

Figure 18 Household Sector Modelling - Basic Steps



As the figure illustrates, the modelling for the household sector takes a two-pronged approach towards reducing the dependence on fossil fuels. Water heating and cooking are identified as the aspects that can be changed to move towards renewable energy. This change entails one of two things – either a change in technology or a change in the fuel, on which the modelling approach for this sector is based. It should be noted that the change in fuel and technology are not necessarily mutually exclusive, for instance changing water heating from electric to solar water heating incorporates changes to both technology and fuel. GSO data shows that the fuels and technologies used differ vastly when looking at the urban regions and rural regions, which is why they need to be looked at individually. The most glaring differences between the two are in the type of fuel used for cooking. While the penetration of electricity and LPG for the purpose of cooking was around 8% and 70% in the urban regions in 2015, it was around 1% and 8% in the rural regions in the same period. Whereas the penetration of biomass as a cooking fuel was 7% in the urban regions, but a staggering 84% in the rural regions. This has been taken into account when projecting the adoption of the different fuels in both the scenarios. The steps taken in the modelling of the household sector are briefly described in the Table 15 below.

Table 15 Simplified methodology for the modelling of the household sector

Step	Process/Methodology
Projecting the population growth and to 2050, and their calculation of their potential energy requirements	Urban and rural population considered separately Initial values based on GSO data for population in 2020, and then scaled in accordance with recent growth rates - roughly 3.2% pa for urban areas and 1% pa for the country Energy requirements projected to grow at the rate of 4.8% as mentioned in the Energy Master Plan scenario A1-C15-E10-RE15.
Identification of potential for improvement	Water heating and cooking identified as areas of high consumption within a household Consumption or source of energy can be changed through change of fuel or technology over the coming years
Calculate energy consumption associated with each potential change	LPG identified as fossil fuel source that can be replaced in the cooking sector Energy requirements for cooking and water heating expected to remain the same from scenario to scenario as they depend on the population. As the fuel or technology is changed, more renewable sources make up for the replaced non-renewable sources in the projected years.

As almost 100% of Vietnam's population has access to electricity as of 2022, it is considerably more practical to implement the increased rate of electrification that is required to replace the fossil fuels with electricity, which can be generated from renewable sources of energy.

4.2.5 Transport sector

The transport sector in Vietnam is a primary source of petroleum consumption and a significant source of carbon emissions hence its conversion to renewable energy is of prime importance. Figure 19 shows a schematic of a block model we have previously used to model energy consumption of the transport sector to illustrate the salient features. The overriding issue is that the model enables scenarios of vehicle transport requirements, people using different modes of transport, changes to vehicle efficiencies and fuel blends and can compute emissions and fuel consumption for scenarios of interest. This enabled the emissions under different scenarios for various policies for the transport sector to be evaluated.

Part of this involved computation of electricity demand for electric vehicles and the volumes of renewable fuels that would be required to supply to blended fuels over time for the different modes of transport that need to be considered: passenger vehicles, shipping, aviation, and railway. As the developments in technology stand today, of the suggested modes of transport, it is the 2-Wheeler passenger vehicles that are most likely to be electrified – and this could potentially include cars, buses, trucks, and even trams and trains.

Figure 19 Transport Sector Modelling Method – Block Diagram

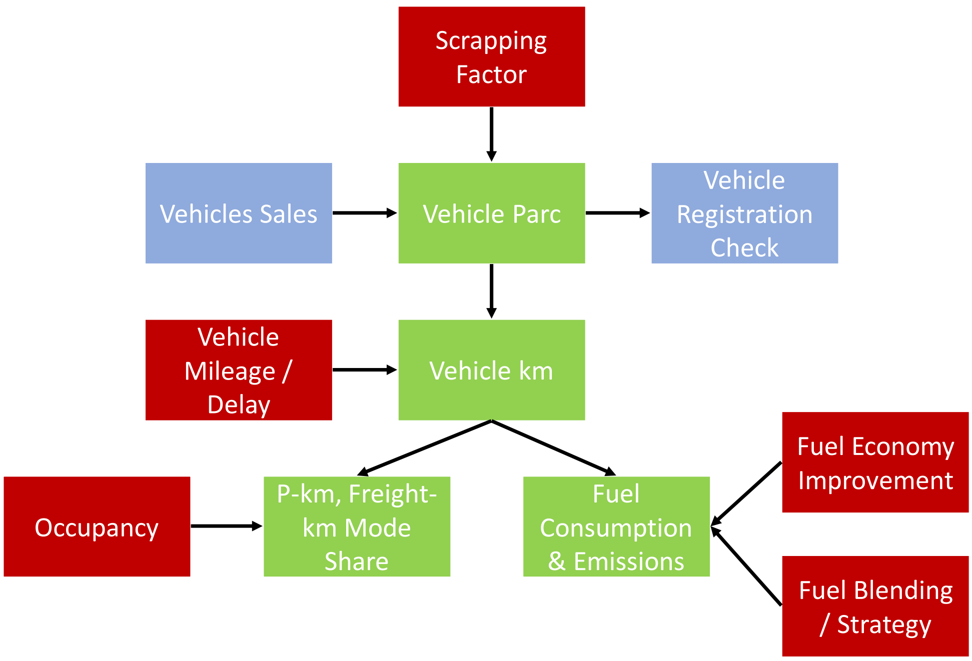


Table 16 Transport demand model methodology

Step	Passenger	Freight
Determination of overall transport requirements (kilometres) to 2050	▪ Based on person kilometres broken down into rail/road/inland waterways/aviation ▪ Initial values (above) based on GSO data in 2018 then scaled in line with GDP growth (roughly 6% pa)	▪ Based on ton-kilometres broken down into rail/inland water ways/maritime/aviation ▪ To account for the impacts of COVID, 2022 estimate is based on the average of 2019 to 2021 historical data from the GSO. From 2023 forward it is assumed that growth returns to trend based on 2019 data grown by GDP. Initial values (above) based on GSO data in 2018 then scaled in line with GDP growth (roughly 6% pa)
Vehicle growth forecast and transport type switching (passenger)	▪ Road requirements category further divided into 2-wheelers, passenger vehicles, light/heavy commercial, buses, by vehicle numbers ▪ Assume scrapping factor based on vehicle life is applied to total vehicle stock at start of year ▪ Determine total replacement vehicles required for each year. ▪ From the total replacements, assume a percentage of sales (profiled) is either electric, renewable fuel (equivalent), or fossil fuel based. Fossil fuel vehicle sales declines over time across all scenarios	▪ Fuel consumption across the freight transport options assumed to change (electrified or renewable fuel) based on a profiled conversion and is dependent on costs and overall economy target ▪ Aviation and maritime assumed to transition to renewable fuels and not electrified

Step	Passenger	Freight
Calculate energy consumption associated with each fuel and vehicle type	▪ Calculate the fuel consumption by vehicle type and by fuel based on the vehicle mileage ▪ Where applicable, apply energy efficiency improvements over time	▪ Calculate the fuel consumption by vehicle type and by fuel based on the vehicle mileage ▪ Where applicable, apply energy efficiency improvements over time

Projecting passenger and freight traffic in person-kilometer (pkm) traffic and ton-kilometer (tkm), respectively, for the BAU scenario.

In the top-down estimate TFEC by fuel type was taken from the EMP as given for the years 2020, 2030 and 2050. In the intervening years TFEC by fuel was estimated as a linear progression. For each year, TFEC by fuel was distributed over the sectors of the economy in accordance with the percentage of fuel used by sector taken from the 2019 Energy Balance table as published by the GSO. The year 2019 was chosen to use the latest available data while avoiding the impact of COVID-19 on activity.

Traffic in the year 2020 is much lower than the historical trend. This is likely due to the impact of COVID-19 on the world economy. To avoid the impacts of 2020 being reflected in the long-term projections the following approach was adopted:

- 2022 is estimated as the average of 2019 to 2021 grown by the GDP growth for 2022;
- 2023 is estimated based on 2019, the year before the impact of COVID-19, grown by the GDP growth for 2023; and
- 2024 onward was estimated based on the previous year grown by the GDP for the year being estimated. For example, 2024 is based on 2023 grown by GDP growth for 2024.
- GDP growth numbers are taken from the EMP.

The TEFC projected for the transport sector was split among the fuel types using information from the recent study on Vietnam transport Table 2.1 of "WB and GIZ 2019. Addressing Climate Change in Transport - Volume 1: Pathway to Low-Carbon Transport.". Projected Energy Consumption by Source in Transport Sector under Business-As-Usual Scenario.

Consumption of fuel types was allocated to modes of transport according to Table 17 based on information for the year 2018 from NDC-TIA 2021. Study of electric mobility development in Vietnam, August 2021.

Table 17 Allocation of fuel types to modes of transport

	Gasoline	Diesel	Fuel oil	Kerosene	Electricity	Renewable fuels
Road	2 Wheelers				2 Wheelers	2 Wheelers
Road	Passenger Vehicles	Passenger Vehicles			Passenger Vehicles	Passenger Vehicles
Road	Light commercial vehicles	Light commercial vehicles			light commercial vehicles	light commercial vehicles
Road		Heavy Trucks Buses			Heavy Trucks Buses	Heavy Trucks Buses
Rail		Rail			Rail	Rail
Waterway		Inland			Inland	Inland
Water			Maritime			Maritime
Aviation				Aviation		Aviation

Source: Tabulated based on information in NDC-TIA 2021

Maritime and Aviation each use a single fuel. Diesel was allocated among the three modes listed in the table; Road, Rail and Inland Waterway; in proportion to the freight traffic in tkm they carry. Gasoline is only used by Road transport. It was further sub-allocated by type of Road transport vehicle using information from the same study, for consistency of estimates. Electrification and renewable fuel conversion of transport was added depending on the scenario. In Table 18 the percentage sales of road vehicles by type of fuel used is shown for selected years of the 100RE scenario. Table 19 shows the replacement rate into electricity or renewable fuel in non-road transport in the 100RE scenario for selected years. The top panel shows passenger transport and the bottom panel relates to freight transport.

Table 18 Road vehicle sales (100RE)

100RE		2018	2025	2030	2040	2050
2 Wheelers	Electric	18.5%	5.0%	30.0%	80.0%	80.0%
Passenger Vehicles	Electric	0.5%	5.0%	30.0%	80.0%	80.0%
Light Commercial	Electric	0.5%	5.0%	30.0%	80.0%	80.0%
Heavy Comercial	Electric	0.5%	5.0%	30.0%	80.0%	80.0%
Buses	Electric	0.5%	5.0%	30.0%	80.0%	80.0%
2 Wheelers	Renewable fuel	0.0%	0.0%	10.0%	20.0%	20.0%
Passenger Vehicles	Renewable fuel	1.0%	1.0%	10.0%	20.0%	20.0%
Light Commercial	Renewable fuel	1.0%	1.0%	10.0%	20.0%	20.0%
Heavy Comercial	Renewable fuel	2.0%	2.0%	10.0%	20.0%	20.0%
Buses	Renewable fuel	2.0%	2.0%	10.0%	20.0%	20.0%
2 Wheelers	Gasoline	81.5%	95.0%	60.0%	0.0%	0.0%
Passenger Vehicles	Gasoline	98.5%	94.0%	60.0%	0.0%	0.0%
Light Commercial	Gasoline	49.3%	47.0%	30.0%	0.0%	0.0%
Heavy Comercial	Gasoline	0.0%	0.0%	0.0%	0.0%	0.0%
Buses	Gasoline	0.0%	0.0%	0.0%	0.0%	0.0%
2 Wheelers	Diesel	0.0%	0.0%	0.0%	0.0%	0.0%
Passenger Vehicles	Diesel	0.0%	0.0%	0.0%	0.0%	0.0%
Light Commercial	Diesel	49.3%	47.0%	30.0%	0.0%	0.0%
Heavy Comercial	Diesel	97.5%	93.0%	60.0%	0.0%	0.0%
Buses	Diesel	97.5%	93.0%	60.0%	0.0%	0.0%

Table 19 Replacement rates of non-road transport - electricity and renewable fuels (100RE)

Passenger transport replacement rates		100RE 2018	2025	2030	2040	2050
Rail	Electrification	0%	0%	0%	20%	50%
Inland waterways	Electrification	0%	0%	0%	20%	50%
Aviation transport	Electrification	0%	0%	0%	0%	0%
Rail	Convert to Renewable fuel	0%	0%	5%	30%	50%
Inland waterways	Convert to Renewable fuel	0%	0%	5%	20%	50%
Aviation transport	Convert to Renewable fuel	0%	0%	5%	50%	100%

Freight transport replacement rates		100RE 2018	2025	2030	2040	2050
Rail	Electrification	0%	0%	0%	20%	50%
Road	Electrification	0%	0%	0%	20%	50%
Inland waterways	Electrification	0%	0%	0%	20%	50%
Maritime transpor	Electrification	0%	0%	0%	0%	0%
Aviation transport	Electrification	0%	0%	0%	0%	0%
Rail	Convert to Renewable fuel	0%	0%	5%	30%	50%
Road	Convert to Renewable fuel	0%	0%	5%	30%	50%
Inland waterways	Convert to Renewable fuel	0%	0%	5%	20%	50%
Maritime transpor	Convert to Renewable fuel	0%	0%	5%	50%	100%
Aviation transport	Convert to Renewable fuel	0%	0%	5%	50%	100%

4.3 Electricity sector modelling

4.3.1 Power system modelling

As the power system is a very important feature of Vietnam's energy transition strategy, it is modelled at the same level of detail typically used in a power development planning process (like PDP8). The modelling approach for the power system used is illustrated in the diagram of Figure 20. This sets out key features for the technical modelling approach on this project. Each of the components shown in the diagram are summarised in Table 20 with further details given throughout this section. The period of the modelling also covers the horizon to 2050 but is simulated using a representative day for each month in the year. The modelling is conducted based on hourly demand and generation profiles for each representative day.

Figure 20 Power System Modelling Method – Block Diagram

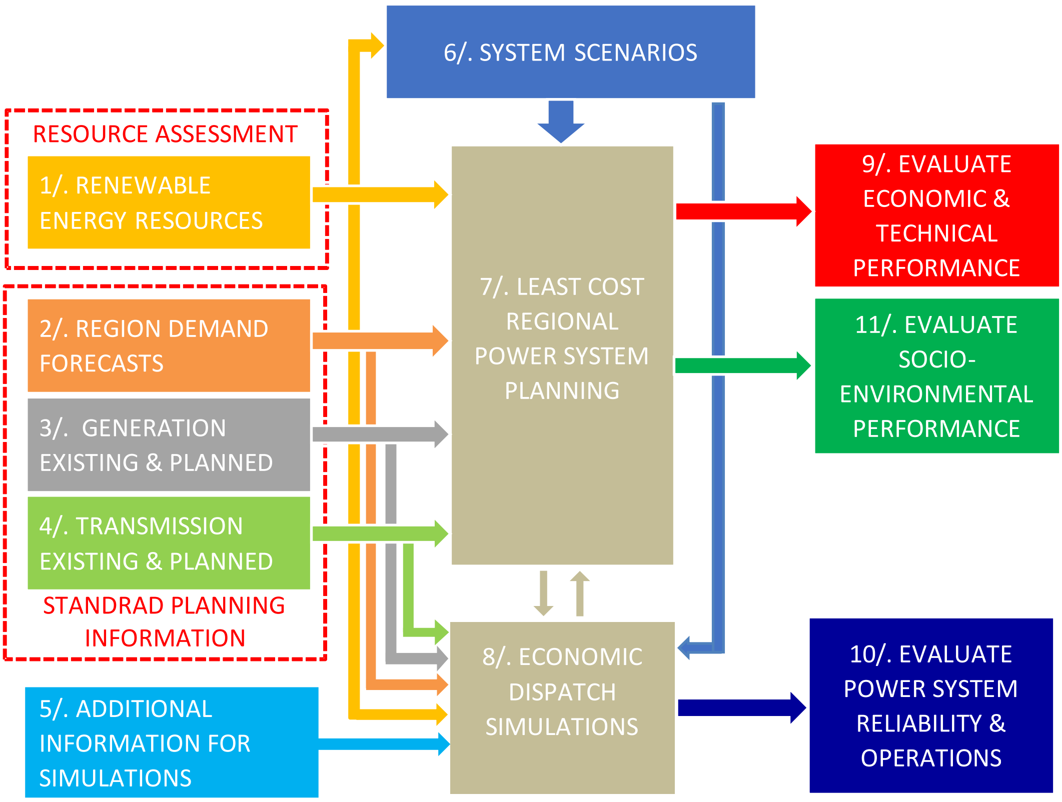


Table 20 Power system modelling components

No.	Name	Description
1	Renewable Energy Resource Assessment (for Vietnam)	Based on the resource information / assessments for solar we will develop representative wind, solar, run of river, ocean, biomass, tidal and other generation profiles for different technologies in different locations / zones.

No.	Name	Description
		Based on previously developed RE studies or we will formulate new ones as required based on GIS solar / wind etc. data.
2	Electricity demand forecasts for Vietnam	The electricity components of the energy demand outlooks was aggregated for each of scenarios 1, 2 and 3 and demand profiles established up to the year 2050
3	Generation existing and planned projects	Existing generators and their technical characteristics are used to formulate the baseline for this modelling for the BAU scenario
4	Transmission existing and planned projects	Existing and planned transmission upgrades are considered in the modelling with the extension of additional transmission upgrades on a cost basis
5	Additional information for simulations	The model used additional technical parameters required to determine the least cost plans, such as minimum stable levels based on the database maintained by IES for Vietnam
6	System scenarios	The Power System scenarios were aligned with those defined in Section 3.
7	Least cost power system plan	Our least cost electricity planning tool, EPM, is used to carry out regional least cost power planning for a range of scenarios. This has the capability to expand generation and transmission as required to satisfy demand and it can be set up to maximally exploit RE potential in the region. Reliability is approximated using a reserve margin of 15%.
8	Economic dispatch simulations	Simulated in EPM. Cost of carbon is not included as part of dispatch and accounted for as one of the economic costs of externalities at the economy-wide level.

No.	Name	Description
9, 10 & 11	Assessments Based on the Results	Various assessments will be made based on the results of the power system modelling, as described earlier. These are important in terms of presenting a technically robust solar uptake scenario.

4.3.2 Assumptions

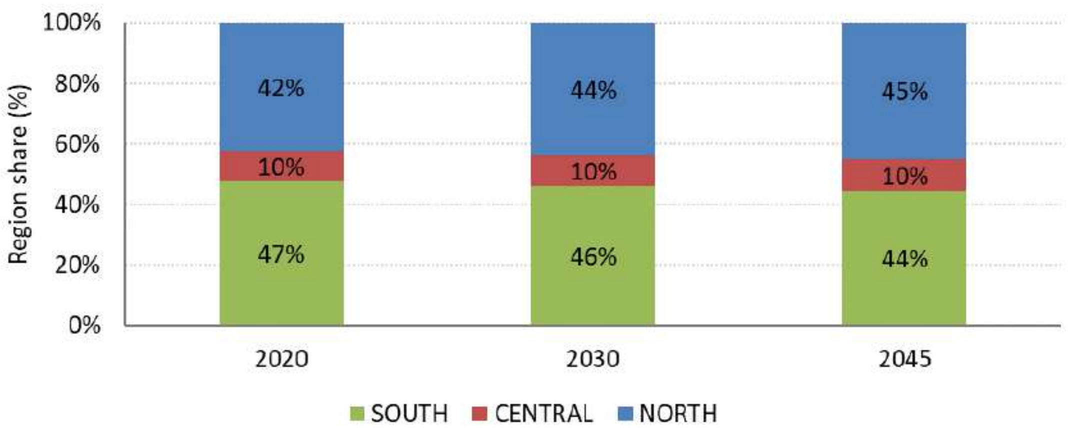
4.3.2.1 Demand Assumptions

Electricity demand in Vietnam has grown substantially over the past 17 years increasing eightfold from 31 TWh in 2001 to 246 TWh in 2020 at an average rate of 11.5% per annum. Real GDP and population grew at a rate of 6.4% pa and 1.1% pa respectively from 2001 to 2020.

The projected baseline electricity demand under the Base case scenario is based on the EMP/PDP8 projection and grows from 240 TWh to 922 TWh by 2050. The continued growth in electricity demand has been driven by the growing economy as a result of increasing foreign direct investments in the manufacturing and industrial sectors, weighted towards the north region in recent years.

The 80RE and 100RE electricity demand assumptions include additional demand from electrifying other economy-wide energy requirements in the Base case. This additional electrified energy consumption is apportioned across the North, Central and South regions in accordance with the baseline electricity demand split over time. The added electricity demand would be highly weighted towards the North and South regions, 45% and 44% respectively, in line with economic activity. The projected demand in the 80RE and 100RE scenarios increases from 240 TWh to 2092 TWh by 2050.

Figure 21 Energy Demand Share by Region



Source: PDP8

4.3.2.2 Transmission

We have modelled Vietnam's transmission system based on a three (3) zone representation of the power system.

Other key transmission assumptions include:

- Transmission losses of 4% across the various interconnectors in accordance with PDP8;
- Generators are assumed to have a marginal loss factor of 1.0, i.e., there are no losses to the zonal reference node; and
- Although the network capability is affected by voltage, other stability constraints between the zones, and potential intra-zone network constraints, these are not considered in this modelling.

4.3.2.3 New Entrant Generation

New entrant generation is scheduled in as required on a least-cost basis accounting for energy and peak demand growth and transmission constraints. Key features of the new entrant schedule include:

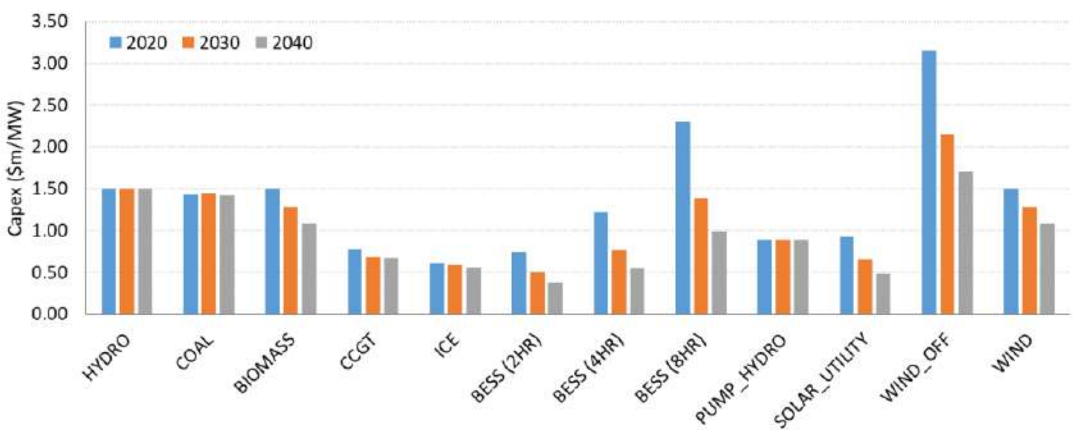
- New entrant generator options are informed by the PDP8 Base case new entrant schedule. This is further broken down into committed new entrants, defined as projects assumed to proceed regardless of scenario outlook because it is already under or close to construction, and prospective new entrants which covers all other new entrants. Projects such as pumped storage hydro (Bac Ai, from 2029/2030), and LNG-based CCGTs (through to late 2030) are assumed to be committed given the long lead times and LNG terminal developments.
    - The expected commercial operation dates of generation projects that are under construction, which generally are what we refer to as "committed new entrants", defines the generator new entrant schedule to 2025 (depending on construction lead times).
    - Prospective new entrant timing is based, generally, on supply and demand requirements.
    - The Base case outlook will correspond to the PDP8 new entrant outlook, with slight differences in timing through to 2040.
- For the 100% RE and 80% RE scenarios, we have increased the build limits to accommodate both for higher demand due to electrification and to satisfy the reduction of emissions.

- Although the capex assumptions across the RE developments across the different zones are uniform, the generation profiles and capacity factors relating to the resource intensity differs.
- Battery energy storage is assumed to be available across all zones as required.

4.3.2.4 New Entrant Costs

Capital costs, fixed operation and maintenance (FOM) and fuel costs are accounted for in the least-cost capacity expansion modelling. Figure 22 below plots the assumed new entrant costs for various new entrant options and are based the draft Vietnam Technology Catalogue 2021 used in the PDP8. Battery costs were instead sourced from the Australian Energy Market Operator's Electricity Statement of Opportunities planning work as the dataset from PDP8 did not provide the full spectrum of capacity to storage configurations.[7] The capital cost projects show significant decline in costs across the renewable energy generation types and battery energy storage.

Figure 22 New Entrant Cost Assumptions



Source: PDP8 and AEMO ESOO 2020

4.3.2.5 Renewable Generation

Utility-scale solar and wind (onshore) capacity developed in the Base case is consistent with the PDP8 Base case as new entrant capacity is limited to the PDP8 Base case outlook updated to reflect the higher level of renewable energy resource contained in the draft PDP8 November 2022 version. However, for the High RE scenarios, additional renewable capacity was made available for development to meet the higher RE generation targets. Key points include:

[7] Starting cost values in 2020 were similar across the two sources.

- It is likely that solar and wind resource levels within a zone are likely to be developed in tranches based on resource intensity.
- Resource potential considers the solar irradiation and wind speeds only whereas technical potential considers resource potential but excludes land areas and buffer zones which reduces the total potential development. Wind resource is fully utilised, but there is room for solar development in the North (but at low capacity factors).
- The resource locations of solar and wind resources are based on the modelling and analysis carried out and reported in the PDP8 (see Section 2.3.1 and 2.3.2).
- The corresponding solar and wind generation profiles are based on profiles extracted from PVGIS and other open-source data such as Renewables. Ninja and are based on average long-term resource levels. North has lower capacity factors compared to the zones in the Central and South region.

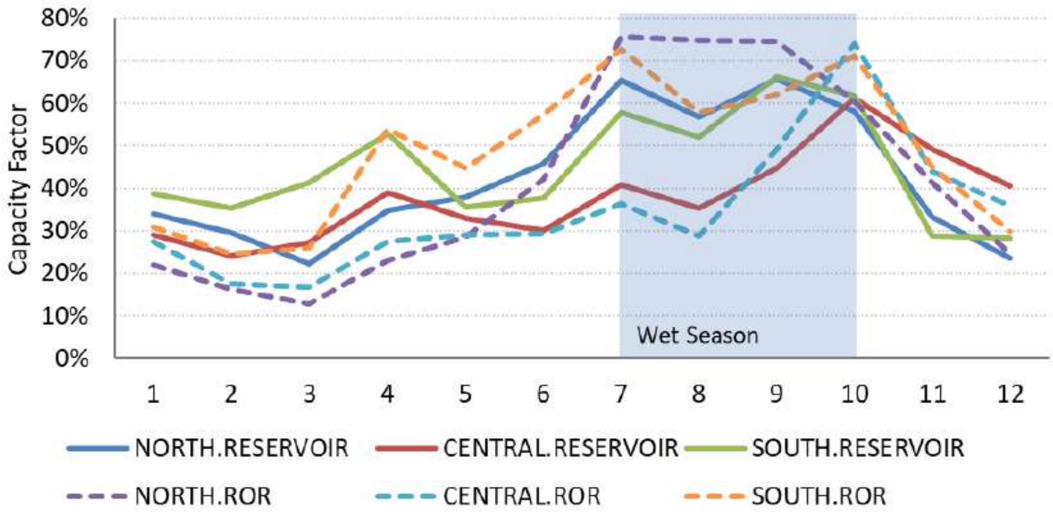
In addition to utility-scale solar and onshore wind, biomass is assumed to run at an assumed flat 65% capacity factor, offshore wind potential is based on the PDP8 resource quantities but with an assumed 45% capacity factor and only made available in the South-Central zone consistent with the PDP8 Base case development location, and rooftop PV is assumed to have 15% lower utilisation than utility-scale solar.

4.3.2.6 Hydro Power Stations

Each hydro power station was modelled based on projected monthly energy volumes published in Decision 4711/QĐ-BCT (2017 Plan for Power System Operations and Power Supply) combined with additional updated hydro information where available. The monthly energy volumes inform monthly energy limits within the EPM model to optimise hourly dispatch for reservoir-based hydro, and fixed MW generation profiles for run-of-river hydro. New hydro plants by type are based on hydro generation patterns from the same region.

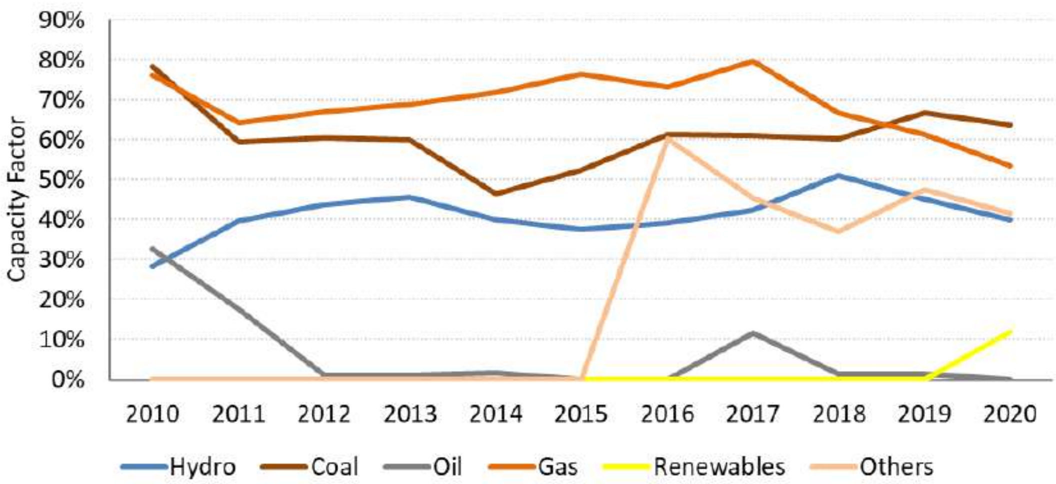
Figure 23 plots the annual average capacity factors used in the projections. Figure 24 plots the historical capacity factors which includes hydro (reservoir and run-of-river based) as a combined category. The average across all annual hydro capacity factors is 40% and is roughly in line with historical generation levels. The 2010 year was a dry year with a capacity factor of 26%.

Figure 23 Average Monthly Capacity Factors



Source: Decision 4711/QĐ-BCT and other data

Figure 24 Historical Capacity Factors by Fuel Type



Source: IES estimates based on generation figures from NLDC 2020 Annual Report.

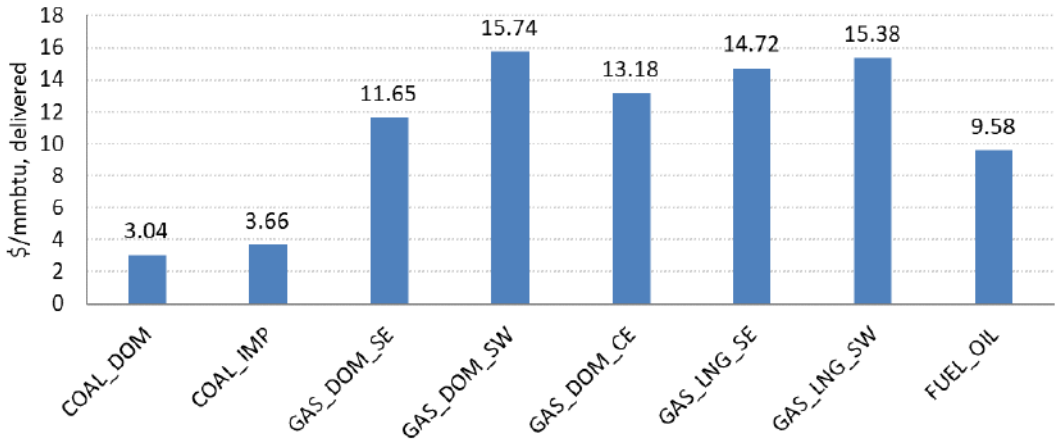
4.3.2.7 Fuel Supply and Prices

Delivered fuel prices are taken directly from the PDP8. The model inputs a simplified fuel price assumption based on the average between domestic and imported prices. A summary of the fuel price outlook is provided below:

- The fuel prices gradually increase over time however for summary purposes are averaged over the horizon in Figure 25;

- Fuel prices are expected to significantly drive the model output as energy prices move in line with short-run marginal costs which is driven mainly by fuel and generator efficiency assumptions.

Figure 25 Delivered Fuel Price Projections (2021-2040)



Source: PDP8

4.3.2.8 Energy Imports

Vietnam currently has power imports from China (about 700 MW) and imports power from hydro projects in Laos (Xekaman 1 and 3). The total potential that can be imported from Laos includes 7.4 GW of hydroelectricity and 5 GW of wind and solar power. Power imports are also expected to increase from China with capacity to reach 2 GW by 2025.

Existing imports such as from Laos (Xekaman 1 and 3) are modelled as hydro power stations with capacity factors for wet and dry seasons. Future expansions on imports to Vietnam are modelled as generators with a fixed cost of $50/MWh. Additional expansions on imports are based on the PDP8 which allows for up to 11 GW of total imports. Assumptions on imports are kept the same across all three scenarios.

4.4 Other measures

4.4.1 Energy efficiency

The project team modelled opportunities for further EE savings in Vietnam's energy sector and applied them to scenarios 2 and 3.

- Scenario 1: BAU energy savings scenario, included EE measures incorporated in the EMP.
- Scenario 2 and Scenario 3: Included further EE savings.

EE has been integrated into the energy demand forecasts and incorporated in the modelling and assessments. Table 21 lists the assumptions that have been made for the various sectors:

Table 21 Energy Efficiency Assumptions

No.	Sector	EE Assumptions
1	Industrial	▪ Assumes an additional 7% energy efficiency in the 80RE and 9% in100RE scenario over and above that assumed in the BAU by 2050[1]
2	Transport	▪ Electrified transport is more energy efficient than fossil fuel transport. No other energy efficiency measure are included in the modelling.
3	Household	▪ Cooking: High Efficiency Electric Stove (90% EE) and Improved Biomass Stoves (30% EE) used in place of standard electric stove (60% EE) and conventional biomass stove (15% EE)[2] ▪ Water heating: Solar water heaters with 85% EE[3]
4	Commercial	▪ 50% improvement in EE of the lighting component of demand due to use of better lighting

Notes: 1- Discussed in Section 4.2.1.4 2- Data provided by WWF 3- based on [17]

4.4.2 Energy substitution

An important part of transitioning the energy industry towards very high levels of RE will be the implementation of measures to transition demand for energy from one energy form to another. Fossil fuel was replaced either by direct electrification or, where not feasible, by renewable fuels. Examples are the adoption of EV in transport or electric process heat in industry. Our modelling accounted for the energy required to produce renewable fuels when substituting fossil fuels by renewable fuels.

4.5 Externalities

Externalities analysed here relate directly to air pollution (SO2, NOx, PM) and carbon emissions associated with energy use across the economy to quantify the broader economic costs. Pollutants (SO2, NOx, and particulates) and emissions (CO2) have material impacts on human health. Specific unit costs of the emission types are based on the assumptions used in the draft PDP8 and draft EMP, summarised below for each of the industries. A carbon cost of $40/t is based on World Bank Group data. Emissions intensity assumptions are based on power sector estimates and is summarised in Table 22.

Table 22   Emission costs ($/ton)

Sector	CO_2	SO_2	NOx	PM2.5
Industry and construction	40	2,000	5,000	6,000
Agriculture, forestry and fishing	40	3,000	6,000	17,000
Transportation	40	3,000	6,000	17,000
Commercial and other services	40	6,000	11,000	31,000
Households	40	6,000	11,000	31,000
Power	40	2,000	4,000	5,000

Table 23   Emission intensity

Emissions intensity	CO_2 (t/mmbtu)	SO_2 (kg/MWh)	NOx (kg/MWh)	PM2.5 (kg/MWh)
Coal	0.1031	4.04	1.68	0.16
Gasoline and other oil	0.0819	4.425	1	0
Gas	0.0592	0.165	2	0.05
Biomass and other	0	0.485	0.89	
RE	0	0	0	0

5 BAU Results

This section discusses the BAU outlook. Comparison of scenarios is carried out in Section 6. The BAU has been updated to reflect the higher level of renewable electricity resource in the November 2022 version of the draft PDP8.

5.1 Notes on charts and tables

The following notes will assist in reading the relevant charts and tables used in Sections 5 and 6:

- Colours relating to the different fuel sources have been applied consistently across the charts. References to RE, or renewable energy, includes hydro and imports (if based on RE). The category 'Biomass, other and Renewable Fuel' in Transport includes only renewable fuels but the label is maintained for consistency across all sectors of the economy.
- Any references to annual fixed costs include annualised capital costs and fixed operating and maintenance costs (specific to power). Investment or technology costs refer to the equivalent costs on an upfront basis.
- Investment cost is presented on a cumulative basis and covers the period from 2022 to 2050. Under the 100RE cumulative costs in a given year include investment in fossil fuel technologies in the earlier years of the modelling horizon.
- References to an aggregated fuel category includes the costs of fossil fuels, biomass and renewable fuels.
- Energy consumption is represented broken down several ways:
    - By sector with the electricity-sector shown separately. This is to show the amount of non-electricity energy consumption in the industrial, transport, household, agriculture and commercial sectors, and the aggregate electricity consumption. Similarly, energy consumption is also reported by fuel with electricity as a separate component.
    - In cases where the electricity sector is not shown, energy used as electricity is attributed to and included in the various sectors and/or fuel categories. Total Final Energy Consumption (TFEC) in a sector shows the consumption in the sector by energy carrier including electricity. The consumption of electricity is typically presented as the aggregate of electricity consumption from renewable and non-renewable sources. Given the focus of this project on renewable energy we have intentionally presented electricity consumption from renewable sources under

the category 'RE' in the charts, and the remaining portion of electricity consumption from the power system is then added back to the sector's consumption of each energy carrier. The charts readily provide a comprehensive view of consumption of renewable and non-renewable energy in a sector.

- Costs that are presented on a net present value basis is based on a discount rate of 10%.

5.2 Summary

The BAU total final energy consumption (Figure 26) increases by almost 4-fold from 2020 to 2050 with main increases in gasoline and gas product categories due to the rapid increase in underlying GDP growth. Coal consumption from 2030 slows down due to Vietnam's stance on new coal power stations developments and policy objectives of increasing renewable generation further displacing coal generation in the power sector. Over the study horizon, fossil fuel consumption is projected to increase because of the growth in industrial and transport sectors which are assumed to largely remain non-electrified (see Figure 26). RE and renewable fuel consumption falls slightly to 24% by 2050 (see Figure 27).

Figure 26 Economy-wide TFEC

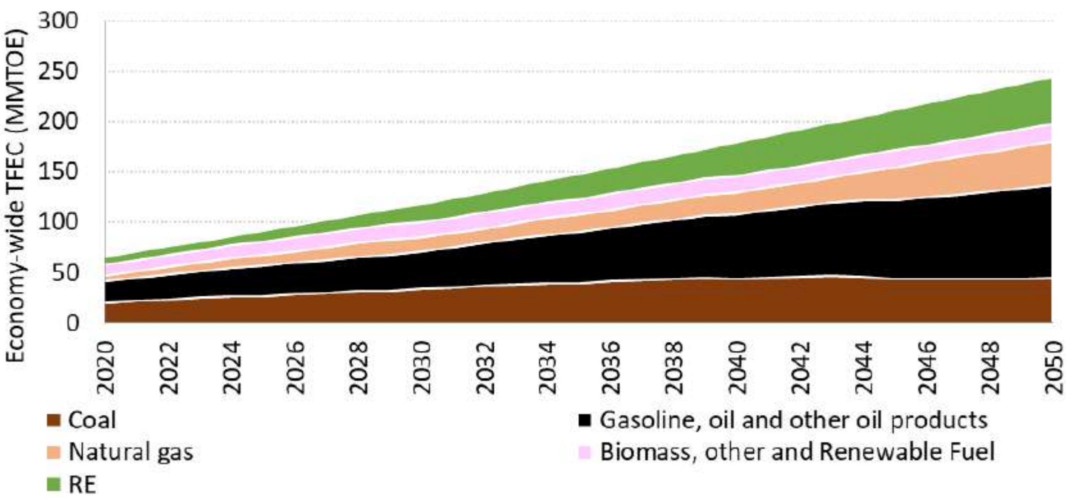


Figure 27 Economy-wide TFEC, share

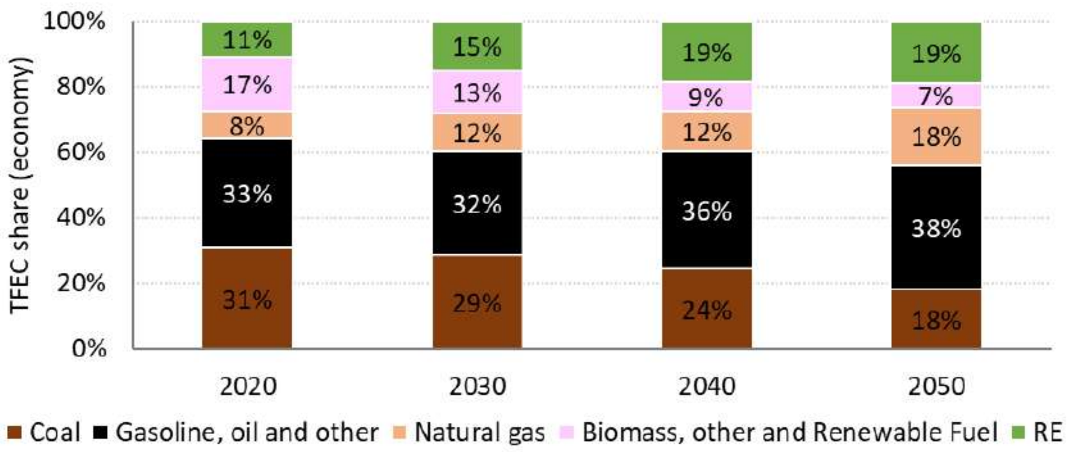
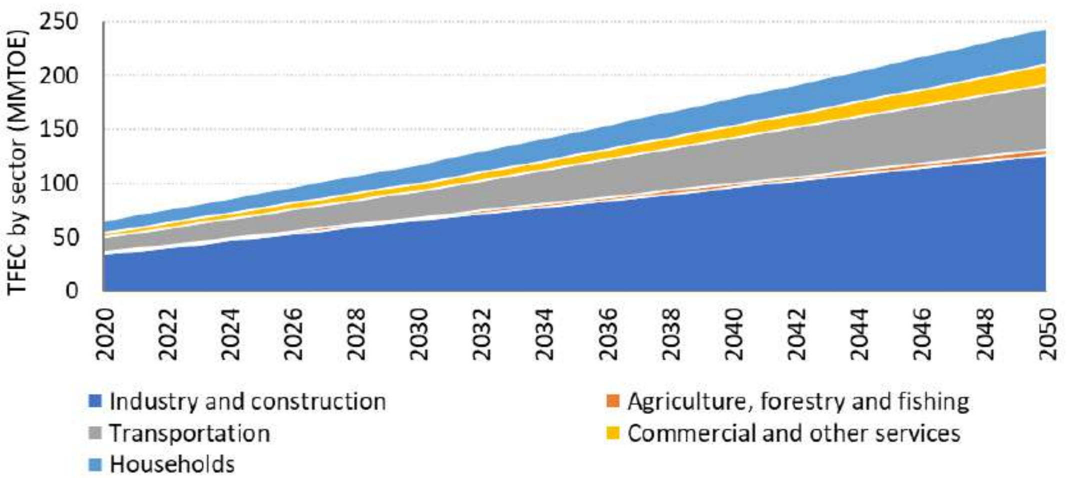


Figure 28 TFEC by sector

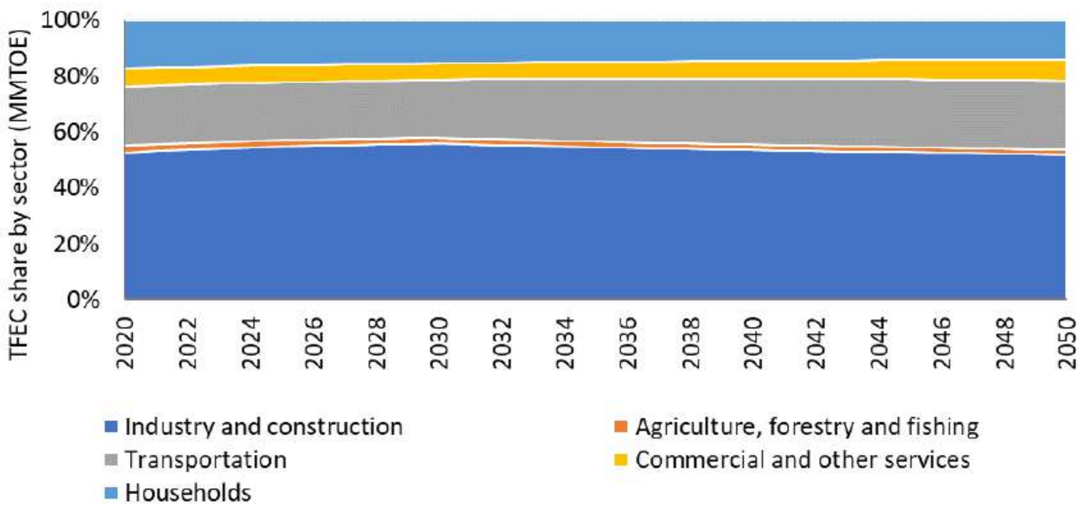


5.3 Energy demand

5.3.1 Industrial sector

The industrial sector is the largest energy consumer in the Vietnamese economy. Figure 29 shows the share of TFEC of all sectors in the economy, with the industrial sector showing a 53% share.

Figure 29 TFEC share by sector - BAU



The consumption by type in MMTOE is shown in Figure 30. The sector consumes fossil fuels directly and also indirectly through the electricity imported from the power system. The contribution of the sector to the consumption of fossil fuels (Coal; Gasoline, oil and other oil products; and Natural gas) is taken into account in the chart below to provide the sector's total contribution – direct and indirect – to fossil fuel consumption. The fossil fuels are the three lower categories in the chart. The same data is shown as percent share in Figure 31. The share of fossil fuels starts at just below 60% and exceeds 70% between 2020 and 2050. Adding the indirect contribution of the industrial sector to fossil fuel consumption provides a better estimate of the footprint of the sector. If we only consider the direct consumption of fossil fuels by the sector, shown in Figure 32 in MMTOE, the share of fossil fuels grows from just below 50% to nearly 60% between 2020 and 2050. This would be an underestimate of the sector's requirement of fossil fuels by approximately 10%. Including the indirect consumption of the sector provides a more representative picture.

Referring to Figure 30, coal consumption of the sector increases in absolute terms but the rate of increase slows down gradually and levels out in the latter years within the 30 to 32 MMTOE range. The consumption of Gasoline, oil and other oil products increases throughout the study period from 5 to 23 MMTOE. Natural gas consumption increases at a faster rate than the other fossil fuels starting at 4 and ending at 34 MMTOE. Biomass increases at a modest rate while the increase in renewable electricity (from the power sector) increases at a higher rate than that of biomass.

Figure 30 TFEC by type – Industrial sector – BAU

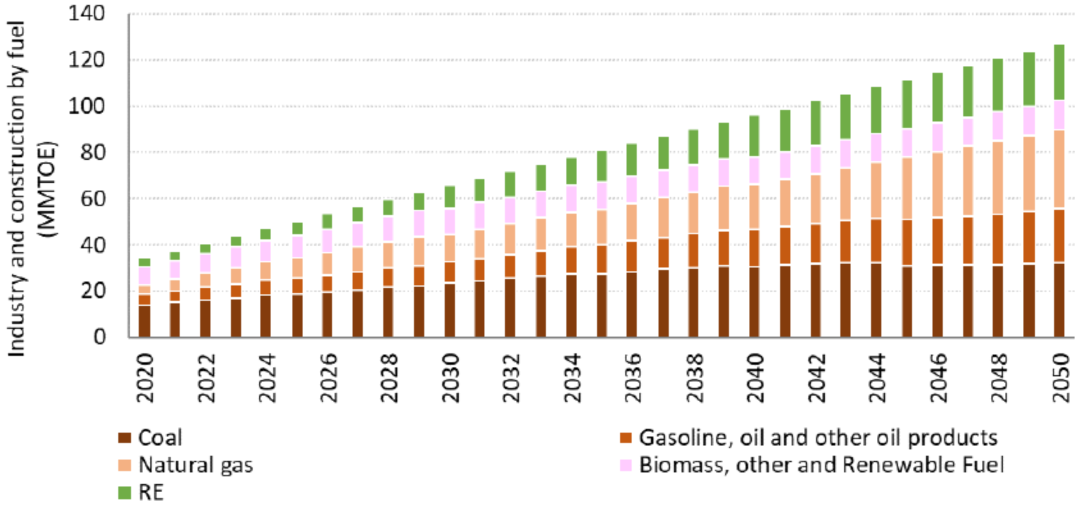


Figure 31 TFEC share by type – Industrial sector – BAU

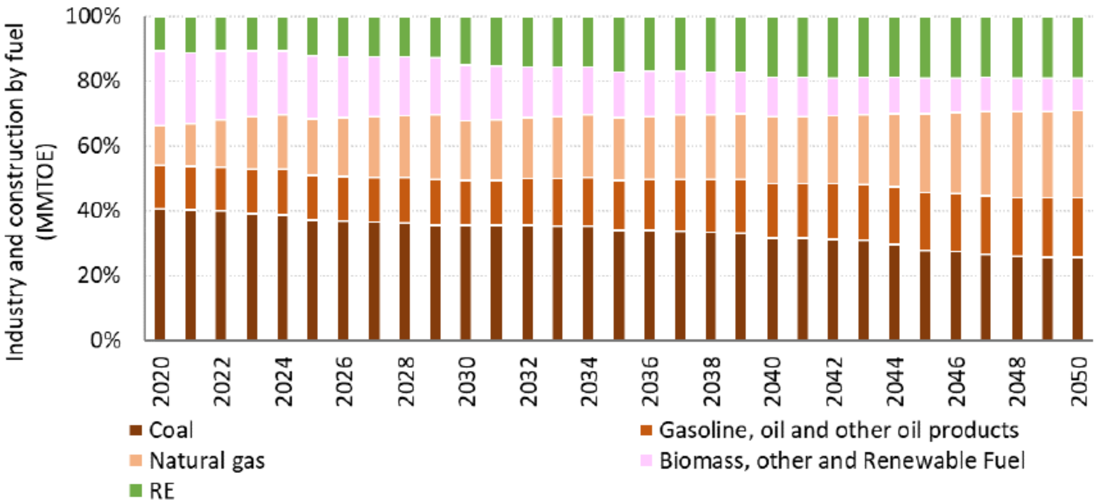
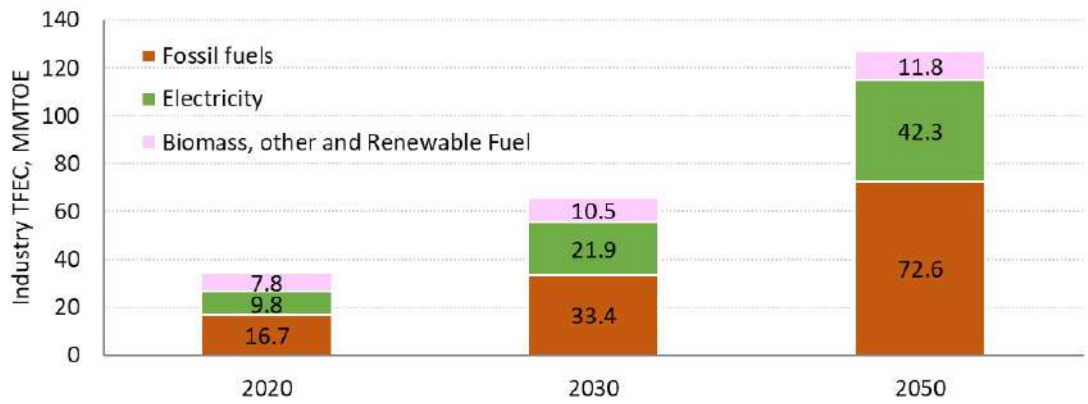


Figure 32 TFEC by type – Industrial sector – BAU



5.3.2 Transport sector

The transport sector under the BAU is projected to grow with a corresponding growth in the number of vehicles as shown in Figure 33. Based on the underlying assumption of maintaining transport modality over the horizon, 2-wheelers remain the dominant transport option for passenger travel. Passenger and freight traffic is projected to increase by 6 to 7 times from current levels by 2050. Figure 34 and Figure 35 show respectively the growth, by mode of transport, in passenger traffic (in billion person-kilometres) and freight traffic (in billion ton-kilometres). Road transport has the highest share of passenger traffic with a significant share for aviation. In freight, maritime transport continues to command the largest share followed by Road and inland waterway modes. The BAU assumes little to no electrification or conversion to renewable fuels and therefore remains heavily reliant on gasoline, diesel and oil products (see Figure 36). The category 'Biomass, other and Renewable Fuel' in Transport includes only renewable fuels but the label is maintained for consistency across all sectors of the economy.

Figure 33 Passenger vehicle numbers

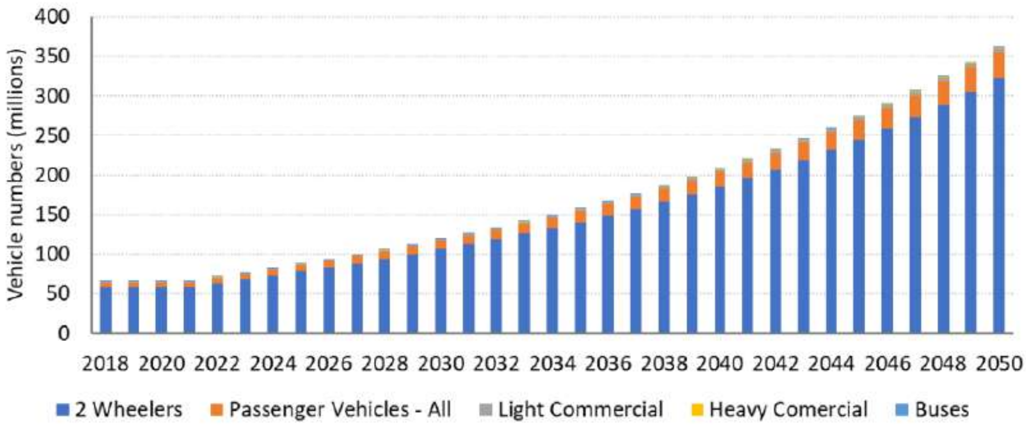


Figure 34 Passenger requirements by category

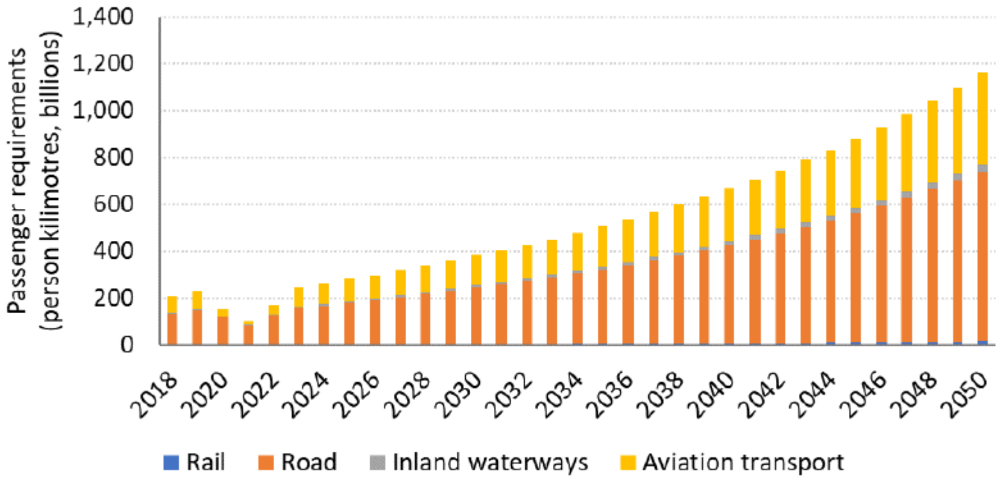


Figure 35 Freight requirements by category

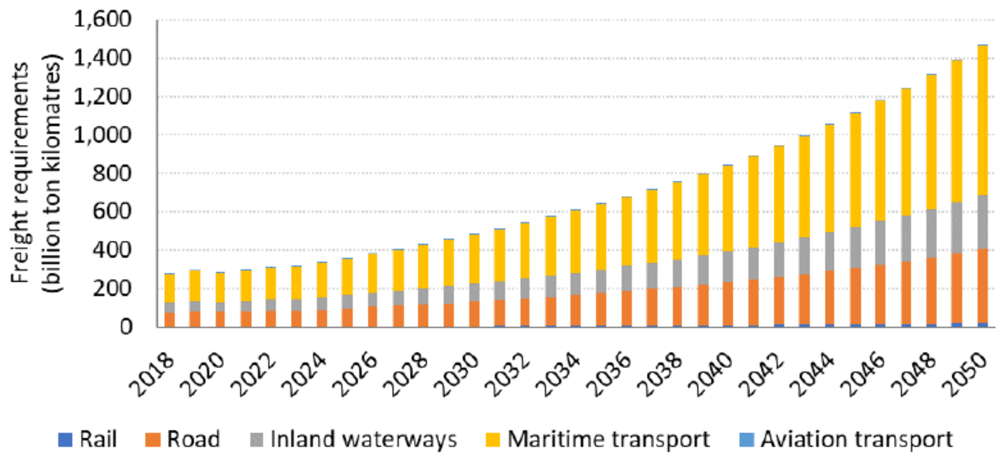
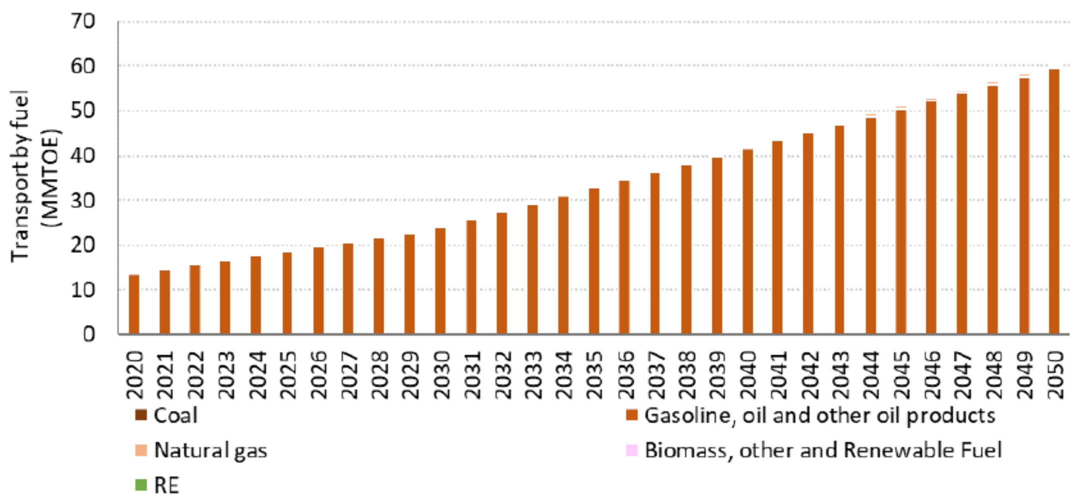


Figure 36 Transport TFEC (MMTOE)

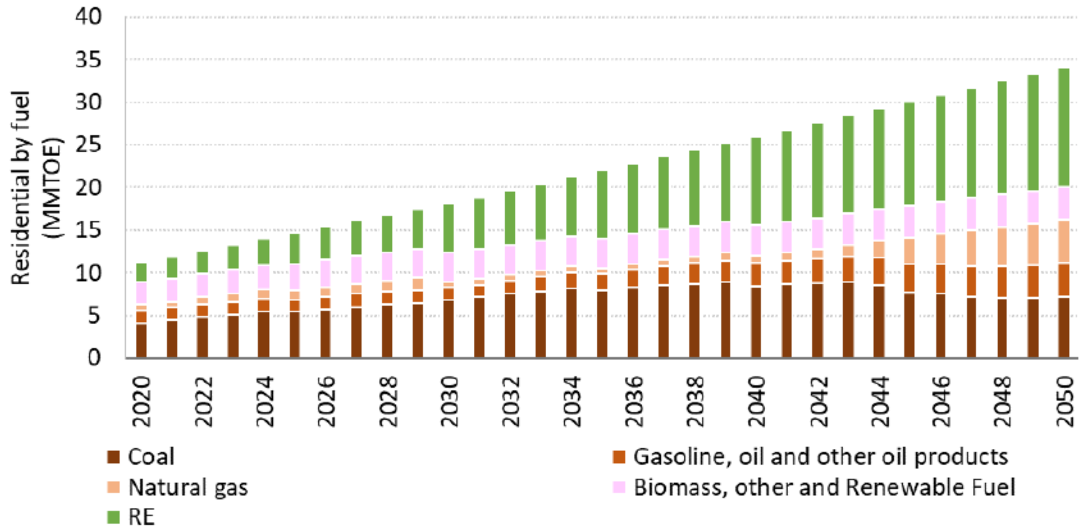


5.3.3 Household sector

As mentioned in Section 4.2.4, the Household sector is a major consumer of energy in Vietnam, with its population rising steadily and on route to reach 100 million within the next few years. The improvement in the quality of life in the country is accompanied by an increased influx of people towards the urban areas and expansion of urbanisation. The rising middle class, supported by a growing industrial sector, consumes more energy as changes in lifestyle include increased dependence on appliances, artificial lighting, and most importantly, heating and cooling.

Information from multiple GSO reports were used to project demand and the expected generation mix for the residential sector as shown in the Figure 37 below.

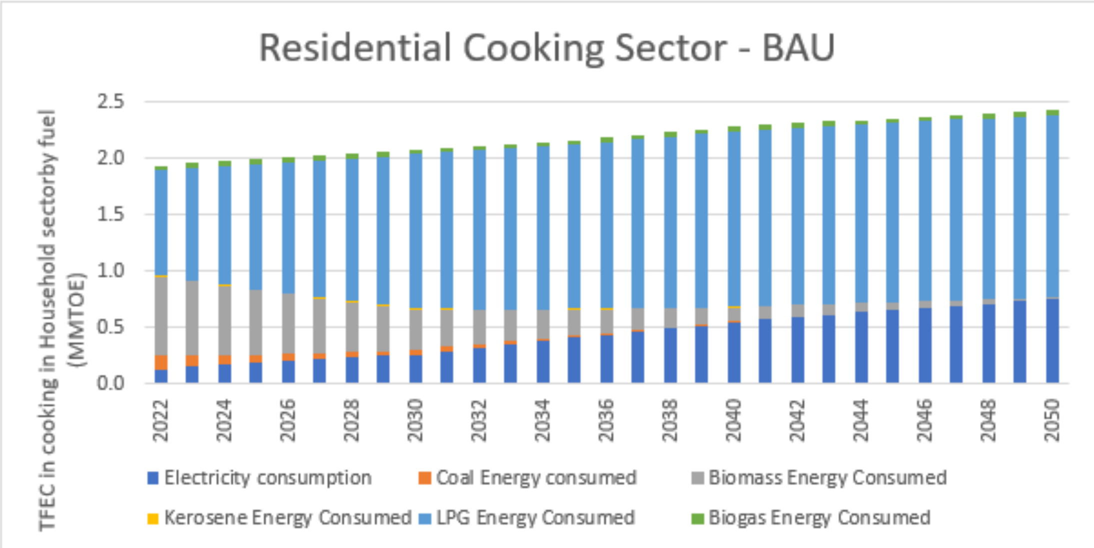
Figure 37: Residential Sector Energy Demand by fuel type



As is evident from the above figure, electricity is the major contributor to the residential sector, but by 2050 just above 25% of the energy comes from other sources, and about 50% of that is from fossil fuels.

As mentioned earlier, water heating and cooking , with a combined share of a quarter of total final energy consumed in this sector, have been identified as two areas within the household sector that consume a sizeable amount of energy and can be affected through changes that can be implemented in the coming years. VNEEP estimates that a four-person household spends between 16% to 21% of its electric energy usage on water heating. Additionally, data about current cooking consumption was received from WWF for the urban and rural areas and used for projections, as shown in Figure 38 below. The data shows a heavy reliance on LPG for cooking with over 65% of the energy coming from it in 2050, with most of the remaining coming from electricity and a small fraction coming from biomass and biogas in the rural areas.

Figure 38 Energy consumption by fuel for cooking in residential sector



These figures help determine a plan of action towards the 2050 scenario that relies solely on renewable energy (100RE). The heavy dependence on fossil fuels for cooking, and in the residential sector as a whole, needs to be reduced in the years leading up to 2050 by changing technologies and fuels, as mentioned in Section 4.2.4.

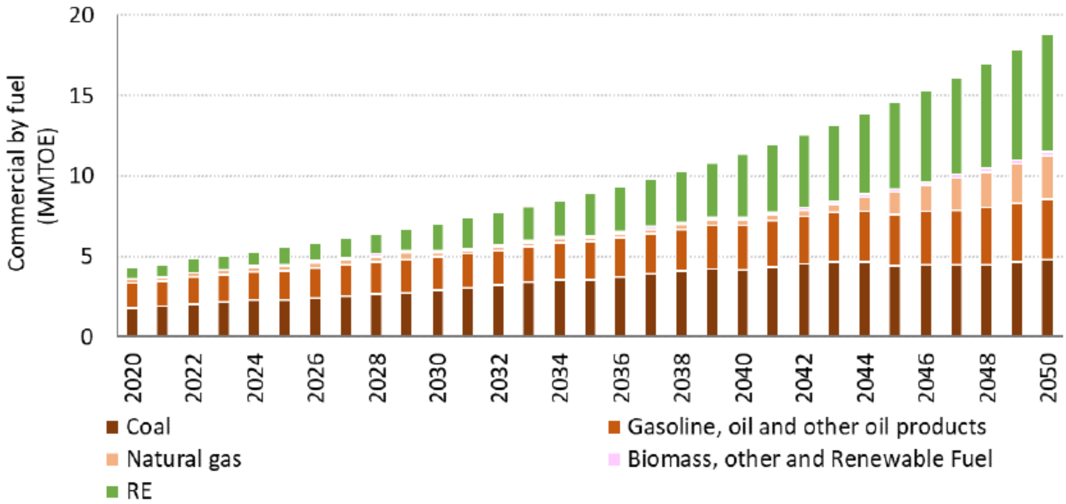
5.3.4 Commercial sector

Although the Commercial sector is growing in Vietnam, the total energy consumed by it is still a very small portion of the total energy consumption in the country, accounting for only about 5% in 2020. The majority of this consumption comes from fossil fuels, as seen in Figure 39.

The data from the GSO has been projected to 2050 to reflect the rising consumption of the steadily growing commercial sector. Two of the most important areas that have been identified for potential improvement are heating, ventilation, and air conditioning (HVAC) and lighting. Elevators and diesel-based generators are also considered large consumers of energy in this sector. The projections show that if energy use continues at its current trend, by 2050, just above 50% of the energy for the commercial sector could potentially come from fossil fuels.

The use of electricity, sourced from renewable sources, needs to be increased in this sector along with a reduction in the dependence on fossil fuels. The fact that biomass and renewable fuels do not currently contribute to the energy consumption in the commercial sector can be seen as a massive opportunity for transitioning to purely RE-based consumption in the coming decades.

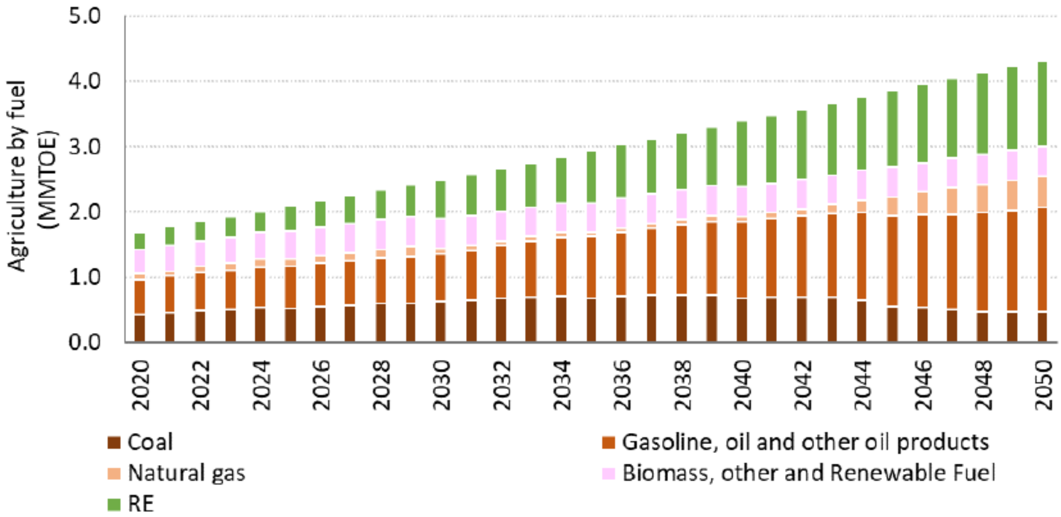
Figure 39 Commercial Sector Energy Demand by fuel type



5.3.5 Agricultural sector

The agriculture sector includes forestry and fishery/aquaculture in addition to agriculture. The total energy demand of this entire sector is not very significant when looking at Vietnam's entire economy. As was seen in Section 4.2.2, the sector amounted for about 3% of the country's total consumption. Figure 40 shows that by 2050, the demand for energy in this sector would have increased to almost twice the current levels.By 2050 just over 30% of energy demand is projected to be from fossil fuels, most of it being from gasoline and oil-based products, and about 10% from biomass and renewable fuels. The motorised equipment used in the agriculture; including but not limited to tractors, harvesters, pumps, and motors; all typically require diesel or gasoline to operate. Motorised equipment is also required in forestry, and pumps are seen as a major consumer of energy in the fishery/aquaculture sector.

Figure 40 Agricultural Sector Energy Demand by fuel type



The dependence on fossil fuels can be reduced by switching fuels used in the agriculture sector and sourcing the electricity from renewable sources.

5.4 Power sector development

5.4.1 Installed Capacity and Generation Mix

Figure 41 and

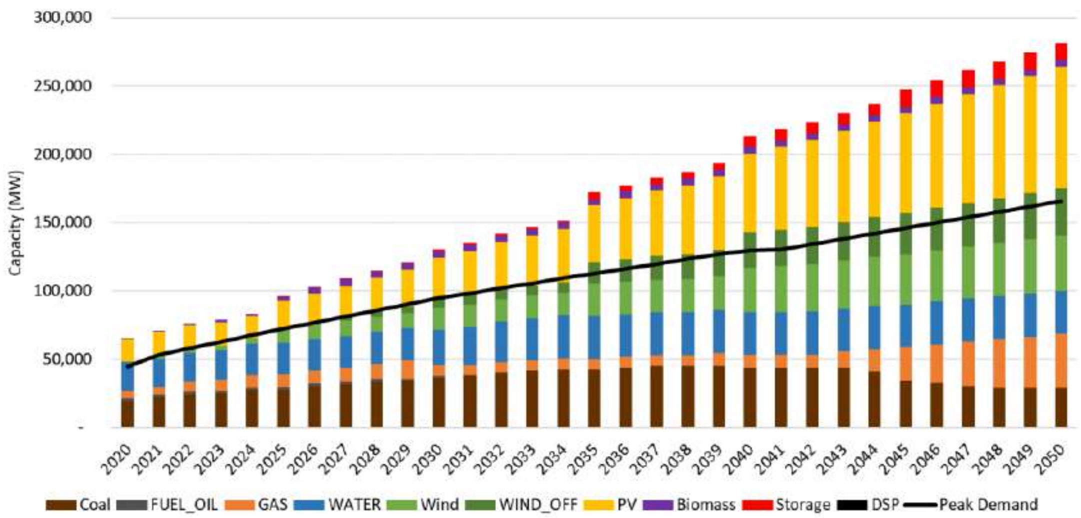


Figure 42 plot the capacity and generation mix across the entire system over the horizon. The demand outlook and new entrant schedule is based on the PDP8 base case and least cost new entrants. Key points of the outputs include:

- The outlook from 2021 to 2040 includes 24 GW of coal developments, 5 GW of gas (mainly CCGTs), 57 GW of wind of which 25 GW is offshore wind and 40 GW of solar. Most of the thermal developments are situated in the North region whereas solar and wind is concentrated in Central and South.
- Thermal generation mix starts at 60% and remains at this level until 2030 when new wind and offshore wind developments occur. Gas generation starts to overtake coal generation in 2045 with the retirement of coal plants and development of new gas plants.
- From 2040 to 2050, the capacity mix changes because of 15 GW of existing coal fleet retirements. This is replaced 30 GW of solar and 17 GW of wind (equal mix of onshore and offshore wind) to meet the increase in demand. There is also additional gas and 13 GW storage to support the RE capacity. Based on the capital costs of battery and future cost reductions, batteries are more cost effective in the long term and are developed in preference to pumped hydro storage.
- Total domestic renewable generation share declines with the development of new coal and gas but increases to 57% by 2050 including biomass and imports. The share of renewable generation in the north is still quite low with most new thermal developments situated in the North. Low RE capacity factors reduce cost efficiency of RE.

Figure 41 System Installed Capacity and Peak Demand

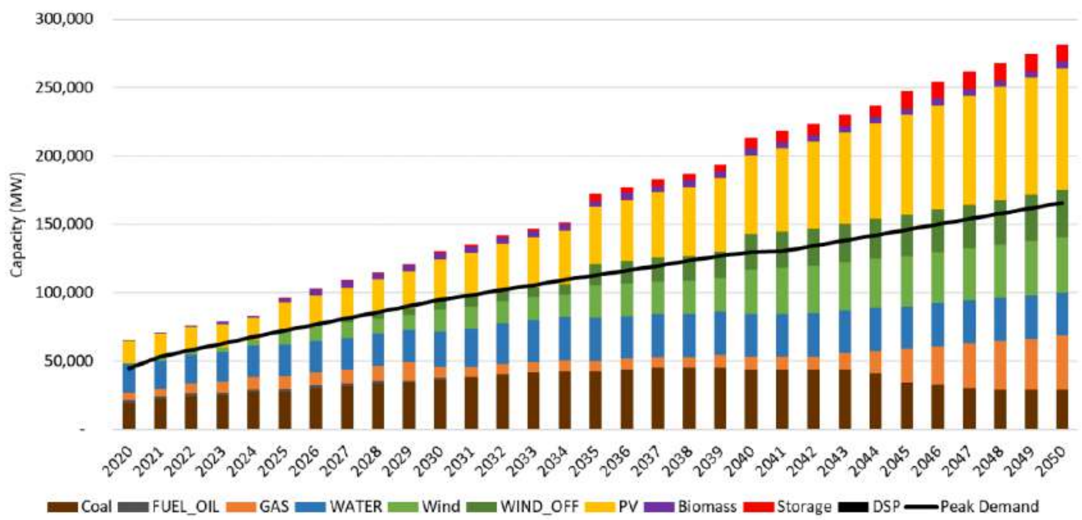


Figure 42 System Generation Mix

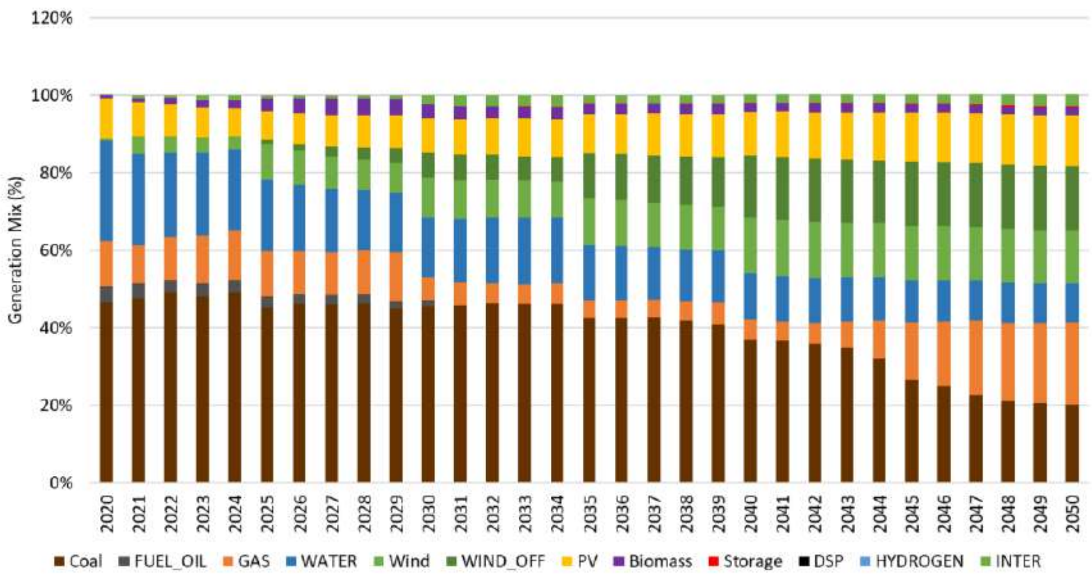
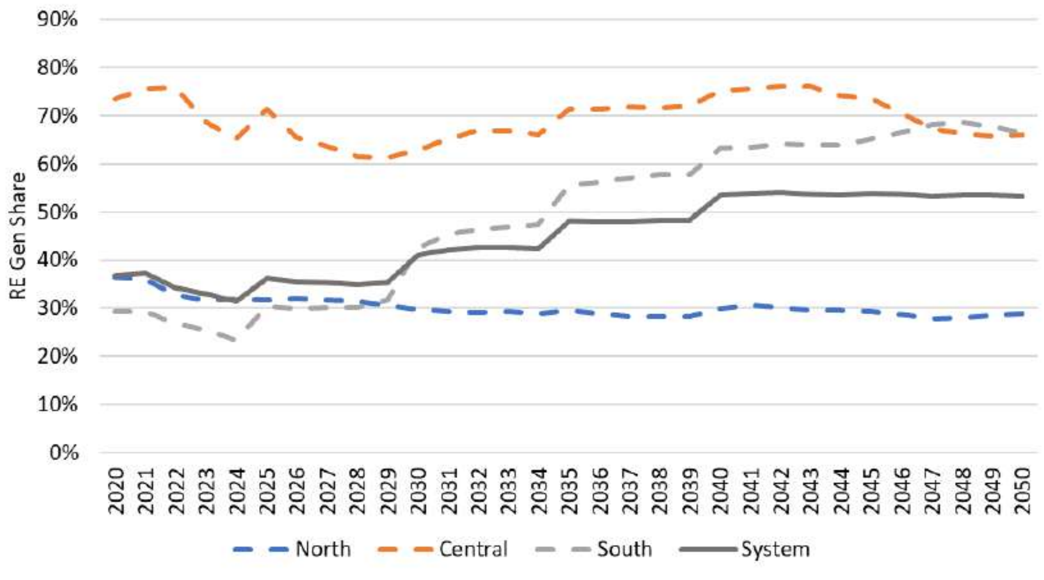


Figure 43 RE Generation Share



5.4.2 Fuel use and emissions in power sector

Figure 44 and Figure 45 plot the fuel consumption and emissions in the power sector. The required fuel use is dependent on the level of generation from each thermal generation type. Coal use increases from 2020 to 2030 which coincides with the added coal capacity and plateaus until 2040 when retirement of coal generators reduces the coal use. Gas consumption is constant with stable capacity factors to 2028 before new committed gas generators are added into the system. Gas consumption outlook post 2040 increases largely with much higher levels of gas capacity introduced into the energy system replacing coal as the major fuel.

Emissions increase steadily from 2020 to 2030 at the same rate as demand because the demand is met by new thermal developments as reflected by the flat profile in emissions intensity during this period. After 2030, the total emissions are relatively stable but the emissions intensity halves from 0.5 to 0.25 tons per MWh. This is driven by higher RE penetration as well as coal being replaced with lower emitting gas generators.

Figure 44 System Fuel Consumption

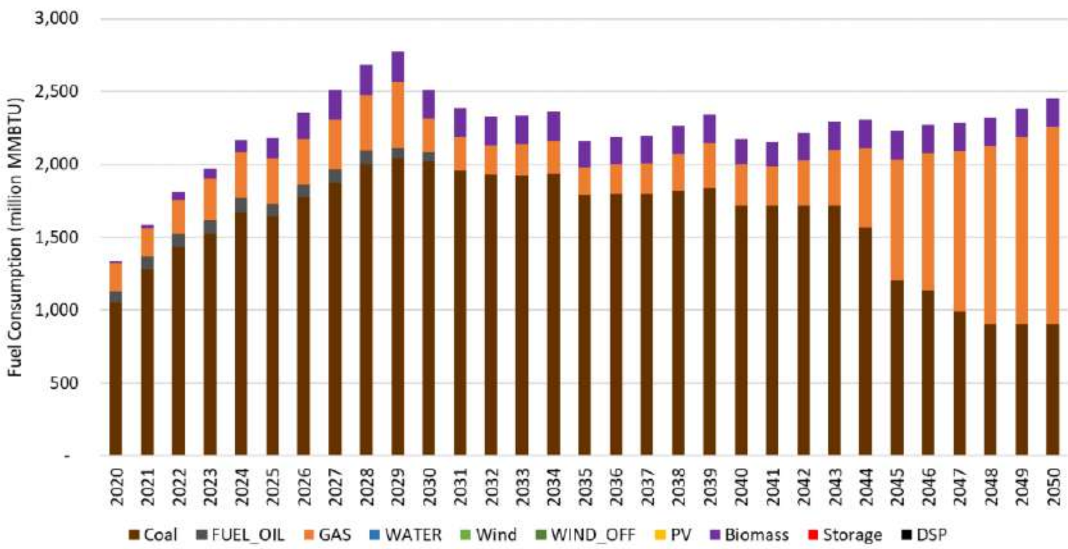
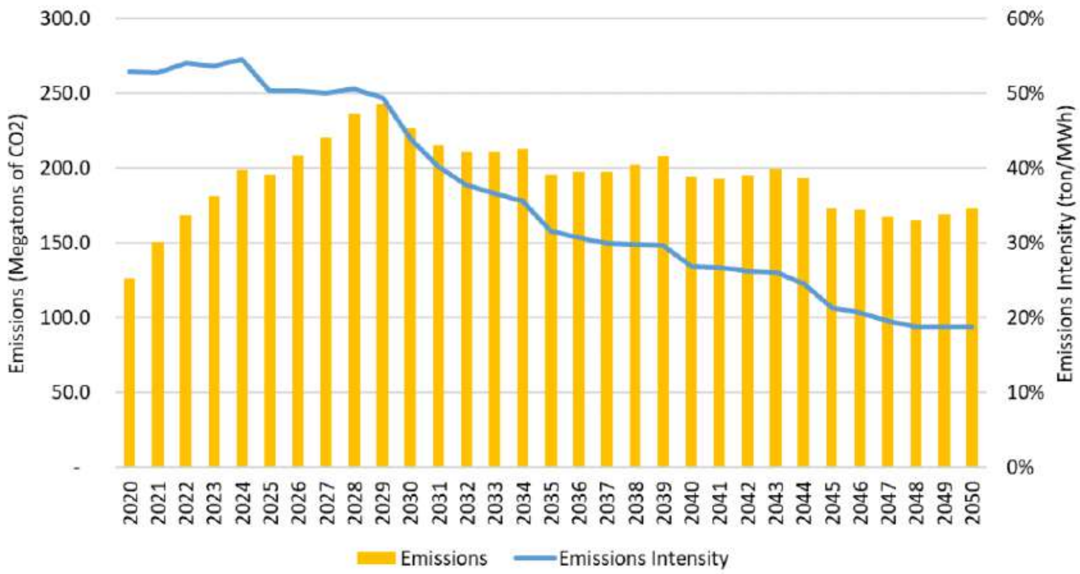


Figure 45 System Emissions and Emissions Intensity



5.4.3 System Costs and Levelised Cost of Energy

Figure 46 and Figure 47 show the annual system cost and the average system cost for met load. The split between annualized capex and fuel costs are relatively constant. The increase in system cost to meet the increasing demand is met with committed developments of coal and gas in the short term followed by solar and wind in the medium term. In the period after 2040, the fuel cost doubles from 10 billion to 24 billion driven by the increasing proportion of generation from natural gas which has much higher fuel costs than coal. The levelized cost of energy follows the same trend with slight increases in the short term before falling in the medium term with the introduction of solar and wind. In the long term, energy prices start to increase as a direct result of the additional fuel costs.

Figure 46 System Energy Costs

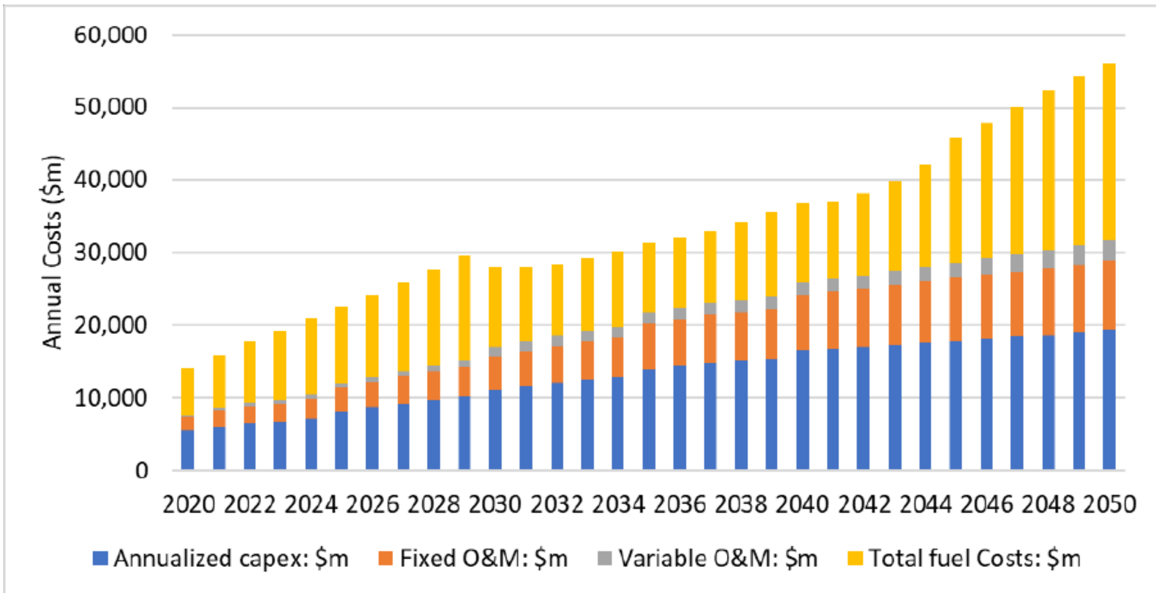
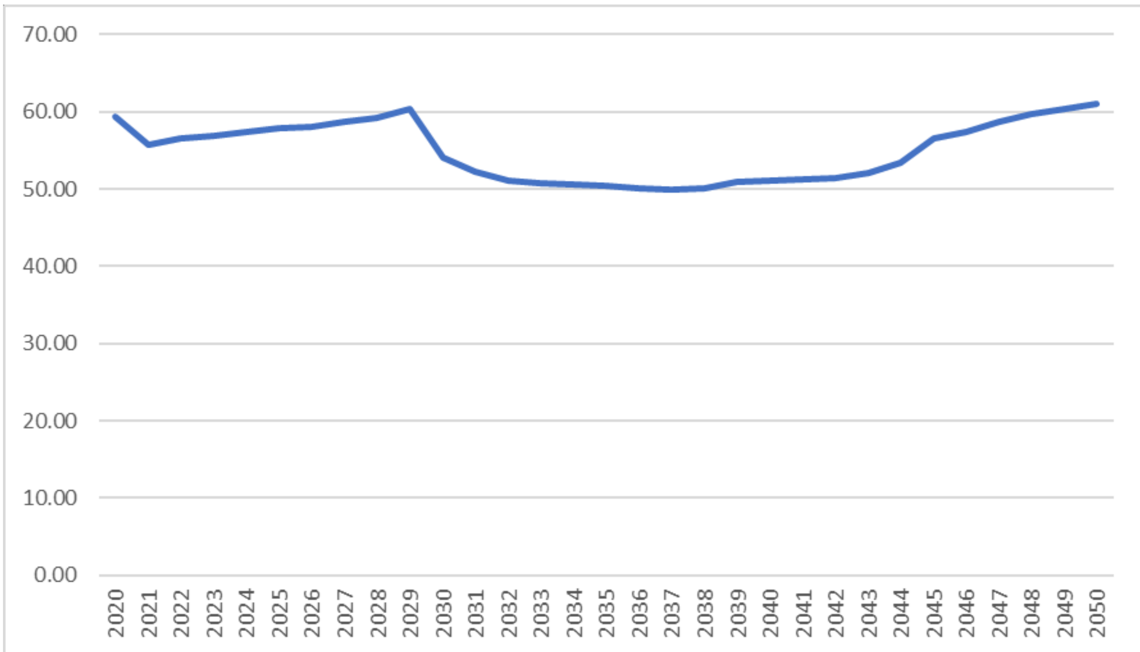


Figure 47 System Levelised Cost of Energy



5.5 Investment and technology costs

Costs relating to energy consumption are reported by component (variable fuel and fixed technology/investment) and for the electricity and non-electricity sector. The power sector has increasing costs from $14 billion in 2020 to $56 billion (Figure 48) in line with increasing electricity demands from 240 TWh to 950 TWh by 2050. The shares of fixed and variable costs remain similar across the horizon due to a relatively stable generation mix across RE and thermal generation. Non-electricity sector costs are comprised mainly of technology costs, with fuel comprising a smaller component of the total annual costs (Figure 49). Technology costs mainly relate to the transport sector.[8]

Total investment is shown in Figure 50 and shows investment in the non-electricity part of the economy outpacing electricity. Under the BAU, electricity consumption comprises approximately 30% of total energy consumption but only 12% of total energy costs out of the $470 billion per year in 2050 (Figure 51).

Figure 48 Power sector costs (annual)

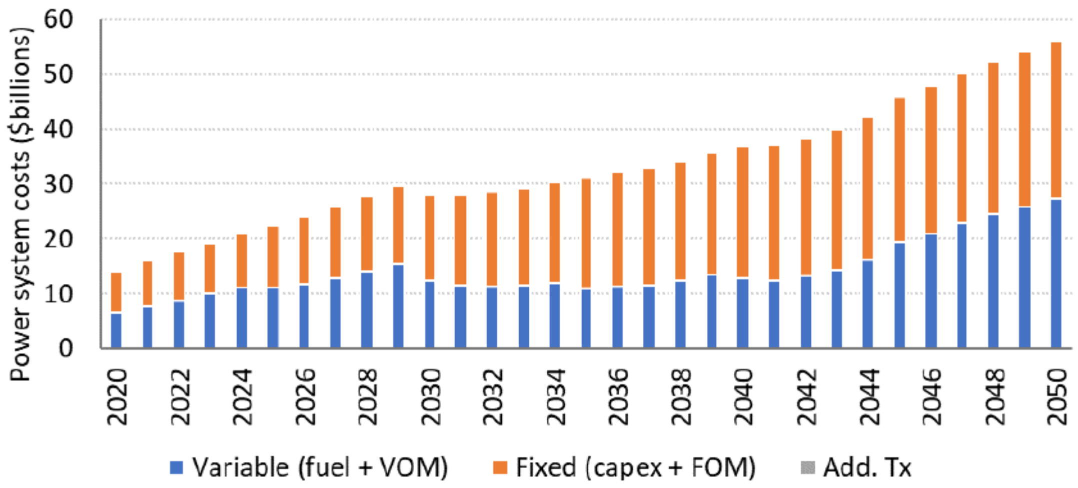
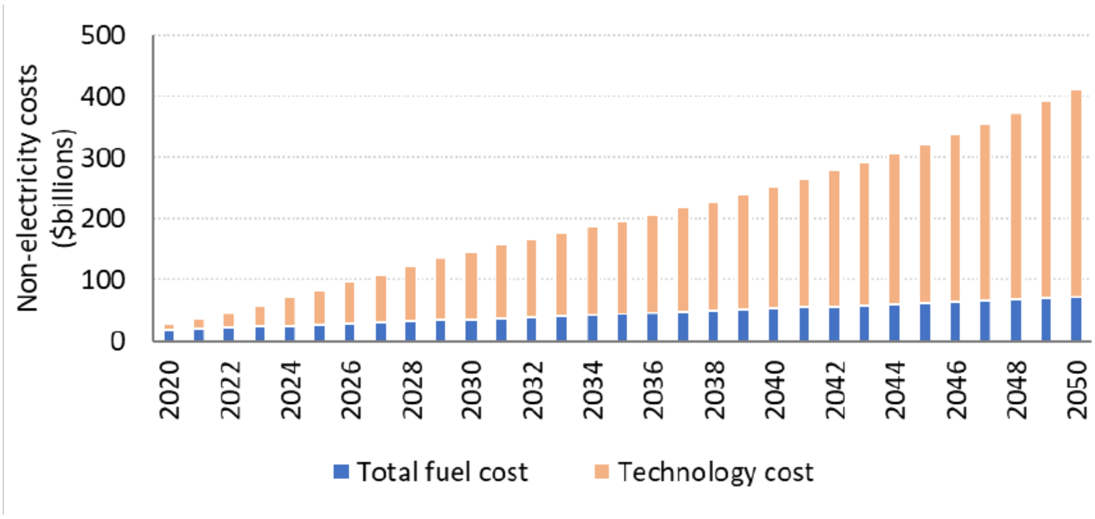


Figure 49 Non-power sector costs (annual)



[8] The transport model has a lot more coverage (bottoms-up modelling) than the other sectors.

Figure 50 Economy-wide investment cost (cumulative)

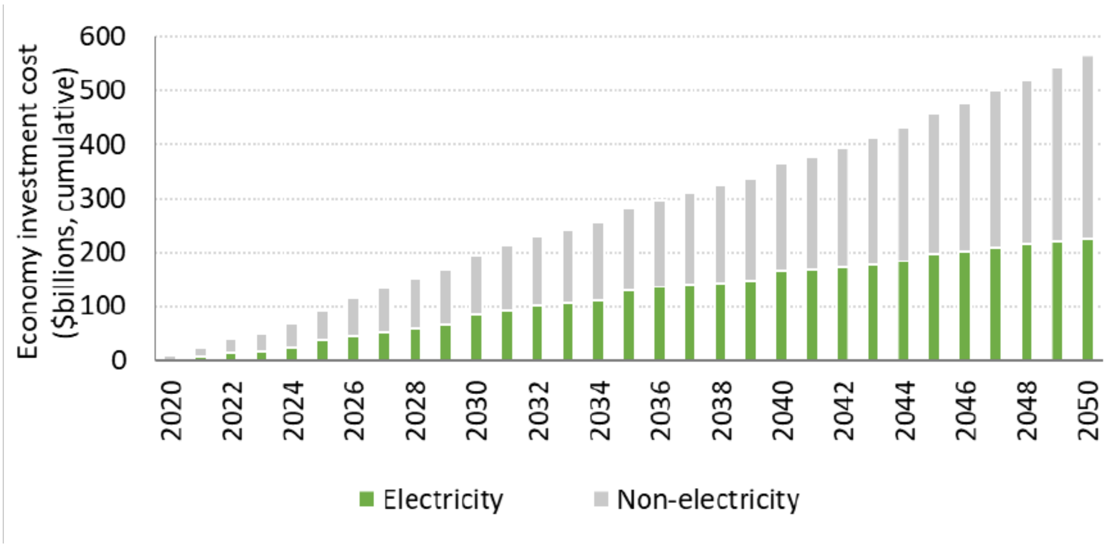
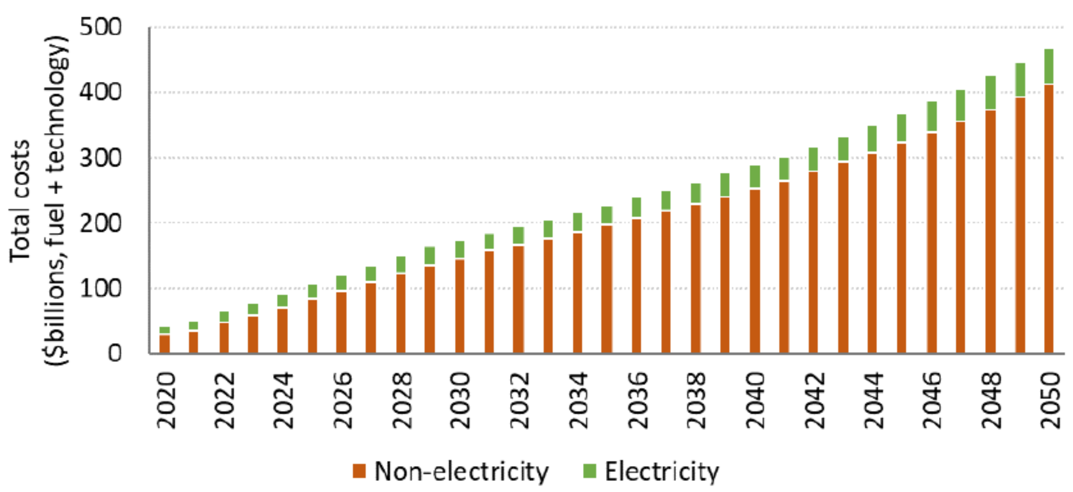


Figure 51 Economy-wide total annual cost



5.6 Primary energy supply

The projected primary energy supply is plotted in Figure 52 and shows a relatively stable energy mix throughout the horizon under the BAU except for the declining coal share over time. To meet this energy supply, it is expected that (a) additional crude oil will need to be imported and processed into gasoline and oil products, (b) imports of LNG to commence and support most of the growing natural gas demands, namely for power production, (c) increasing domestic exploitation of its renewable energy sources in wind and solar, and (d) reduction in imported coal for power generation over time. Figure 53 and Figure 54 are sample snapshots of the modelled energy balance in 2020 and 2050 respectively.

Figure 52 Primary energy supply

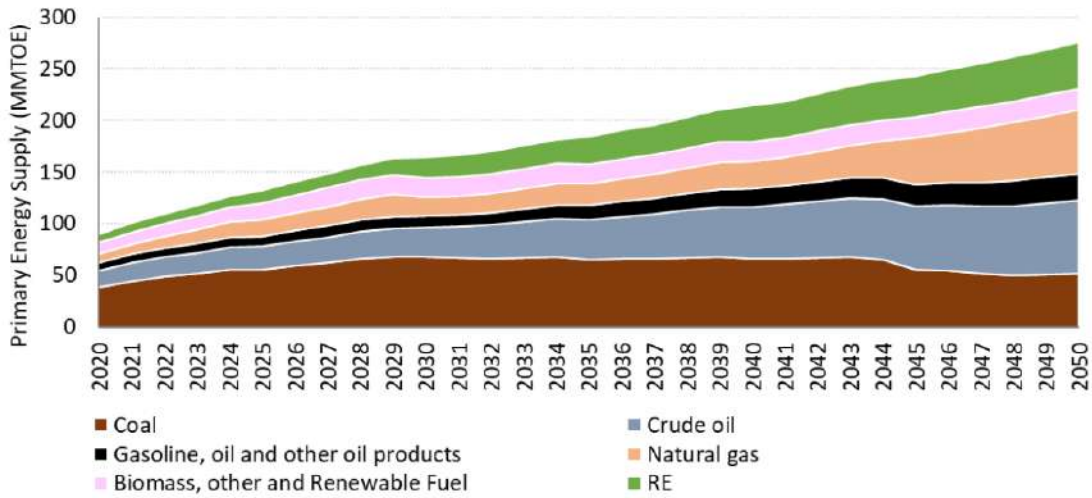


Figure 53 Energy balance in 2020, MMTOE (BAU)

Modelled	Total energy sources	Coal	Crude oil	Gasoline, oil and other oil products	Natural gas	Biomass, other and Renewable Fuel	Electricity
Total primary energy sup	**89.6**	**38.2**	**16.3**	**7.7**	**8.5**	**11.3**	**7.6**
Oil refinery facilities	-0.5		-15.3	14.8			
Gas processing facilities	0.0		0.0	0.4	-0.4		
Power plants	-20.3	-26.5	0.0	-1.9	-4.8	-0.6	13.5
Own use	-1.6	0.0	-1.0	0.0			-0.6
Distribution losses	-1.7	-0.2	0.0	0.0			-1.5
Total final consumption	**65.4**	**11.5**	**0.0**	**21.0**	**3.2**	**10.7**	**18.9**
Industry and constructio	34.4	9.4	0.0	4.2	3.1	7.8	9.8
Agriculture, forestry and	1.7	0.1	0.0	0.5	0.0	0.4	0.7
Transportation	13.8	0.0	0.0	13.6	0.2	0.0	0.0
Commercial and other s	4.3	0.9	0.0	1.5	0.0	0.0	1.9
Households	11.3	1.1	0.0	1.2	0.0	2.5	6.4
Non-energy consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 54 Energy balance in 2050, MMTOE (BAU)

Modelled	Total energy sources	Coal	Crude oil	Gasoline, oil and other oil products	Natural gas	Biomass, other and Renewable Fuel	Electricity
Total primary energy sup	**276.2**	**51.5**	**71.6**	**25.5**	**61.8**	**20.6**	**45.2**
Oil refinery facilities	-2.2		-67.2	65.0			
Gas processing facilities	0.0		0.0	1.7	-1.7		
Power plants	-17.7	-22.8	0.0	0.0	-34.2	-5.0	44.2
Own use	-5.5	0.0	-4.2	0.0			-1.3
Distribution losses	-6.7	-0.2	-0.2	0.0			-6.3
Total final consumption	**244.0**	**28.5**	**0.0**	**92.3**	**25.9**	**15.6**	**81.8**
Industry and constructio	126.7	23.9	0.0	23.5	25.2	11.8	42.3
Agriculture, forestry and	4.3	0.0	0.0	1.6	0.0	0.4	2.3
Transportation	60.1	0.0	0.0	59.5	0.6	0.0	0.0
Commercial and other s	18.8	2.3	0.0	3.8	0.0	0.0	12.8
Households	34.1	2.3	0.0	4.0	0.0	3.4	24.4
Non-energy consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0

5.7 Externalities

The calculation of externalities across the economy covering carbon emissions and air pollution from SOx, NOx and PM2.5 is plotted in Figure 55. Carbon emissions comprise almost half of all externality costs, with more than 50% of the costs driven by coal consumption to 2040 (Figure 56) but declines to less than 30% as coal generation tapers off in the power sector to 2050. Figure 57 shows the contribution of emissions from energy consumption in the power and non-power sectors and a reducing share from the power sector due to its increasing renewable energy generation share in the BAU.

Figure 55 Emissions cost by type

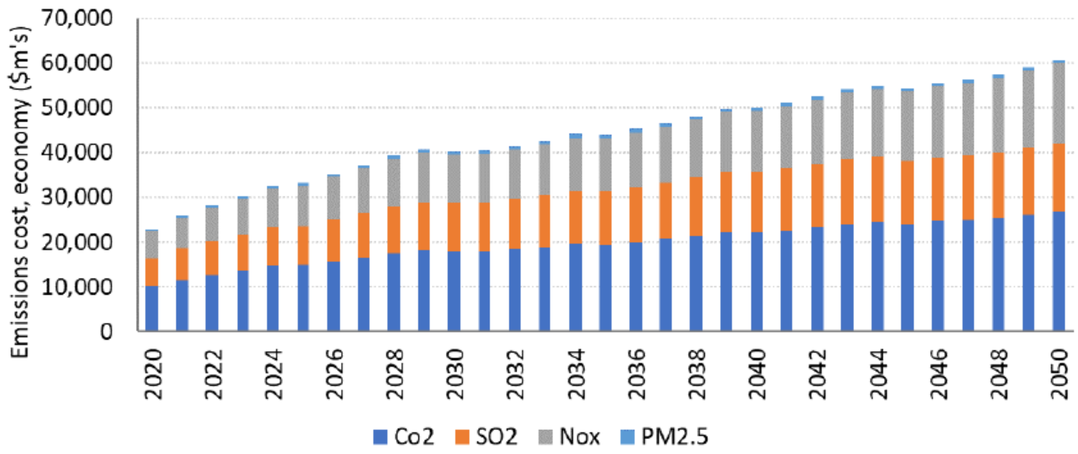


Figure 56 Emissions cost by fuel

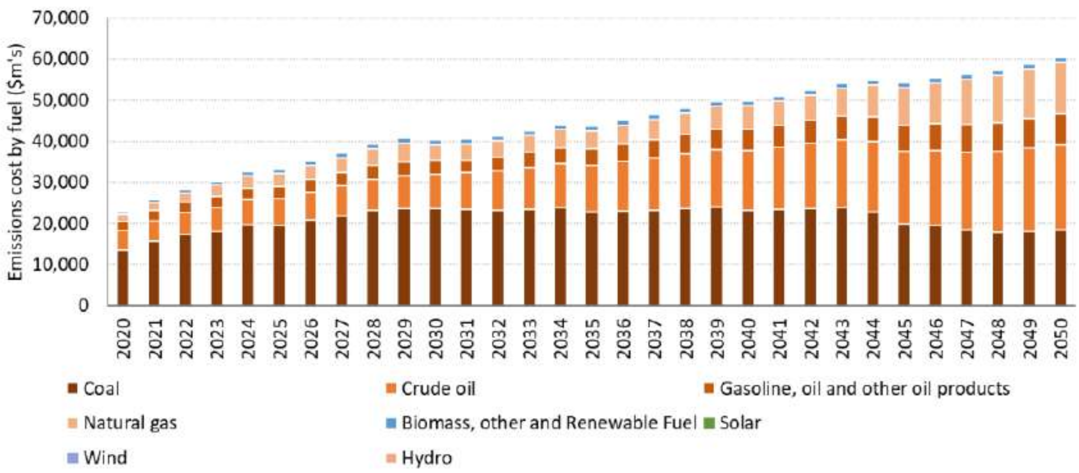
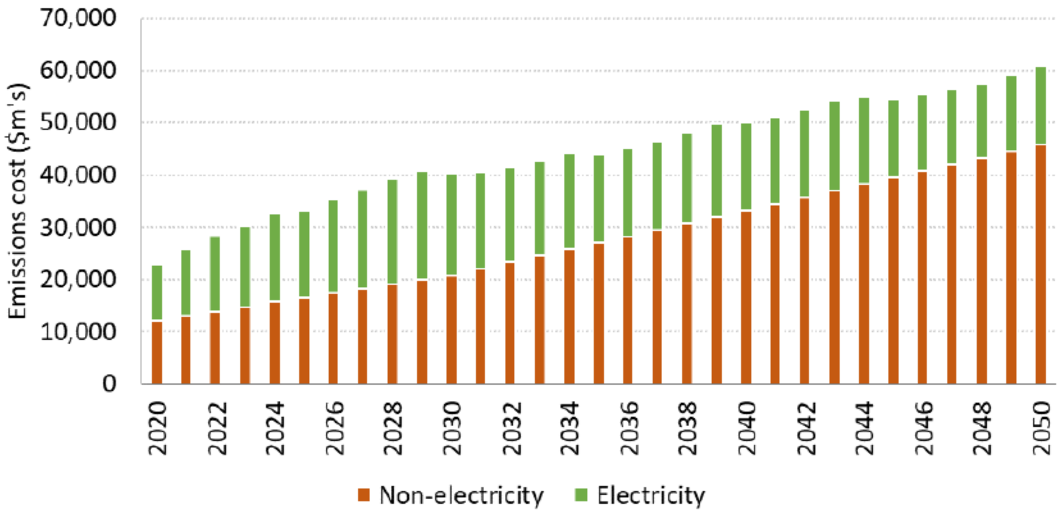


Figure 57 Emissions cost by sector

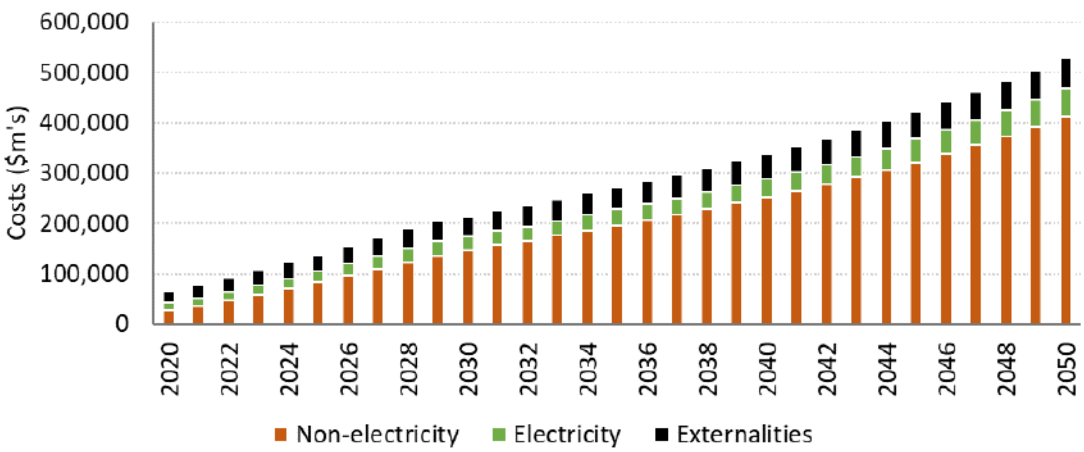


5.8 Key findings

The consumption of all energy carriers grows in the BAU. The share of fossil energy (coal; gasoline, and other oil products; and natural gas) increases in total. Within the fossil category coal's share reduces while that of natural gas increases the most. The growth of gasoline, and other oil products is mainly driven by increasing transport sector demand. Biomass' growth is limited mainly by resource availability while the share of renewables has minimal growth.

Figure 58 shows the economy wide cost in the BAU where, due to low electrification, the costs associated with electricity are a minor component of the economy wide costs.

Figure 58 Economy wide cost (annual)



6 Scenario comparisons

6.1 Summary

The following section compares the key findings across the BAU and two RE scenarios modelled. At a high-level, the 80RE and 100RE scenarios can deliver a high renewable energy future for Vietnam at a lower ongoing cost and investment requirements. After including externalities, the reduction in annual costs is approximately $180 billion or approximately 9% against the BAU, however, achieving this requires significant electrification of Vietnam's energy requirements. By 2050, the 100RE scenario relies on renewable electricity generation for 78% of its energy consumption and the balance from renewable fuels. In comparison, the 80RE scenario generates 65% of its energy needs through renewable electricity, with approximately 14% from renewable fuels but still relies on fossil fuel consumption (20%) for processes that are costly to electrify. The BAU remains largely fossil-fuel based (76%). The significant reductions in costs to achieve these objectives is largely driven by increased energy efficiency (mainly in the transport sector) and declining cost curves over time (from projected declining electric vehicles, solar, wind and battery energy storage system costs).

Table 24 Summary metrics

Metrics	BAU	80RE	100RE
TFEC (2050)	244	229 (-6%)	223 (-8%)
TFEC (fossil fuel, 2050 share)	74%	21%	0%
TFEC (RE, 2050 share)	19%	65%	78%
TFEC (Biomass, other and Renewable Fuel, 2050 share)	7%	14%	22%
NPV of costs (incl externalities, billions USD)	1,943	1,767 (-9%)	1,747 (-10%)
Total investment requirements (billions USD)	5,133	3,817 (-26%)	4,089 (-20%)

** Percentage difference from the BAU is shown between parentheses.*

The BAU is based on the current expected energy outlook in Vietnam, whereas the 80RE and 100RE scenarios correspond to more ambitious targets for Vietnam's energy transition towards higher renewables. Under the 100RE scenario, the entire economy has shifted away from relying on fossil fuels and is 78% electrified with the remaining 22% based on renewable fuels (see Figure 59 and Figure 60). The 80RE scenario allows for approximately 20% of the economy still consuming fossil fuels by 2050. Some other key points relating to the difference between these two scenarios against the BAU include:

- The 22% renewable fuel composition in the 100RE is close to the minimum that must be converted to renewable fuels as some sectors and activities are hard to electrify (aviation transport for example).
- The industrial and transport sectors are the most costly to electrify and therefore under the 80RE scenario are the sectors that still have fossil fuel consumption by 2050. See Figure 64 and Figure 65 for the sector consumption composition, and Figure 61 for the split in fuel costs by scenario. The annual fuel cost by 2050 in the 100RE relative to the 80RE is only slightly lower because of its higher dependence on renewable fuels which are more costly than fossil fuels used in the 80RE.
- Figure 62 plots the NPV of the associated economy-wide energy costs, and based on fuel and fixed costs only, show the BAU having the highest cost before considering externalities. The 80RE has the lowest cost, followed by 100RE then the BAU. The BAU has the highest cost because of continued and growing fossil fuel consumption against a backdrop of declining RE generation, and the 80RE has a lower cost compared to the 100RE because costs associated with moving towards a 100% RE energy system is more costly than allowing for some fossil fuel generation to remain. This is due to the underlying assumptions where (1) the cost of fossil fuel consumption increases due to rising fuel prices and non-decreasing technology costs, (2) declining EV and RE technology costs over time, for example, passenger EV cost reducing by almost half by 2050, and (3) lower energy consumption in the 100RE because EVs are generally more fuel efficient than ICE.
    - The 100RE scenario cumulative cost includes a significant component of fuel costs because (a) the NPV includes all years across the horizon including earlier years which still have fossil fuel consumption, and (b) the 100RE is still reliant on renewable fuels to achieve 100% RE by 2050. Note that as mentioned in Section 5.1 the fuel category includes costs of both fossil and renewable fuels. See Figure 61 for the split in fuel costs by scenario.
    - The waterfall chart in Figure 63 shows the main components contributing to the lower cost of the 100RE scenario relative to BAU. Externalities cost is shown as a separate category and is not double counted in sector costs. The main cost reductions come from the transport sector, reflecting the significant benefits of transitioning to EVs as mentioned above, and externalities. Costs in the industrial sector represent the largest component of where costs are higher in the 100RE scenario than BAU.

- Figure 66 and Figure 67 plot the carbon intensity and energy intensity (based on energy required to generate a dollar of GDP), respectively, and show in all scenarios the carbon intensity reduces from 2030, however, the 100RE has the lowest energy intensity. This is because shifting to electricity, such as in the case of passenger EVs, is significantly more energy efficient.

Figure 59 Economy wide energy consumption by scenario

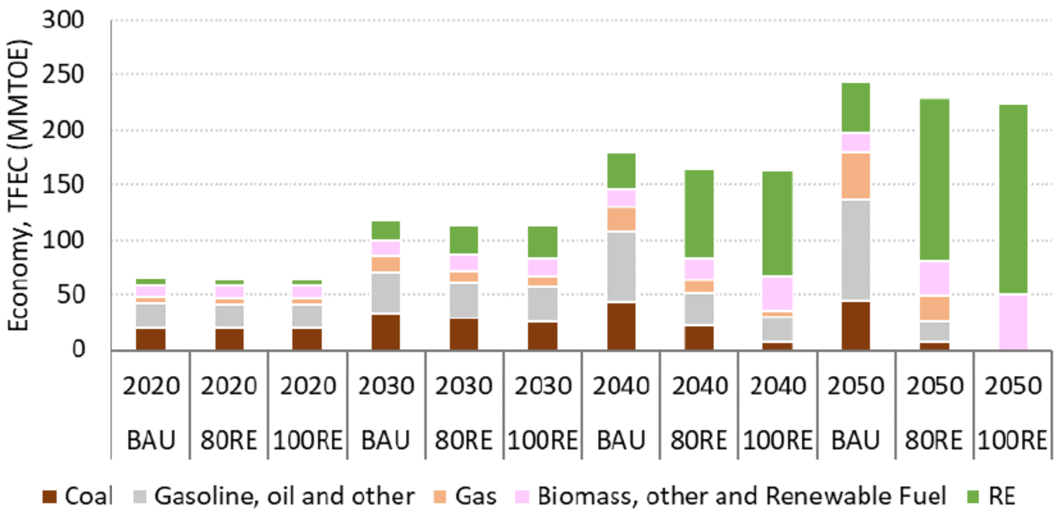


Figure 60 Economy wide energy consumption by scenario (share)

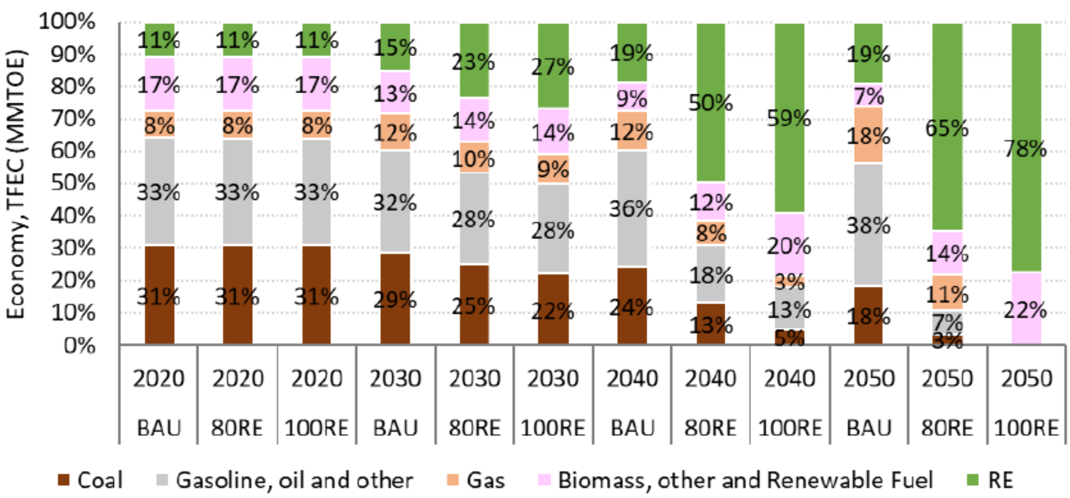


Figure 61 Economy wide fuel costs by scenario

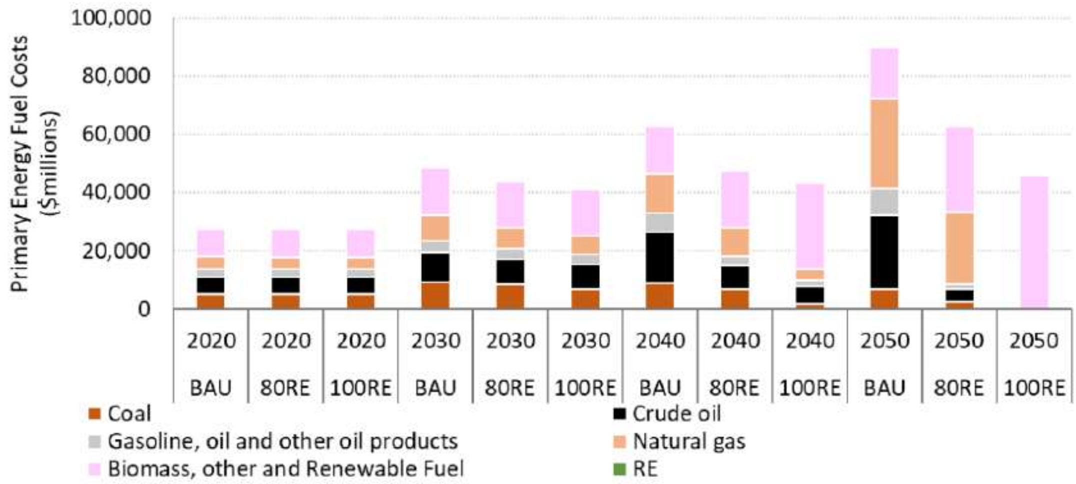
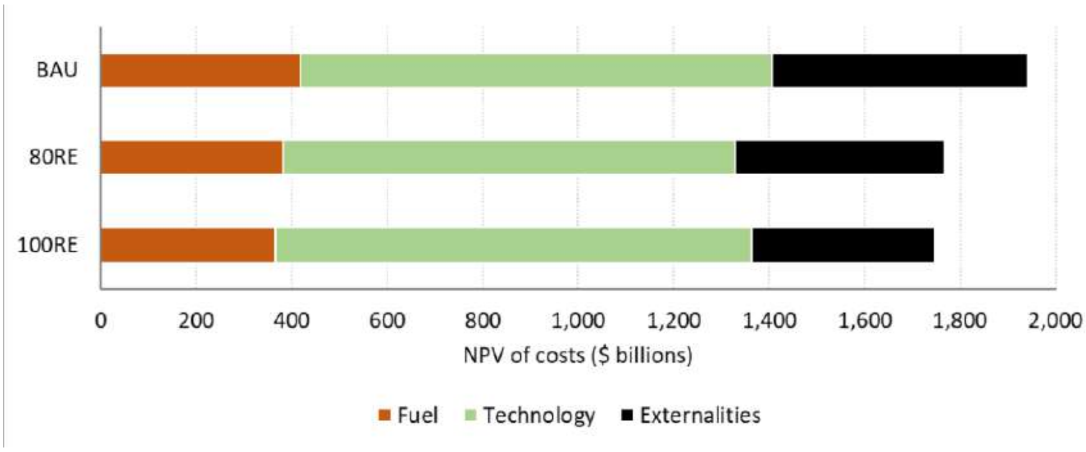


Figure 62 NPV of costs by scenario



Note: Assumes discount rate of 10%

Figure 63 BAU to 100RE Cost Differences

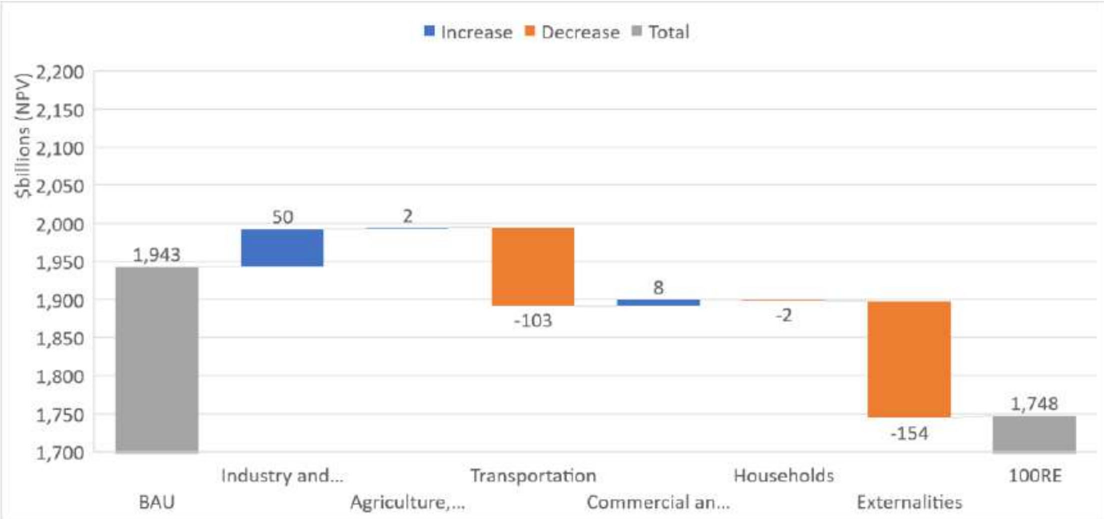


Figure 64 Sector energy consumption by scenario

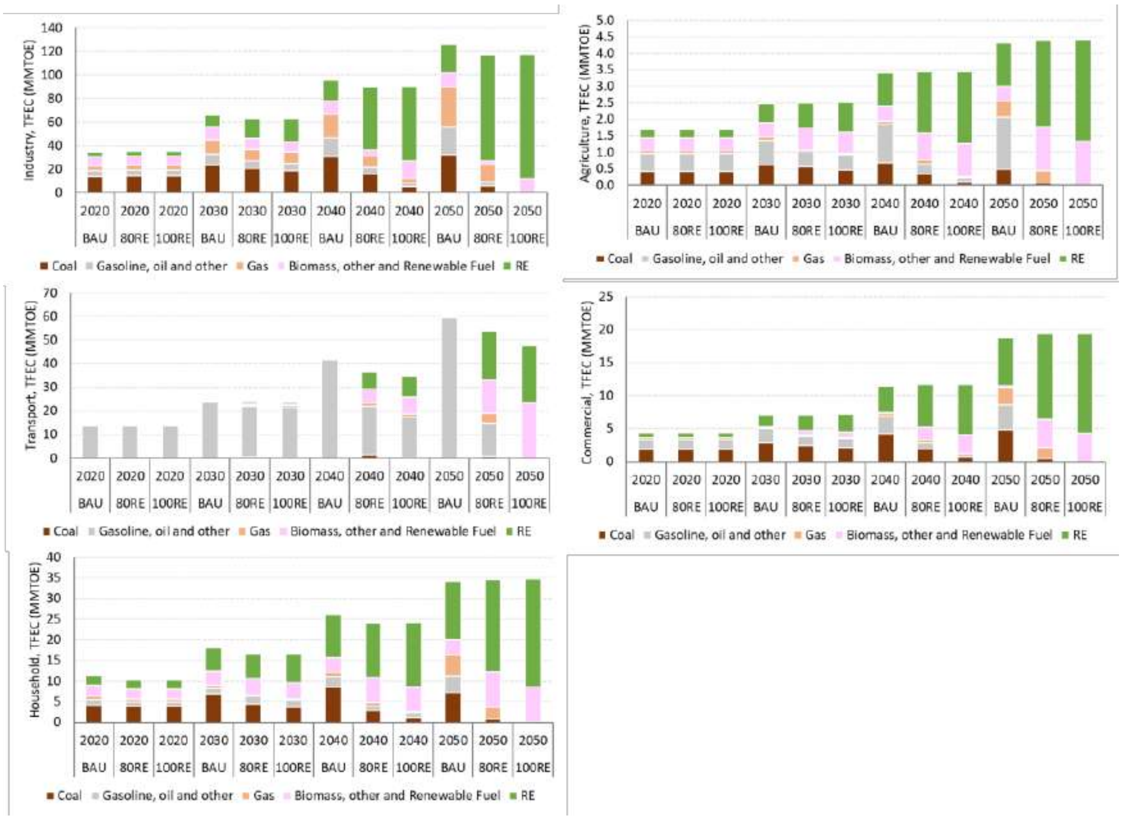


Figure 65 Sector energy consumption by scenario (share)

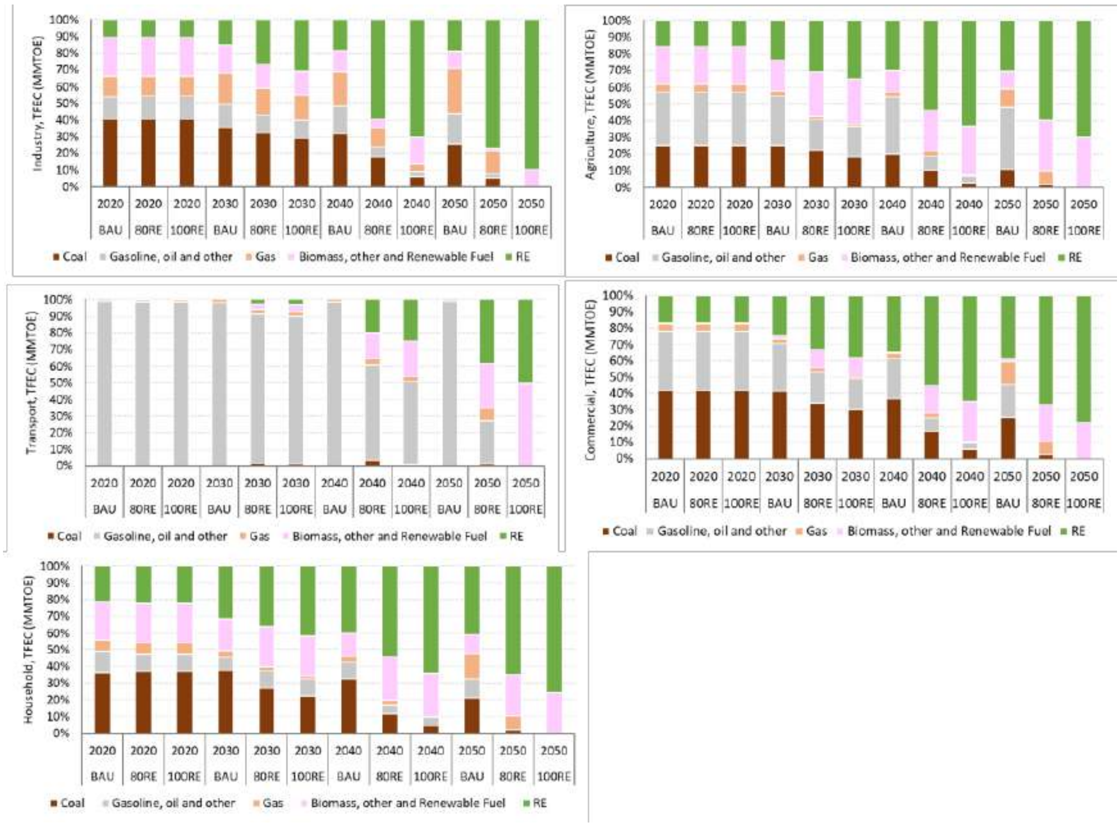


Figure 66 Economy-wide carbon intensity

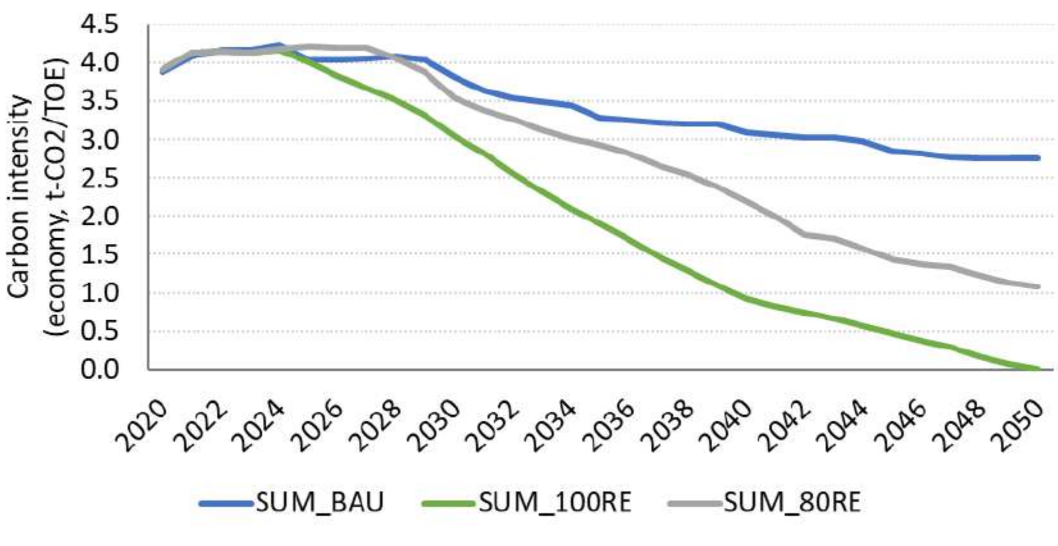
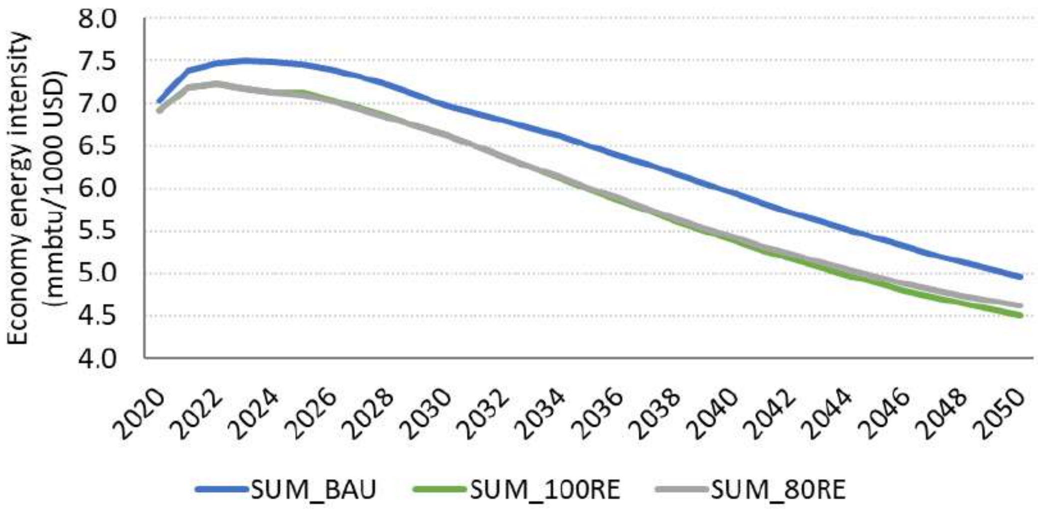


Figure 67 Economy-wide energy intensity



6.2 Energy demand

6.2.1 Industrial sector

In this section we compare the three scenarios by comparing the snapshot years 2020, 2030, 2040 and 2050. All three scenarios start in the year 2020. Following the same reasoning used for the BAU in Section 5.3.1, attributing the consumption of the sector by fuel type (indirectly through electricity imported from the power system) provides a more representative view of its total contribution. This is shown in Figure 68. The renewable energy from the power grid and renewable fuel are the renewable energy portions of energy consumption. They grow somewhat in the BAU case but grow more in both the 80% and 100% scenarios. The share of these two fuel types, seen in Figure 69 is still modest in 2030, even in the 80% and 100% scenarios, but becomes more significant in 2040, reaching approximately 55% and 70% in the two scenarios. By 2050 all energy is sourced from renewable sources in the 100RE while in the 80RE we see fossil fuels remaining in the system in 2050, consistent with the target of the scenario. Figure 70 shows that in both 80RE and 100RE electricity used directly in industry is nearly at the same level but the share of biomass and other has decreased by giving way to fossil fuels. Turning back to Figure 68 we see that the RE bar in 2050 in 80RE is smaller than in 100RE. This difference comes from the difference in the power system in both scenarios. In the 80RE the marginally more expensive power to switch into RE was avoided resulting in a smaller RE share attributed to the industrial sector.

Figure 68 TFEC by type – Industrial sector – Scenario comparison

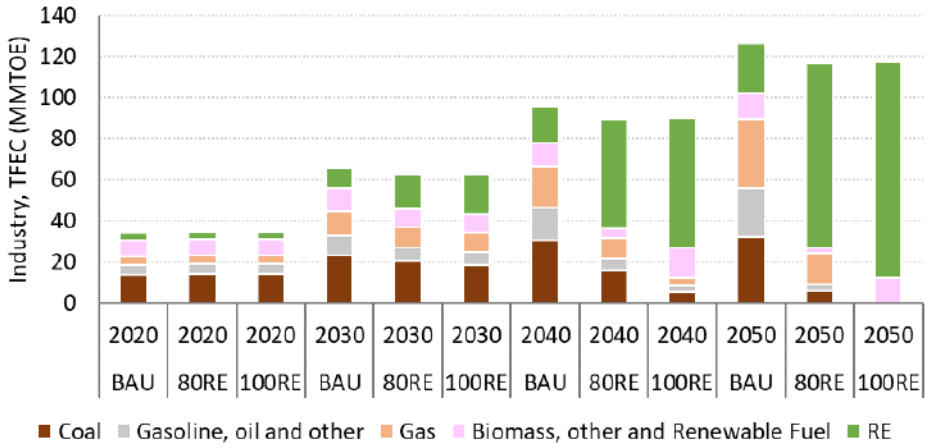


Figure 69 TFEC share by type – Industrial sector – Scenario comparison

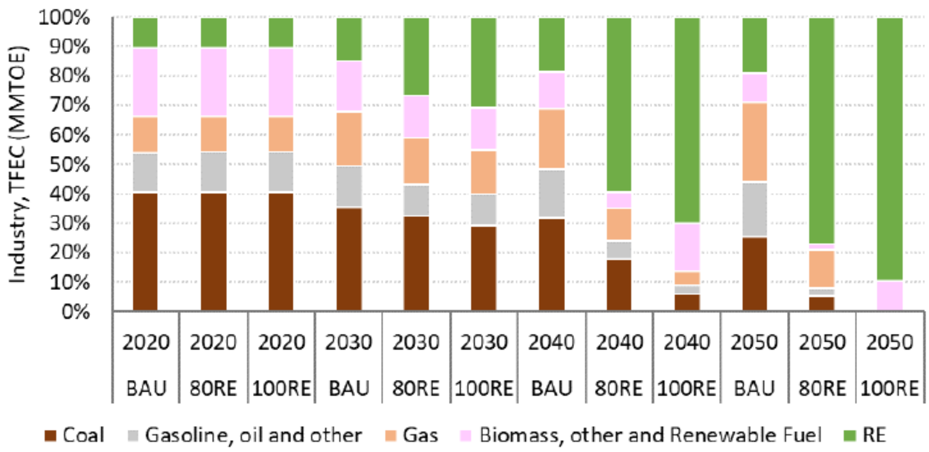
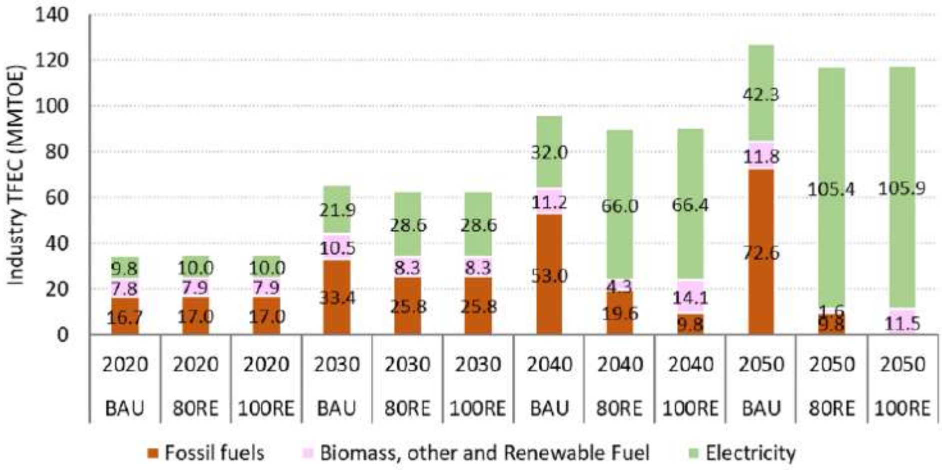


Figure 70 TFEC by type – Industrial sector – Scenario comparison



6.2.2 Transport sector

Under the BAU, transport remains close to 100% fossil-fuel based and requires almost 60 MMTOE by 2050 (Figure 71). The other scenarios notably have lower energy requirements due to higher uptake of EVs that are more energy-efficient than its fossil-fuel counterparts. The 80RE and 100RE transport outlooks electrify up to 50% of the sector, mainly in the road passenger vehicle categories, with the balance converted to renewable fuels in 100RE, and spread across renewable and fossil fuels in the 80RE case (Figure 72). Other key points include:

- To reach 100% RE across the transport sector, vehicle replacements or shift towards EV and renewable fuel need to occur by 2040 at the latest due to the 7-10 year average vehicle life.
- Total transport TFEC in the 100RE is almost 25% lower than in the BAU by 2050 because EVs have higher fuel efficiency.
- The lower fuel cost associated with EVs is offset by the higher investment cost of the vehicles and infrastructure (charging stations) required initially. It is noted that technology costs associated with EV is forecast to decrease rapidly. Over the forecast horizon EVs start at higher cost levels, compared to the cost of traditional fossil-fuel based vehicles, but end up lower than their counterpart in the fossil category (see cost assumption section).
- The 20% allowance of fossil fuels in the 80RE case found it efficient to keep some fossil fuel consumption in the transport sector. Conversion to renewable fuels was otherwise significantly more costly which is required in the 100RE and generally only starts to comprise a meaningful share of TFEC from late 2030 onwards. The category

'Biomass, other and Renewable Fuel' in Transport includes only renewable fuels but the label is maintained for consistency across all sectors of the economy.

Figure 71 TFEC by fuel – transport sector – Scenario comparison

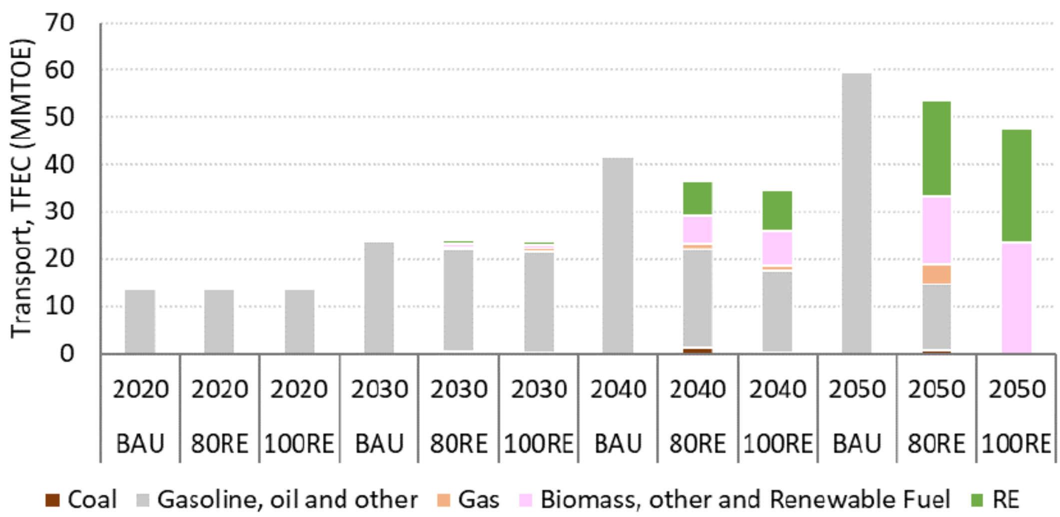
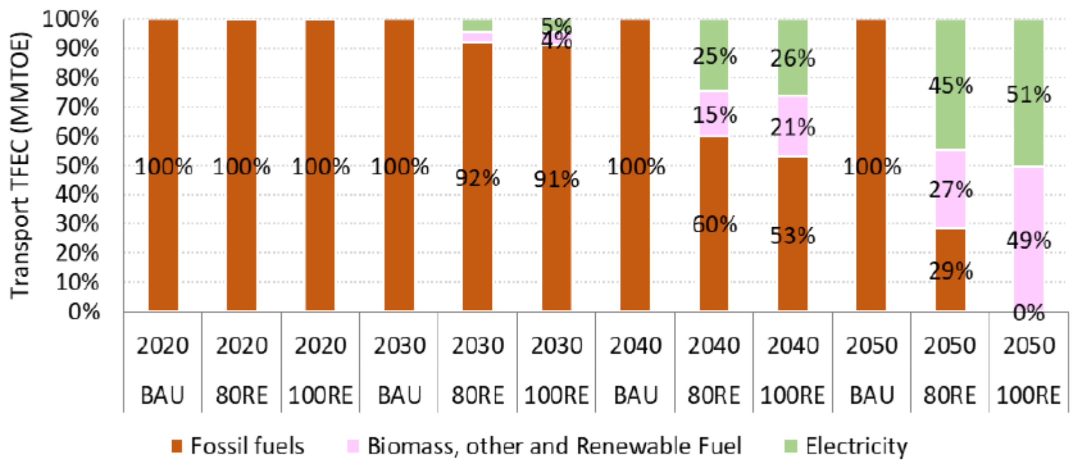


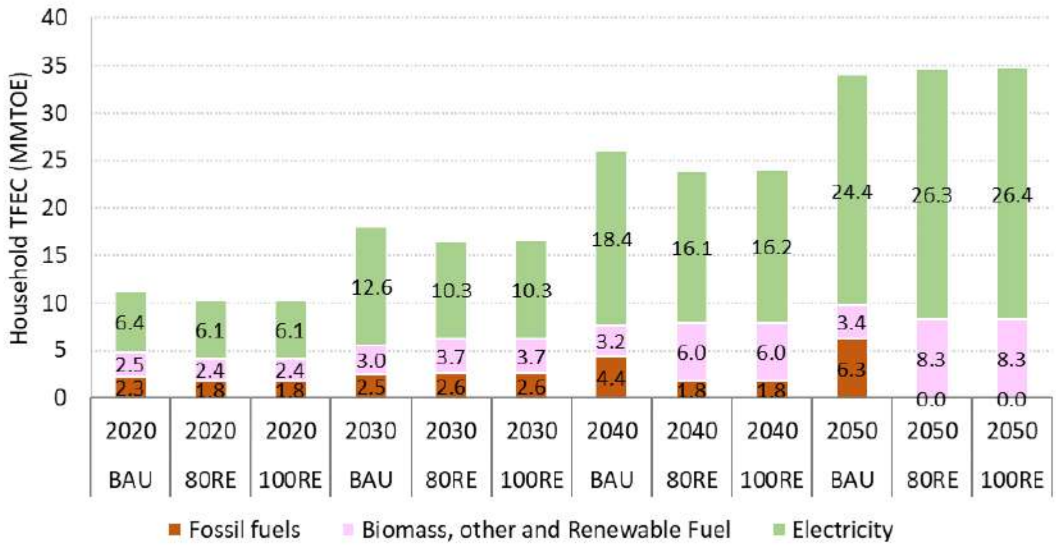
Figure 72 TFEC share by fuel category – transport sector – Scenario comparison



6.2.3 Household sector

The two-pronged approach described in Section 4.2.4 is designed to push for the use of renewable energy and renewable fuels for water heating and cooking in the residential sector. The remaining areas of consumption within this sector are mostly for heating and cooling and for the operation of household appliances, all typically dependent on electricity. Changing the source of the electricity supplied to the households will make these areas dependent on renewable energy as well. The use of coal is assumed to be for cooking or heating particularly in the rural areas. The electrification of these over the coming decades through the adoption of electrical appliances or cooking methods is the fastest way of ensuring that the residential sector is free from fossil fuels and dependent only on renewable energy by 2050. Other consumption areas like HVAC, and other white goods are expected to be powered through RE in the coming years and have been accounted for under the Electricity part in the household sector. Figure 73 below depicts the energy mix when an aggressive adoption policy is used to electrify the energy or shift it to depend on renewable fuels wherever possible.

Figure 73 Residential sector energy mix to reach 100% RE by 2050

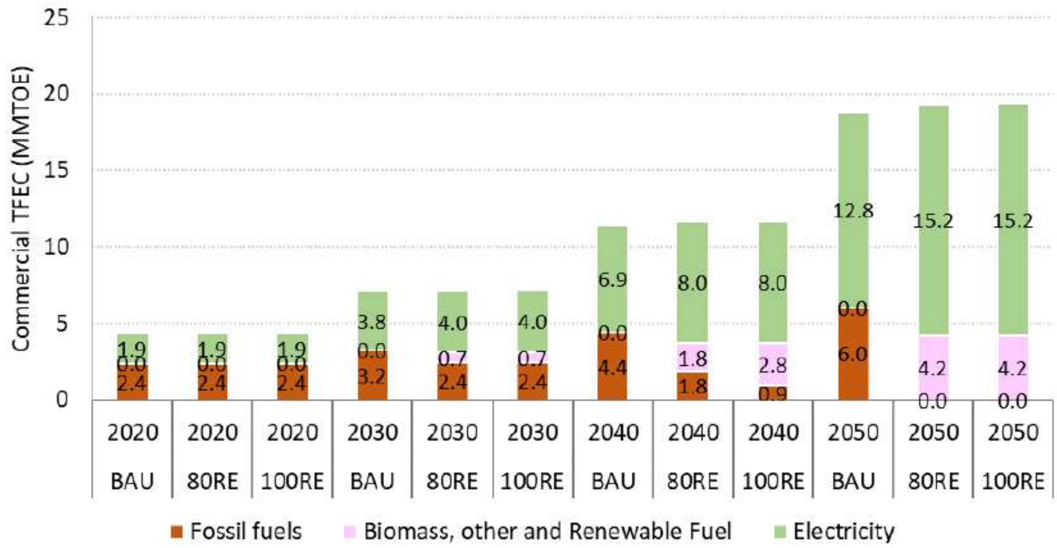


The above figure shows that electricity would make up the majority of the supply in this sector, as should be expected. However, there is a significant contribution from biomass, which is expected to be used for cooking in the rural areas with the adoption of improved, high-efficiency biomass stoves. The 80% Renewable Energy scenario retains a bit of the fossil fuel contribution, which allows for a marginal leeway in the adoption of renewable energy technologies. This can be taken advantageous when implementing RE policies in the rural areas where it may be difficult or financially unviable to adopt the require changes.

6.2.4 Commercial sector

The commercial sector in Vietnam, though growing as mentioned in Section 4.2.3, consumes a small portion of the total energy, with a majority of it coming from fossil fuels. As mentioned earlier, the identified areas that can be targeted to move towards complete reliance on renewable energy are HVAC, lighting, and diesel-based generators. The adoption of more efficient lighting while making use of natural light, installation of better HVAC systems and elevators, and replacement of diesel-based generators with those based on either biodiesels or batteries is seen as the way forward to reach the renewable energy targets over the coming decades. Figure 74 shows that integrating biomass and renewable fuels into the commercial sector is a viable option for replacing the fossil fuels and reaching the renewable energy targets of 2050.

Figure 74 Commercial sector energy mix to reach 100% RE by 2050



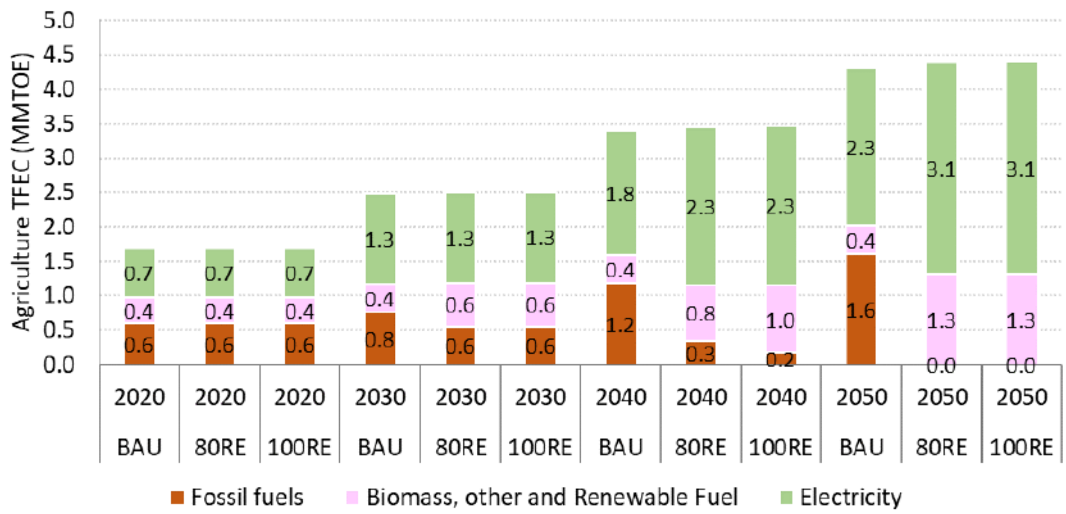
The commercial sector is one of the two smallest sectors in the country, and mostly consists of equipment, appliances, and machinery that is relatively easy to electrify. Therefore, the 80% renewable energy scenario for 2050 is similar to that of the 100% renewable energy scenario. This is a conscious decision as it is easier to replace the fuels used in this sector or to electrify the sector to as much as possible. The share of electricity can be seen to have increased by 2030 and 2040, with the fossil fuels decreasing and biomass/renewable fuels increasing with each making up 50% each of the remainder of the energy mix in 2040. The reduction in fossil fuel usage is gradual, until it is completely replaced by biomass, renewable fuels and electricity by 2050.

6.2.5 Agricultural sector

The agricultural sector, which includes forestry and fisheries, does not account for a large demand in the overall energy mix of Vietnam. The dependence on fossil fuels, which currently amount to about 30% of the total mix can be reduced by implementing an aggressive policy of replacing the gasoline and other fuels with renewable fuels. This, along with the increased electrification of the system can lead to the generation mix represented in the Figure 75. Biomass, shown in the figure comprises, for the most part, renewable fuels. The share of electricity in this sector is also increased from just under 50% currently to about 70% in 2050. This is possible because the equipment and machinery used in this sector is relatively easy to electrify and modify to operate on renewable fuels. This slight advantage should be exploited and every effort should be made to ensure that renewable energy sources are used in this sector.

Similar to the commercial sector, the agriculture, forestry, and fishery sector also consumes a small fraction of the total amount of energy consumed in the country. The 80% renewable energy scenario is the same as that of the 100% renewable energy scenario because of the comparative ease of electrification and integration of biomass and renewable fuels. This sector is concentrated in the rural areas of the country which already have a high consumption of biomass in the Household sector which can be extended to this sector. Like the Commercial sector, this is a conscious decision as it allows for more flexibility in the other sectors which can be much harder to electrify.

Figure 75 Agriculture sector energy mix to reach 100% RE by 2050



6.3 Power sector development

6.3.1 Capacity and generation mix

Figure 76 and Figure 77 show the installed capacity and generation mix for the snapshot years between the scenarios. The BAU has a growing proportion of installed gas generators whereas the RE scenarios rely on solar and wind generation. The higher electricity demand in the RE scenarios is reflected in higher total installed capacity compared to BAU (almost five times higher in MW terms). By 2050, there is an additional 226 GW of solar in the 100RE compared to the 80RE scenario to replace the remaining coal and gas that is allowed in the 80RE scenario. The high levels of installed capacity of solar (450 GW in 80RE, 730 GW in 100RE) require large areas of land. The PDP8 shows more than 1500 GW of solar technical potential estimated based on GIS mapping with a total large-scale potential of 386 GW. However, other studies, such as the EOR21 report, suggest that the majority of this can be developed. EOR21 includes 953 GW of solar (utility, floating and rooftop PV) in its Net Zero scenario with a land requirement of 11,000 km^2 (1,100,000 Hectare) representing 3% of total land available in Vietnam. The 100RE results included a more conservative capacity of 730 GW of solar for the 100RE scenario.

The transition to higher RE and electrification show steady decline in participation of coal in the generation mix. By 2030, thermal generation decreases from 60% to 40% in the 80RE and to 30% in 100RE compared to BAU. In 2050, this number decreases to just 12% in the 80RE scenario and 0% in the 100RE scenario. The power system in the RE scenarios shows much higher wind and solar in the generation mix. The shares of wind and offshore wind in 2050 between the two RE scenarios remain with same and the thermal generation is replaced by a mix of solar and battery combination. DSP provides up to 2% of generation share in 2050.

Hydrogen is not featured in the transition to RE due to low efficiency and the assumed availability of solar and wind. The conversion of electricity to hydrogen through electrolysis and reconversion of hydrogen to electricity was estimated using a regression model based on data published by GE for gas turbines covering a wide range of capacity, from 10 MW to 560 MW. The analysis shows that 4.39 MWh of input electricity is required to produce 1 MWh of hydrogen which represents a round-trip efficiency of 23%.[9] We have also considered the capital costs involved in building electrolysers, the cost of building hydrogen generators and energy costs in determining whether hydrogen is a reasonable least cost new entrant. Based on the assumption of widely available wind and solar, hydrogen is not efficient unless there are limitations on wind and solar limits. This does not preclude the utilisation of hydrogen in specific instances where, for certain local conditions, it may prove to be more cost effective than other options or if it is desired to gain experience on research and production of hydrogen to keep it alive as an option for future.

Figure 78 compares the RE generation share in each of the scenarios for snapshot years. In 2030, the share of RE generation in the 100RE scenario is much higher compared to the BAU from 47% to 69%. The 80RE scenario shows a slightly lower increase to 55% with some thermal capacity still allowed in the system. In 2040, the RE generation share grows for all scenarios resulting in 58%, 75% and 96% RE generation share for BAU, 80RE and 100RE scenarios respectively. RE generation for 100RE reaches 100% with coal and gas contributing zero generation. Both the 80RE and 100RE RE generation share is higher than the BAU RE generation share of 58%.

[9] Refer to the analysis in Appendix A Hydrogen for Power.

Figure 79 plots the total capacity and storage capacity in the system for the snapshot years across the three scenarios. Battery is not required in the BAU scenario until 2030 whereas battery is introduced earlier into the system starting 2025 in both RE scenarios. The BAU has 2 GW of one hour storage from 2030 and increases to 13GW by 2050. The amount of storage installed in the BAU is much lower than the RE scenarios as there is remaining baseload. By 2040 there is 77 GW and 88 GW of battery capacity for 80RE and 100RE respectively. By 2050, this increases to 135 GW and 198 GW. The energy storage capacity of batteries for both RE scenarios is between five to six hour duration, which allows the system to meet demands in peak demand periods.

Figure 76 Comparison of System Installed Capacity

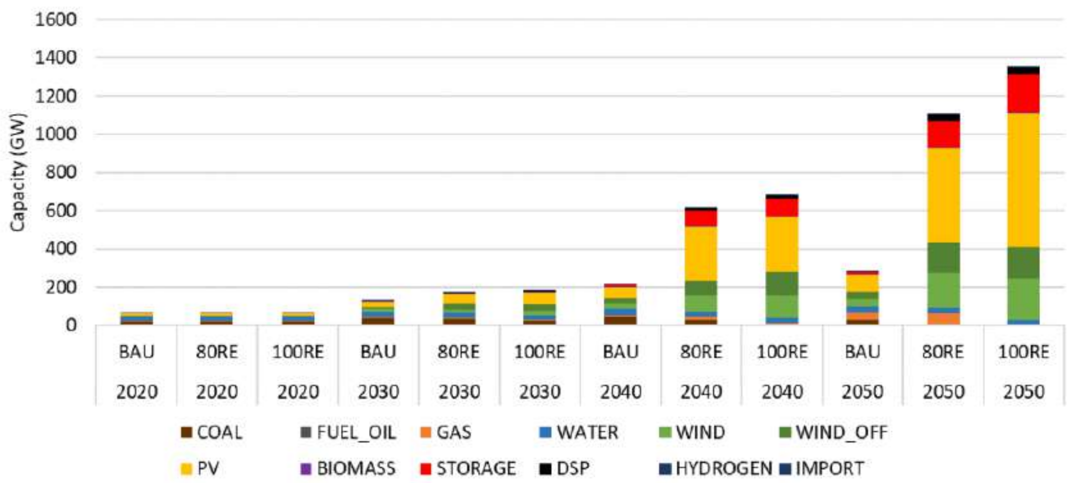


Figure 77 Comparison of Generation Mix

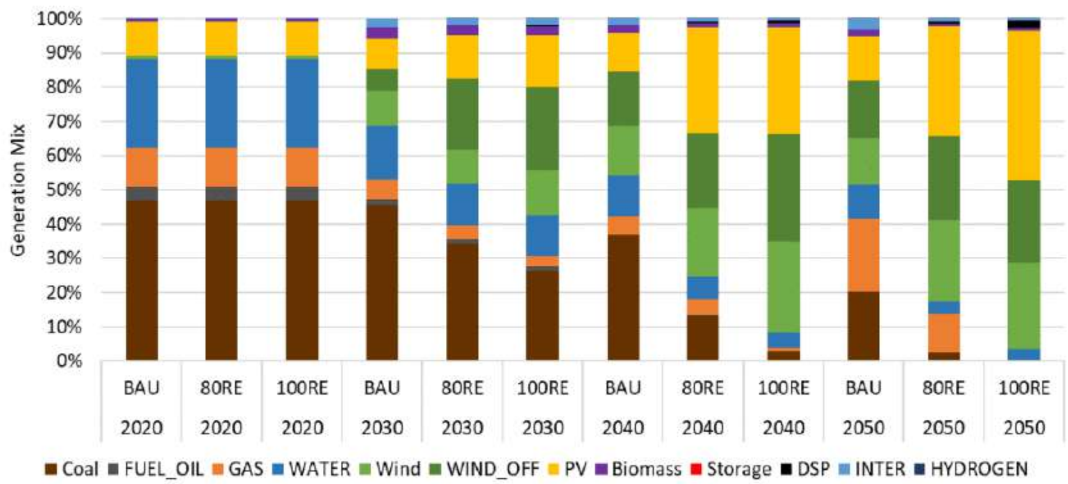


Figure 78 Comparison of RE Gen Share

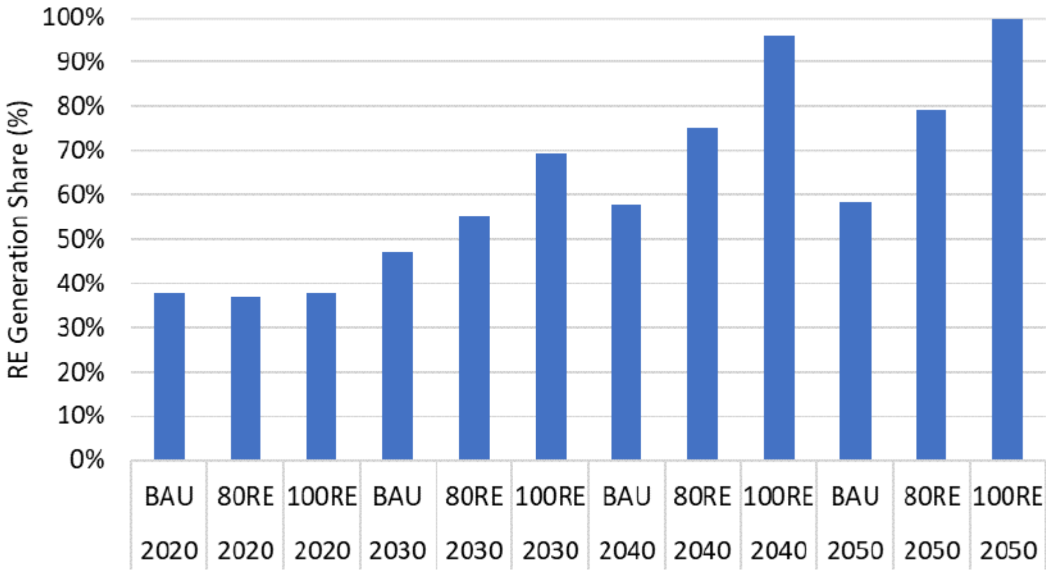
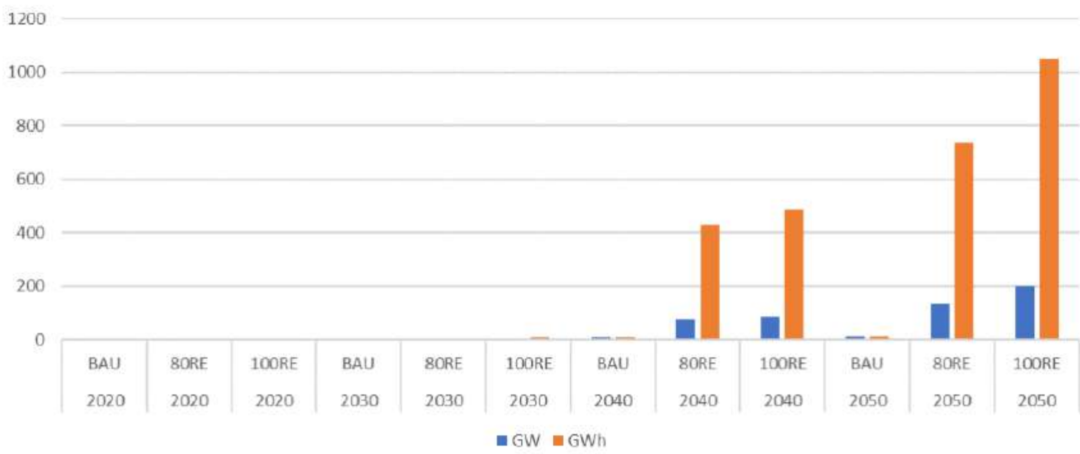


Figure 79 Storage Components

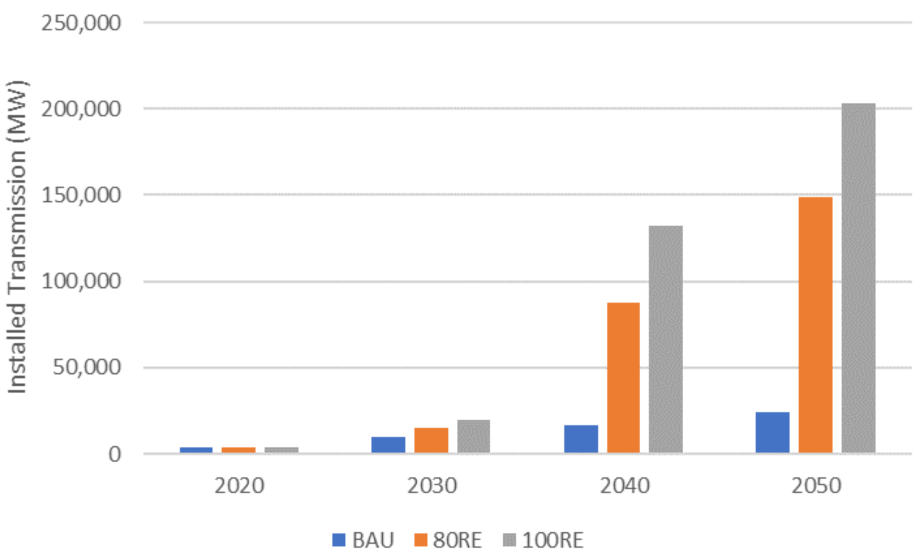


6.3.2 Transmission Network

Additional transmission is required to achieve high RE shares by transporting renewable energy from regions having higher renewable potential and resources. The model only considers inter-regional transmission and transmission within the region and distribution system is not included. Figure 80 plots the total installed transmission in the energy system for the three different scenarios. The transmission required in the RE scenarios is up to 8 times the installed transmission in the BAU. This is mainly concentrated in the North to Central inter-regional lines that transport energy from the

Central region that has higher generation capacity to the North whose generation capacity does not meet its demand completely.

Figure 80 Installed Transmission



6.3.3 Dispatch Charts

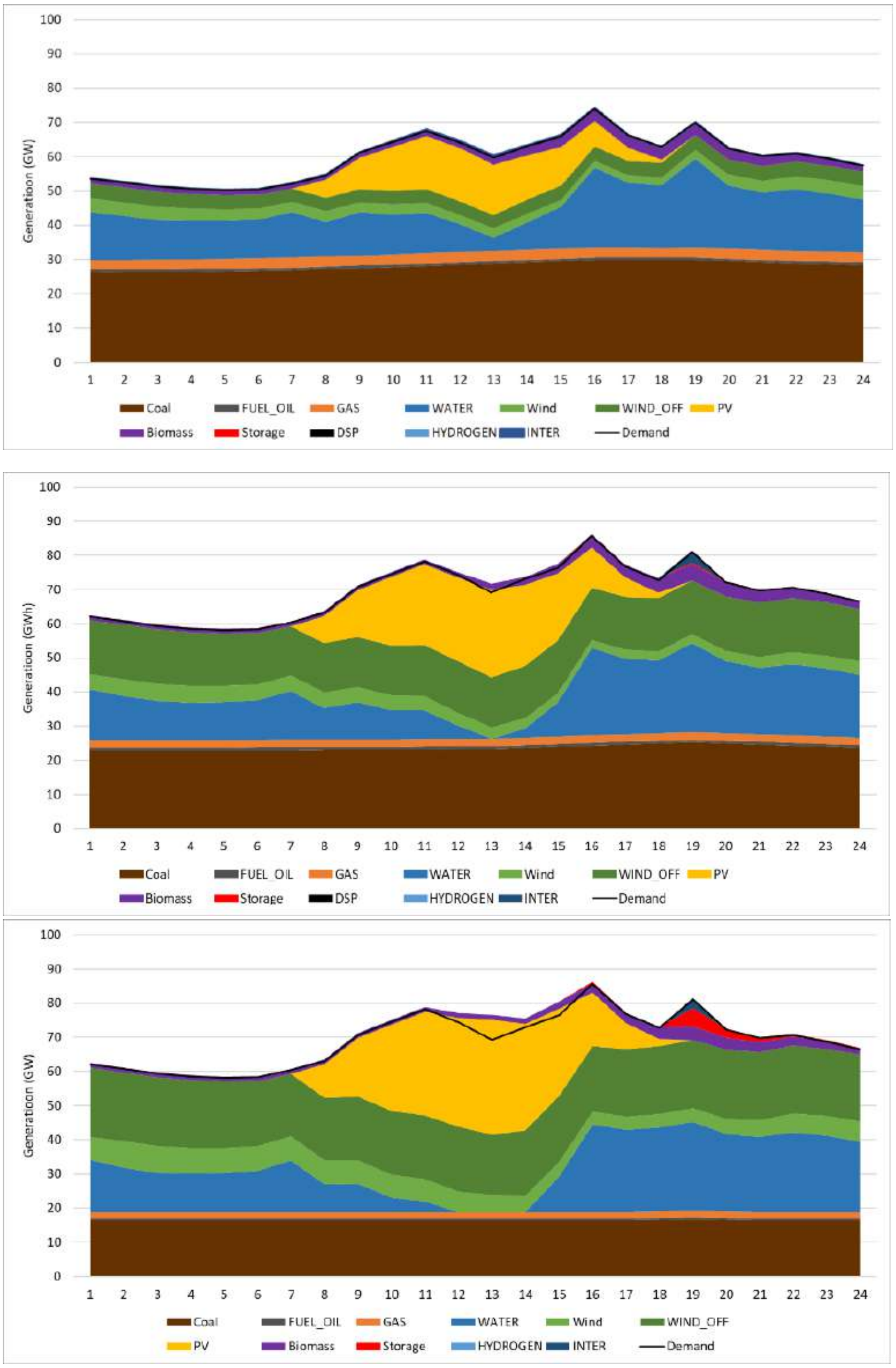
Figure 81 plots a sample dispatch chart for a single day in 2030 for the three scenarios starting with BAU, 80RE and 100RE (top to bottom). The key points are:

- There is 30 GW of thermal baseload (coal and gas) in the BAU compared with 25 GW and 20 GW in 80RE and 100RE respectively.
- Hydro acts as base load in the BAU whereas it only runs predominantly outside of solar periods. Hydro has the same dispatch profile in the 80RE and 100RE scenarios.
- The BAU has around 7 GW of total wind dispatch throughout the day whereas there is 20 GW and 25 GW for 80RE and 100RE respectively.
- The 100RE scenario includes battery storage, which charges during solar generation, which corresponds to the area where the demand line is below total generation in the middle of the day. This stored energy is then dispatched to meet demand between 6pm and 8pm.

Figure 82 plots a sample dispatch chart for a single day in 2050 for the three scenarios starting with BAU, 80RE and 100RE (top to bottom). Note that the y-axis is different for the BAU which has 250 GW compared to 500 GW in 80RE and 100RE. The key points are:

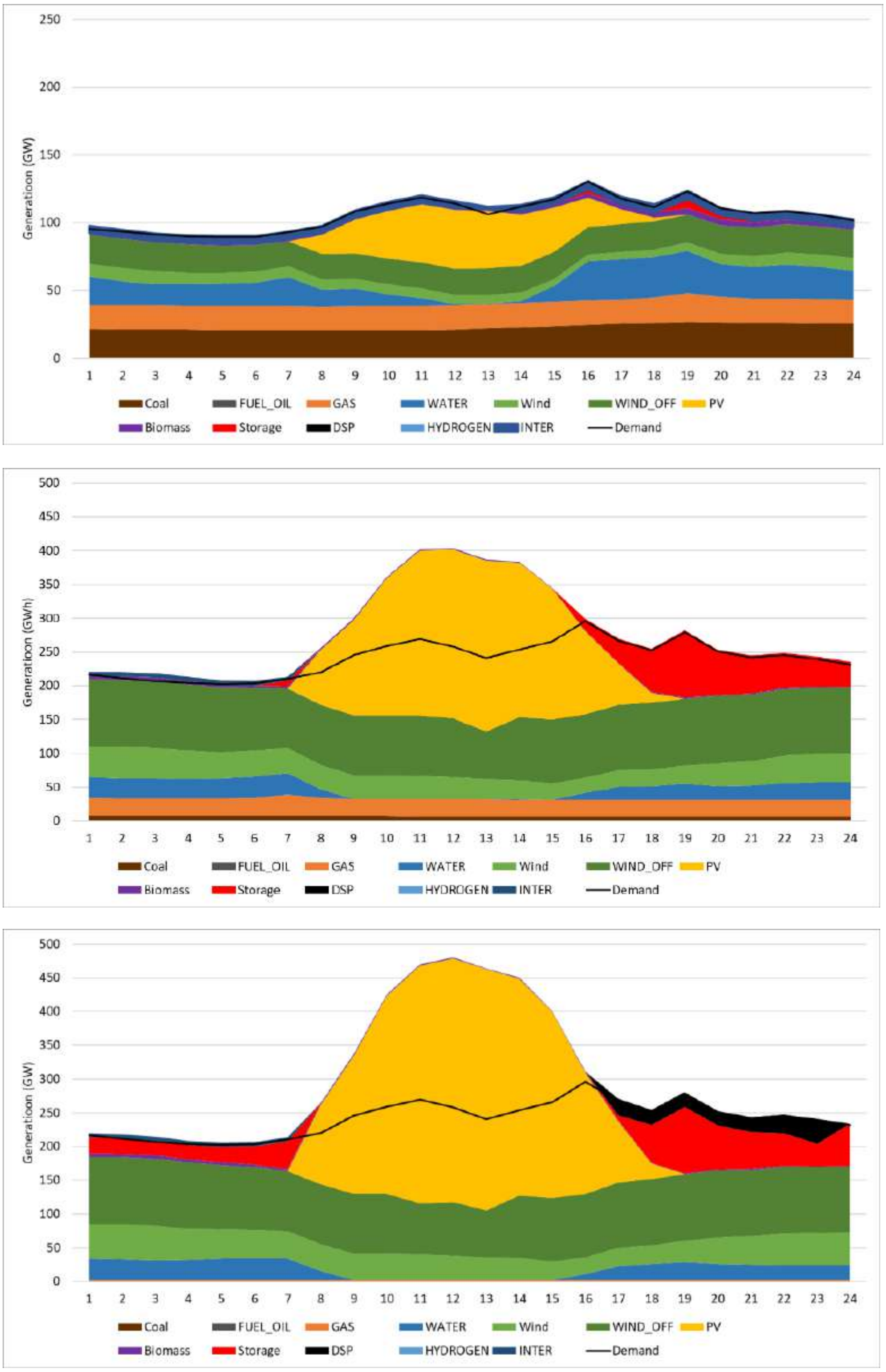
- Dispatch profile in BAU is similar to 2030 dispatch profile. The total thermal generation in 2050 is similar to 2030 but gas overtakes coal as the main fossil fuel in the mix in the 2050 snapshot.
- The 80RE scenario features 26 GW of baseload thermal generation made up of mostly gas whereas the 100RE scenario is fully reliant on renewable energy sources.
- PV peaks at 360 GW in the 100RE compared to 252 GW in the 80RE scenario. This additional generation supports the difference in the baseload generation between these scenarios. Battery storage outputs a total of 480 GWh in 80RE and 600 GWh in 100RE in the periods after solar generation.
- Storage is shown in the diagram to provide information on typical dispatch. As the diagram shows storage is utilized from late afternoon and into the night hours. The 100RE scenario has a higher level of dispatch from storage.
- DSP is dispatched during the afternoon peak and reduces energy demand over this period.
- Imports are fully utilized during periods where there is no solar generation.

Figure 81 Sample Dispatch for 2030 (BAU, 80RE and 100RE)



Note: From top to bottom: BAU, 80RE and 100RE

Figure 82 Sample Dispatch for 2050 (BAU, 80RE and 100RE)



Note: From top to bottom: BAU, 80RE and 100RE

6.3.4 Fuel use and emissions in the power sector

Figure 83 and Figure 84 plot the fuel consumption and emissions intensity in snapshot years. The fuel use is not standardised for the demand differential, but emissions intensity does account for the difference in demand in the RE scenarios.

The BAU has the highest fuel use across the three scenarios. By 2050, the fuel use is only limited to biomass in the 100RE scenario. Coal and Gas consumption are much lower in 2050 for the 80RE compared with the gas dependant BAU scenario.

Emissions intensity falls across the horizon in all scenarios with higher reductions in the RE scenarios. The 100RE has half the emissions intensity than the BAU in 2030 before falling to 0 by 2050 with no thermal capacity remaining in the system. The 80RE has a slower emissions intensity decrease, but still reaches below 0.1 ton/MWh by 2050 where the BAU remains at 0.19.

Figure 83 Comparison of Fuel Use

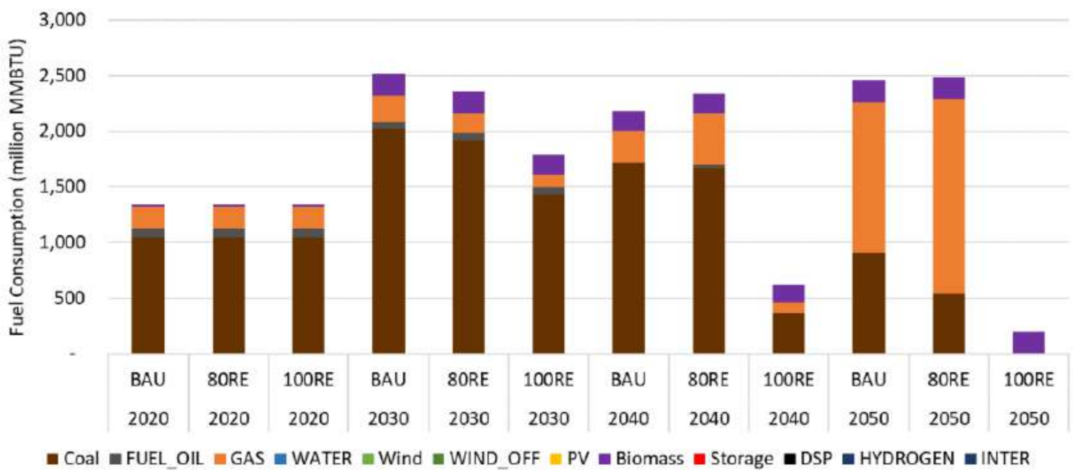
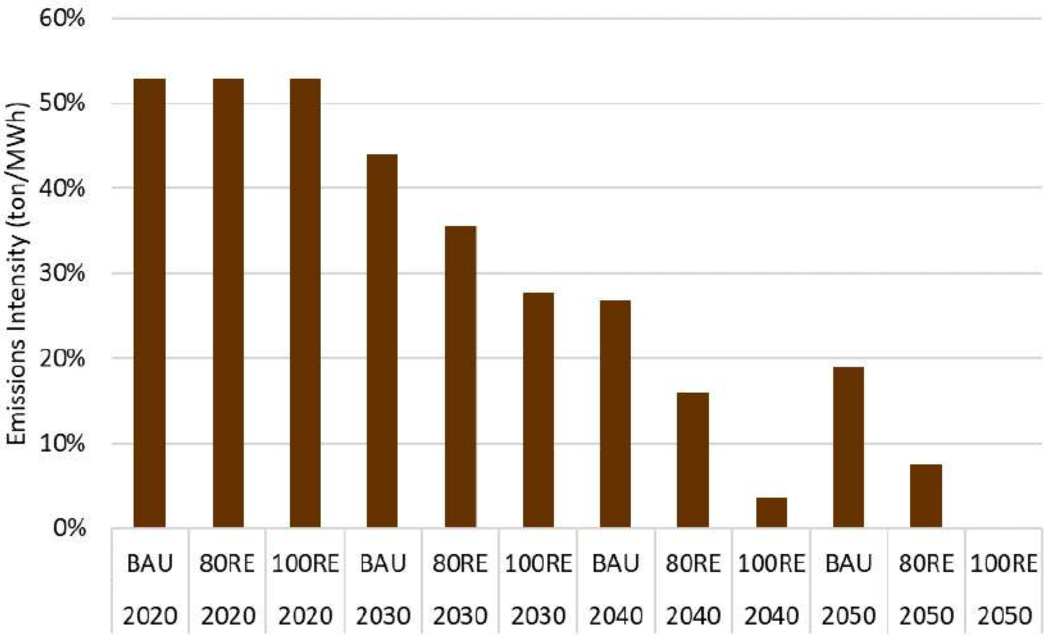


Figure 84 Comparison of Emissions Intensity



6.3.5 System Costs and Levelised Cost of Energy

Figure 85 compares total system cost including annualised investment, fuel costs, variable, and fixed costs. Compared to the BAU system costs are higher and demand is more than double the demand in the RE scenarios. The 100RE scenario has higher costs than the 80RE scenario to achieve the remaining emissions reduction and replacement of coal and gas. The cost-wise composition in the RE scenarios show much higher annualised capital expenditure, driven by higher investment requirements in the long term. However, the fuel costs decrease as these technology types do not require fuel. Total inter regional transmission costs over the entire horizon is 36% higher in the 100RE than the 80RE to accommodate the additional RE built and supplied to the North regions.

Figure 86 shows the levelized cost of energy in the three scenarios for snapshot years. The price trends downwards in the medium term followed by increase in LCOE in the long term. This increase is driven by higher fuel costs in the BAU whereas the driver in the RE scenarios is higher investments needed to achieve higher RE penetration.

Figure 85 Comparison of Total System Cost

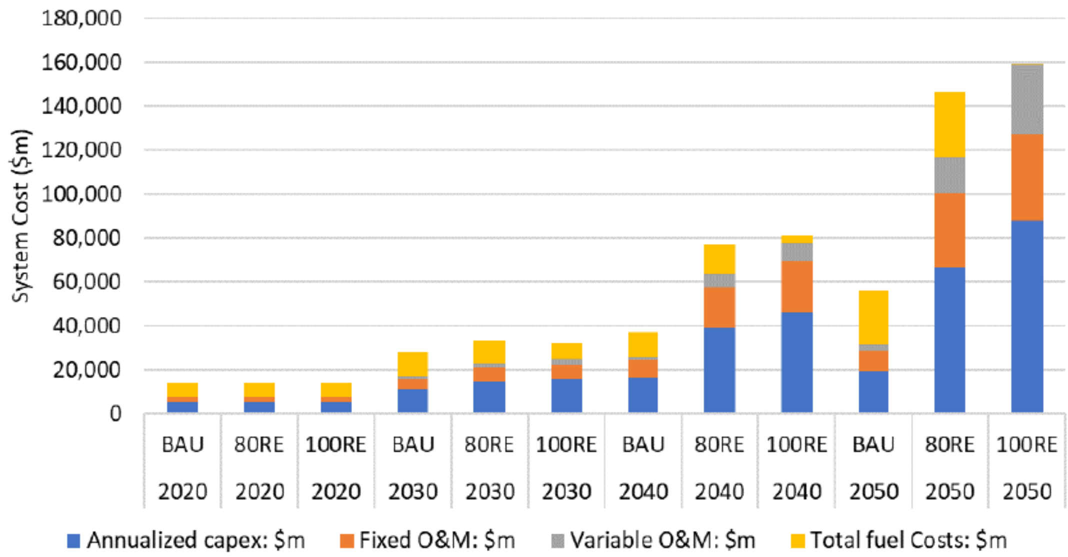
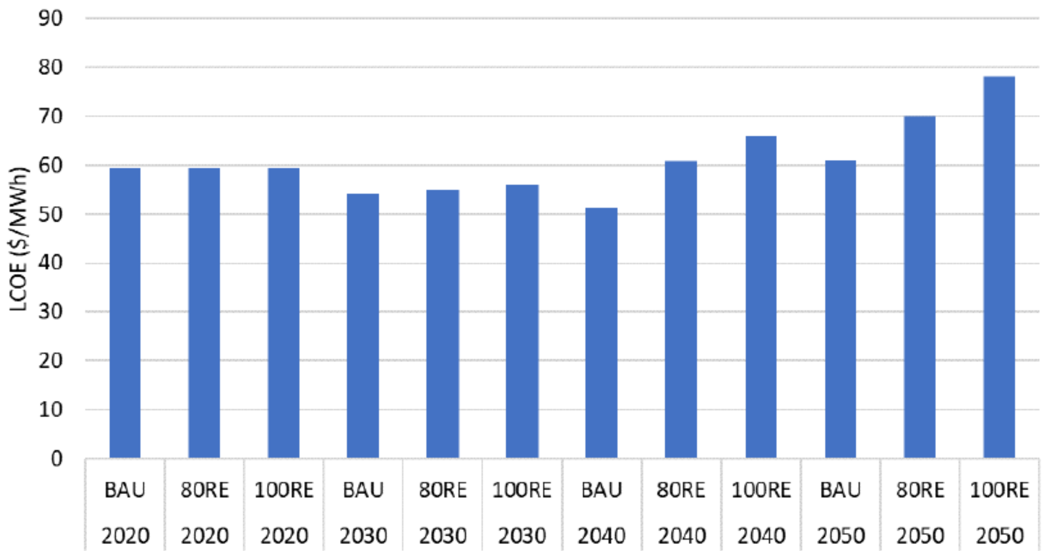


Figure 86 Comparison of LCOE



6.4 Investment and technology costs

Total investment requirement across the economy for each of the scenarios is plotted in Figure 87 and presented by sector in Figure 88 - the cumulative investment across each of the sectors. Technology/investments relating to buying new equipment, and converting existing processes on-site are included within the sectors, but costs relating to building power plants and transmission are specifically captured in the power sector bar. The investment costs are highest for the power and transport sectors due to the bottoms-up nature of the modelling of these sectors relative to others (see methodology section). The transport sector has the highest cost across all scenarios due to the cost of vehicles and high scrapping factor relating to the life of transport assets. As the economy gets electrified, the transport sector shifts from gasoline passenger cars to EVs which is assumed to rapidly fall below the cost of gasoline cars in future years. A move towards 100RE has a lower investment across the non-power sectors and higher investment in power sector but overall shows a net decrease. The 80RE has the least investment required. The charts also show significant power sector investment to keep up with increasing demands from electrification in the 80RE and 100RE.

Figure 87 Cumulative investment cost, economy-wide

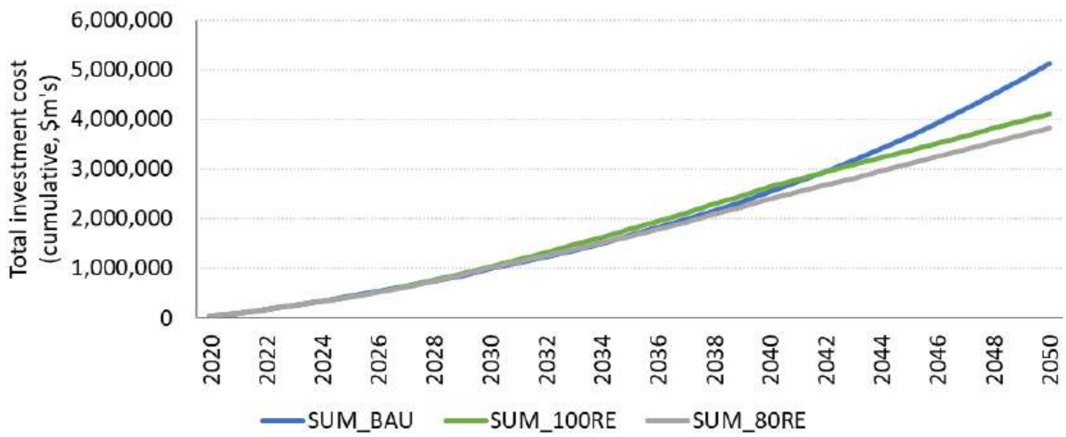
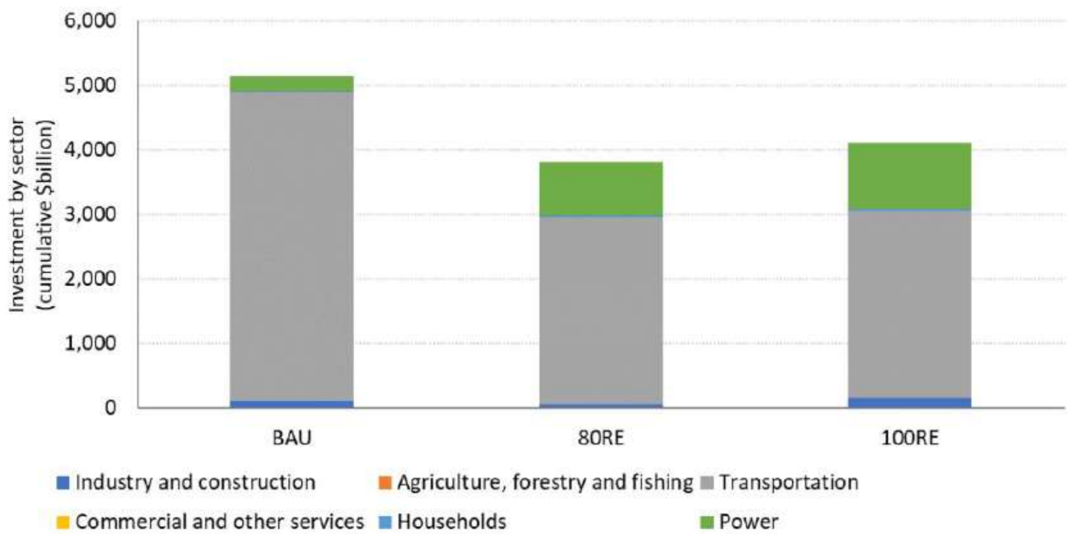


Figure 88 Cumulative investment cost by sector



Annual costs for snapshot years by component for the power and non-power sectors are plotted in Figure 89 and Figure 90 on a percentage basis. Over time, technology/investment costs increase more than the fuel cost components. By 2050, technology/investment costs comprise more than 75% of the total annual cost. Although the 100RE case electrifies more than 75% of the total energy consumption, there is still large amount of technology costs associated with converting traditional fossil-fuel based energy processes to electricity.

The average energy cost (in $/MWh terms) across the economy and power sector (which includes annualised investment requirements and fuel cost) is presented in Figure 93 and Figure 94. The costs show the 80RE is the cheapest driven by cheaper fuel costs (RE energy) and reducing RE technology costs over time relative to the BAU followed by the 100RE then BAU. The power sector shows a higher cost in the 100RE because achieving 100% RE in the power sector is considerably more expensive (per MWh basis).

Figure 89 Snapshot year costs by component and scenario

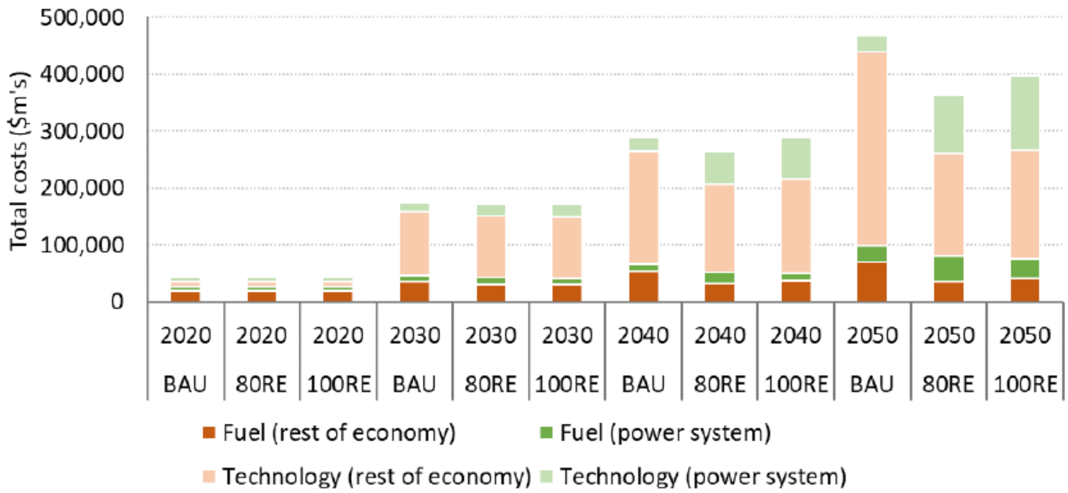


Figure 90 Snapshot year costs by component and scenario (share)

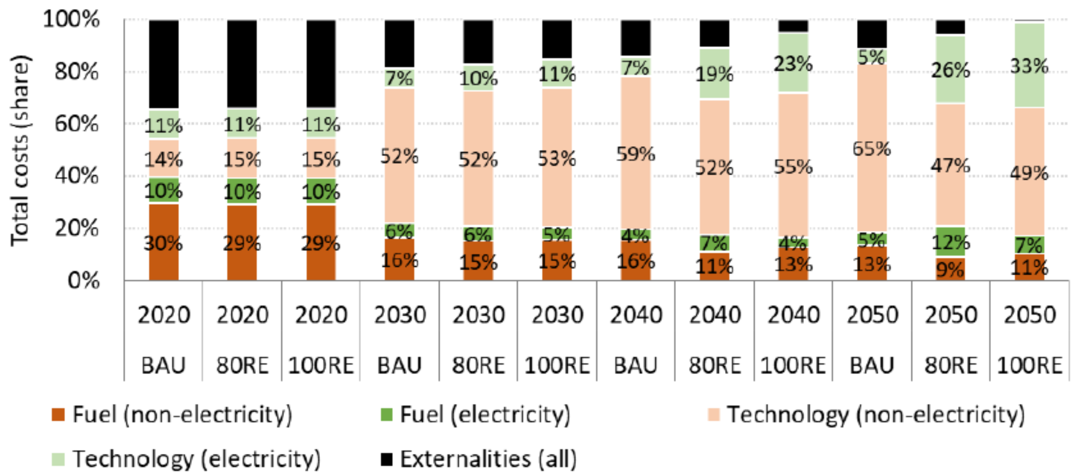


Figure 91 Snapshot year costs by component and scenario (Transport)

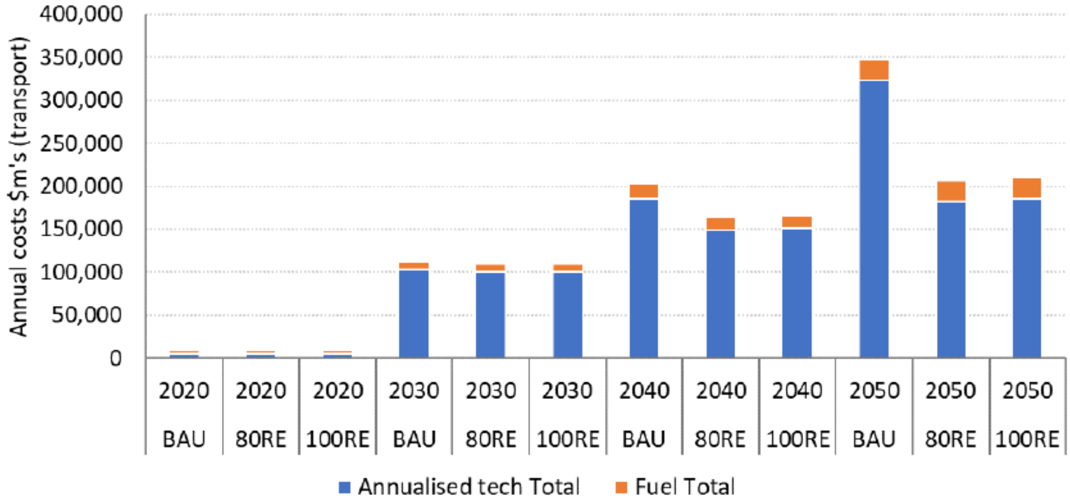


Figure 92 Snapshot year costs by component and scenario (Industry)

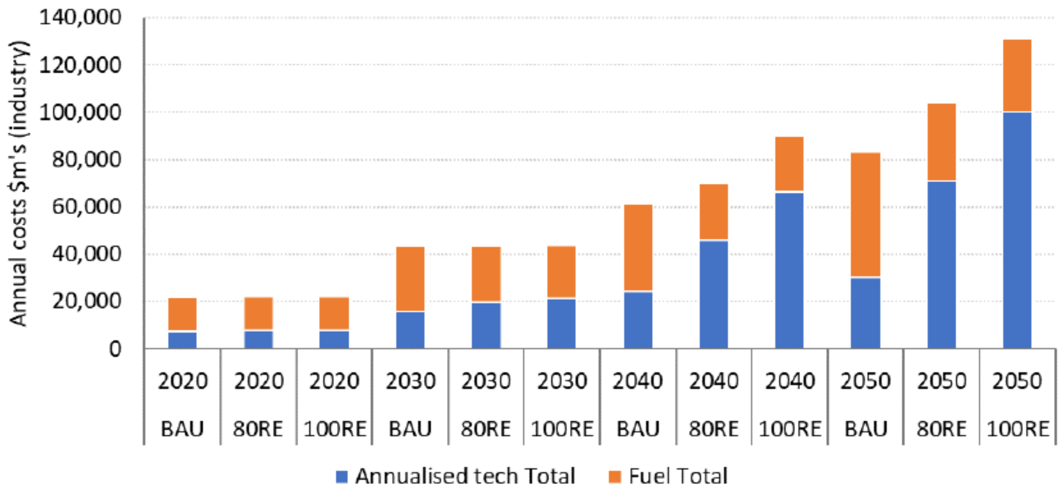


Figure 93 Economy-wide average energy cost

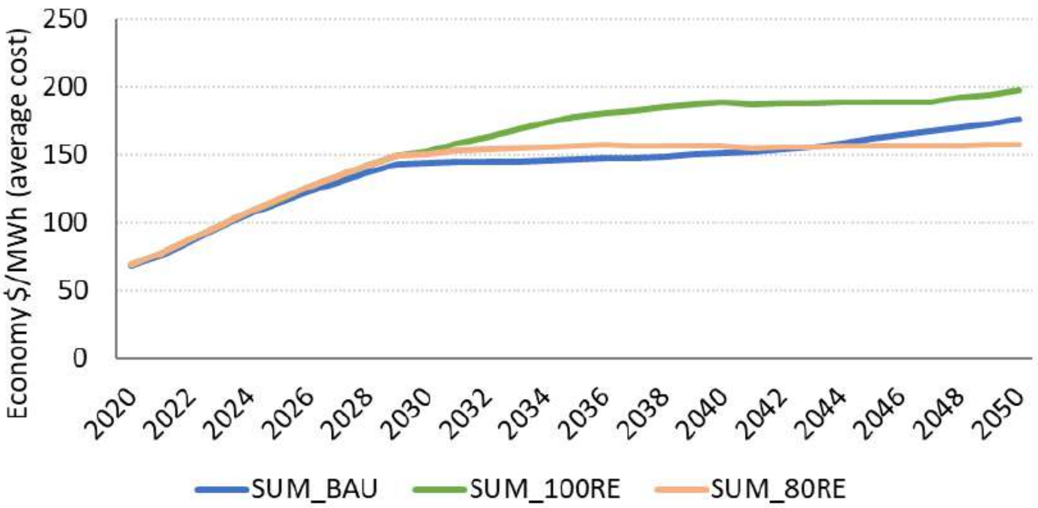
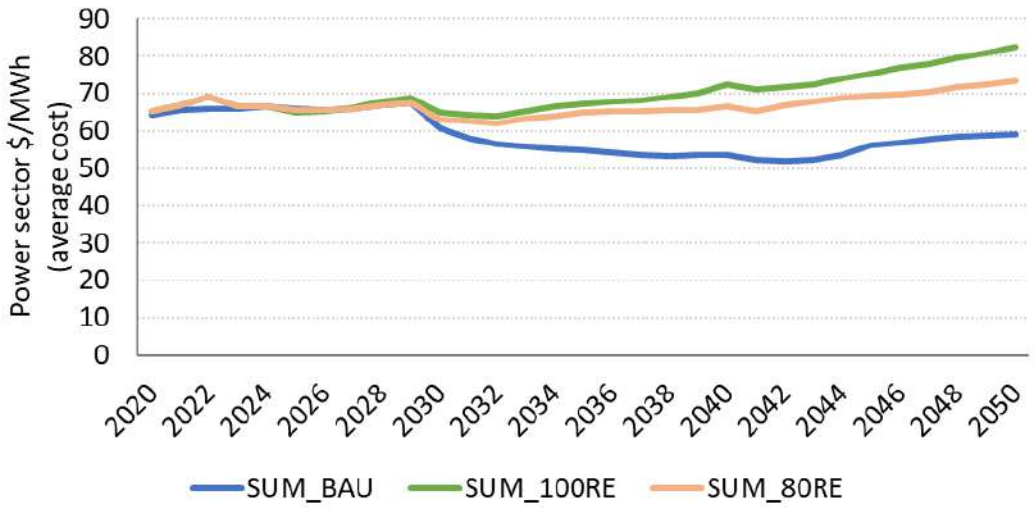


Figure 94 Power sector average energy cost



6.5 Primary energy supply

The primary energy supply across the scenarios is generally consistent with the TFEC trends (Figure 95 and Figure 96). The 80RE case which has a 20% fossil fuel consumption relies heavily on gas (15%) in 2050 and is likely to be imported LNG given the depleting domestic gas reserves.

The energy balance tables for 80RE and 100RE in 2050 are presented in Figure 97 and Figure 98. The 100RE scenario eliminates fossil fuels by 2050, whereas the 80RE scenario allows for fossil fuel reliance across the industrial, transport, and (to a much smaller extent) the power sector. Relative to the BAU, the 80RE sees the highest % reduction of fossil fuel use across coal and crude oil products (65%-80%), whereas natural gas is only reduced by less than 25%.

Figure 95 Primary energy supply by scenario

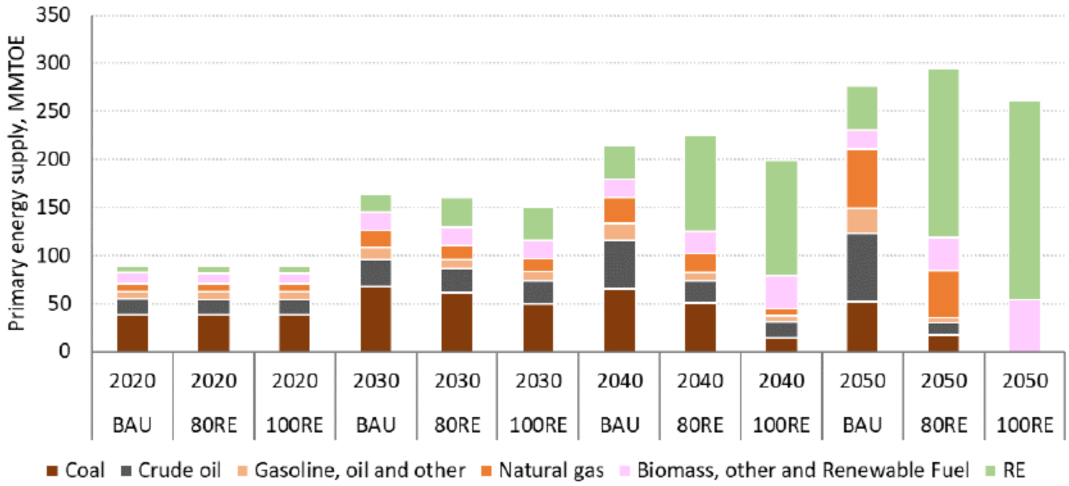


Figure 96 Primary energy supply share by scenario

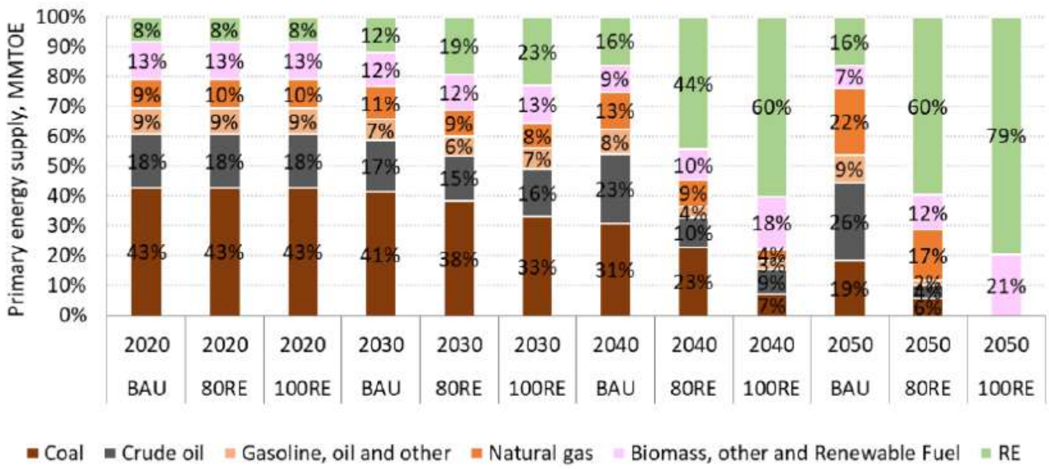


Figure 97 Energy balance in 2050, MMTOE (80RE)

Modelled	Total energy sources	Coal	Crude oil	Gasoline, oil and other oil products	Natural gas	Biomass, other and Renewable Fuel	Electricity
Total primary energy sup	294.2	17.1	13.2	4.7	49.3	34.5	175.4
Oil refinery facilities	-0.4		-12.4	12.0			
Gas processing facilities	0.0		0.0	0.3	-0.3		
Power plants	-55.1	-13.7	0.0	0.0	-44.1	-4.7	7.4
Own use	-1.5	0.0	-0.8	0.0			-0.8
Distribution losses	-8.3	-0.1	0.0	0.0			-8.1
Total final consumption	228.9	3.4	0.0	17.0	4.9	29.8	173.9
Industry and constructio	116.9	3.4	0.0	2.9	3.6	1.6	105.4
Agriculture, forestry and	4.4	0.0	0.0	0.0	0.0	1.3	3.1
Transportation	53.7	0.0	0.0	14.1	1.3	14.3	24.0
Commercial and other se	19.3	0.0	0.0	0.0	0.0	4.2	15.2
Households	34.6	0.0	0.0	0.0	0.0	8.3	26.3
Non-energy consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0

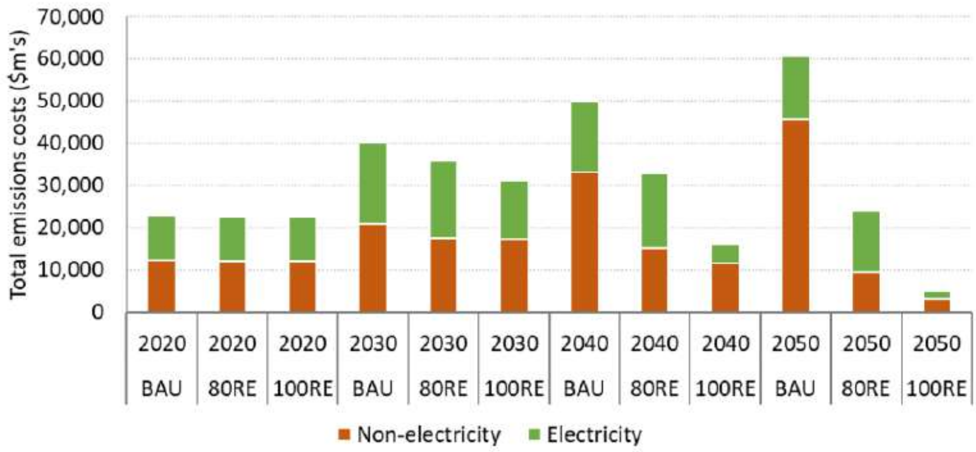
Figure 98 Energy balance in 2050, MMTOE (100RE)

Modelled	Total energy sources	Coal	Crude oil	Gasoline, oil and other oil products	Natural gas	Biomass, other and Renewable Fuel	Electricity
Total primary energy sup	260.6	0.0	0.0	0.0	0.0	53.8	206.8
Oil refinery facilities	0.0		0.0	0.0			
Gas processing facilities	0.0		0.0	0.0	0.0		
Power plants	-28.9	0.0	0.0	0.0	0.0	-4.9	-24.0
Own use	0.0	0.0	0.0	0.0			0.0
Distribution losses	-8.1	0.0	0.0	0.0			-8.1
Total final consumption	223.5	0.0	0.0	0.0	0.0	48.8	174.7
Industry and constructio	117.4	0.0	0.0	0.0	0.0	11.5	105.9
Agriculture, forestry and	4.4	0.0	0.0	0.0	0.0	1.3	3.1
Transportation	47.6	0.0	0.0	0.0	0.0	23.5	24.1
Commercial and other se	19.4	0.0	0.0	0.0	0.0	4.2	15.2
Households	34.7	0.0	0.0	0.0	0.0	8.3	26.4
Non-energy consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0

6.6 Externalities

Externality costs are plotted in Figure 99 and show an increasing cost associated with the BAU because of the growing fossil-fuel consumption, whereas the 80RE and 100RE both increase to 2030 but decline from that point to 2050, with increasing conversion to RE. The 100RE case has minimal cost of externalities in the 2050 as the economic costs of carbon emissions and air pollution fall. The externalities calculated here comprise a modest share of the economy-wide total costs, estimated to fall between $360 to $470 billion across the three scenarios in 2050 as shown in Figure 89.

Figure 99 Total emissions cost by broad sector and scenario



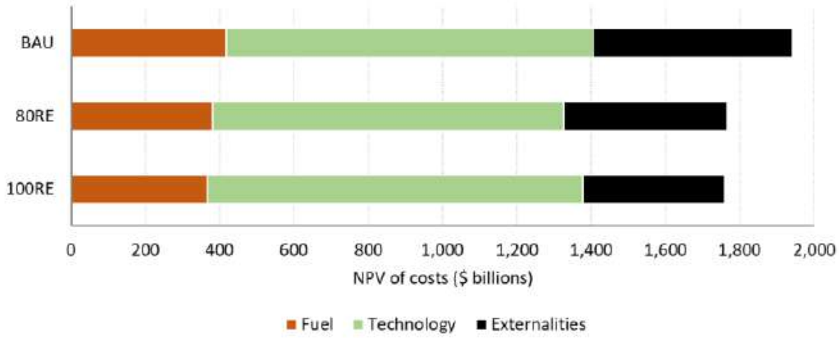
6.7 Key findings

The key findings are presented below organised by aspect.

Aspect	Key findings
Demand	The industrial and transport sector are the most challenging sectors to convert to renewable fuels or become entirely electrified due to the underlying costs, technical challenges in some areas of transport and process related complexities in the industrial sector. Electrifying loads, especially in the case of road passenger transport, is a key driver of reducing energy consumption levels. The sectors that are easiest to electrify in addition to road transport are the household and commercial sectors.
Costs	The BAU is the costliest scenario across all scenarios before considering the cost of externalities. It would be as missed opportunity should Vietnam's economy continue to rely on fossil fuels. Accounting for externality costs further enhance the merits of an energy transition towards 80/100 percent RE. Scenario 80RE is the lowest cost as it avoids the costliest conversion to renewables, refer to Figure 100.
Power system	Enabling RE integration into the system is critical to increasing the share of RE generation resources in the system. Higher shares of VRE generation needs to be supported by electricity storage. This requires improved power system operation and network development. RE Enabling policies, governance structures and capability building is needed.

Aspect	Key findings
Energy efficiency	The amount of economy-wide energy consumption reduces with higher levels of electrification. This is primarily due to fuel efficiency of EV compared to ICE transport and to a lesser extent by energy efficiency improvements in the industrial and other sectors.
Environment, Health and energy security	The transition to RE improves outcomes across all these areas.

Figure 100 Scenario cost comparison



7 Policy Recommendations

The modelling and analysis of the results suggest that 100% RE is achievable by 2050. Vietnam has in place several policies dealing with the energy sector that have been summarised in Section 2.1. Clear and well-defined policies are needed with targets that drive the achievement of 100% RE, the target vision of WWF. The policy recommendations follow the policy framework illustrated in Figure 101 which sets out key areas of policy focused on encouraging the uptake of renewable energy.

Figure 101 Renewable Energy Policy Framework for the Energy Sector

7.1 Energy sector planning

Electrification of the sectors based on expanding RE generation in the power system is key to achieving the 100% RE vision. This can be clearly seen from the large increase in electrification projected in the 80RE and 100RE scenarios. Across the economy, in the high RE scenarios, electricity accounts for more than 50% of the energy consumed by 2040. By 2050 this rises to three quarters of energy consumed in the 100RE scenario and nearly two thirds of that in the 80RE scenario (refer Figure 60).

7.1.1 Power system including networks

- As the share of RE grows in the power system, to replace the retiring fossil-fuelled generators, it is imperative to integrate RE development into energy sector planning. This ensures that appropriate measures are in place to strengthen and maintain system security and reliability. An important area is power system operation.

Upgrading system and grid codes is required to cater for the variability of VRE and enhance the ability to integrate VRE into an orderly dispatch system.

- Integrate RE development into network planning to ensure the ability of RE to move from resource rich to high demand areas. It also ensures that these resources are not unduly constrained from dispatching their generation. This contributes to lower power cost and lower investment risk.

7.1.2 Flexibility, Storage, DSP and Energy Efficiency

- Requiring new systems to be flexible within the limits of their physical capability and requiring fossil-fuelled generators to be capable of accommodating flexible operation (sometimes referred to as two-shifting). As RE share increases in the system, experience has shown that plants that have traditionally operated as base load may no longer be able to operate in that mode. Many such plants have gone through a phase where they operated at low loading for extended periods or developed the capability of turning off during periods of the day when they are not needed and back on when they are. Vietnam has already seen a transitioning in the role of hydro from baseload to intermediate load.

- The modelling shows a growing role for storage in supporting higher VRE penetration. Looking at Figure 82 storage (red area) grows materially from the BAU to the 80RE and 100RE scenarios. Storage in the form of batteries and pumped hydro can play a role in the energy market as well as in the ancillary services market. Developing a market for ancillary services will help to encourage the right type of technology investment that suits the holistic needs of the system. International experience indicates that relying on energy markets alone undervalues the role played by storage and does not provide sufficient incentive for developing these resources.

- The bottom panel in Figure 82 shows the role of demand-side response (represented by the black area in the figure "DSP"). The report notes in Section 6.3.3 the role of demand-side response, in the 100RE scenario in particular, in reducing demand. Encouraging and integrating demand-side response into planning standards or conditions on developments can contribute to the reduction in maximum demand as well as achieving energy saving.

- Given the increased electrification in the high RE scenarios, energy efficiency (EE) gains importance as a measure that needs to be supported by policies. Vietnam has implemented VNEEP programs starting in 2006 and continue with this effort, currently in VNEEP3. This is a commendable step which needs to be strengthened by stipulating higher targets, enforcing clear reporting and strengthening the level of enforcement to ensure targets are achieved. The high RE scenarios incorporate 7%

efficiency gains in the industrial sector on top of the targets in the BAU. Energy savings in the transport sector is primarily due to the improved efficiency of electric transport modes compared to modes in the BAU. The energy efficiency policy should include:

- Financial incentive for achieving energy savings,
- Development of clear methodologies for calculating these savings,
- Development of capability to audit energy efficiency claims and providing the regulator with powers to penalise where required,
- Development of detailed reporting across all sectors,
- Continuation of the regulation of all appliances and equipment sold and installed,
- Driving the improvement of engineering design and operation of all energy consuming devices and systems in the various sectors. This can be achieved by setting clear standards and requirements that need to be met.

7.1.3 Planning more broadly than the power system

- The integration of RE should be considered beyond electricity into the provision of other forms of energy, such as RE to generate heat. The modelling shows this as the share of energy addressed by non-electricity renewables is as large as 22% by 2050 in the 100 RE scenario (pink bar in Figure 60). This is somewhat less in the 80RE scenario which allows fossil energy to remain in the system. In the high RE scenarios, most of the renewable fuel is consumed in the transport sector (middle left panel in Figure 64).
- Integrating EE requirements into planning approval for all new facilities and all expansions or significant modifications of existing facilities. This should not be restricted to the industrial sector but extend to all sectors of the economy including building design, where there are already regulations for energy efficiency in buildings.

7.2 Investment planning

RE resource expansion can be supported by enhancing RE resource mapping to improve visibility of resource potential and contribute to lowering the barrier for investment.

While the industrial, transport and household sectors remain the largest energy consumers there is an impressive increase in the share of electricity consumed in the commercial and agriculture sectors as can be seen in Figure 64.

- Resource mapping will identify the most important sites and locations for RE exploitation. By integrating it into the overall planning requirements across networks, power system requirement, environmental, and health the holistic approach to planning can improve outcomes for the entire economy. The exploitation of offshore wind resources requires attention to issues relating to the various phases from surveying through to construction and operation. Appendix E summarises the areas that are unique or of more significance to offshore wind projects.

- Auctions is a mechanism that has been used successfully in many jurisdictions to achieve competitive rates for RE. Adoption of an appropriately designed auction mechanism can be an effective instrument to encourage the further development of RE and BESS.[10] Key auction design considerations are outlined in Appendix F.

7.3 System operations for electricity

- Transformation of power sectors requires enhancements to the operation and integration of VRE. It is important to upgrade the grid code to integrate VRE into an orderly and robust power dispatch system. Review how often, even intraday, VRE forecasts/bids need to be updated. Dissemination of information to all participants by the system operator allows them to be aware of risks (for example of a potential shortage of hydro storage) and be better prepared to manage it. Dissemination of information requires enhancing system modelling capability.
- Dispatch of storage increases with higher electrification and higher penetration of VRE. Figure 82 represents battery dispatch by a red area which grows as you progress from BAU to 80RE to 100RE. Integration of BESS and VRE sources into dispatch and operations and the underlying IT technologies to achieve that, are critical facets of system operation. This is brought into relief in the modelling as the energy dispatched from storage increases with higher electrification which requires a higher RE capacity).
- Incorporate new advances in VRE technology particularly in the developing area of inverter-based resources. International experience indicates it is more efficient to incorporate these features as early as possible.

7.4 Institutional arrangements

- Governance arrangements should be strengthened including in the areas of monitoring and reporting. Some of the recommendations that apply to EE can be applied to all governance arrangements:

[10] MOIT issued Circular 15/2022/TT-BCT which provided regulations to determine tariff ranges for so called transitional solar and wind plants. In parallel MOIT proposed to EVN how to determine the tariff. One of the proposals was to use auctions as a price discovery mechanism. This is seen by some commentators as a positive step for auctions. Refer to Allens article available on https://www.allens.com.au/insights-news/insights/2022/10/circular-15-issuance-a-baby-step-towards-resolving-orphaned-transitional-wind-and-solar-projects-in-vietnam/

  - Development of detailed reporting across all sectors,
  - Development of capability to analyse the information and audit performance, and
  - Providing the regulator with powers to enforce regulations.
- Develop carbon accounting standards, methods and reporting systems.
- Develop workforce development policies to ensure that the required skills are available to support the planned system. This requires the identification of capacity building needed to support energy sector transformation.

7.5 Energy pricing and contracts

Energy pricing should be set at an efficient level to drive appropriate investment and encourage behaviour that benefits the needs of the system for energy and/or ancillary services (such as primary and secondary frequency response to maintain system security by keeping system frequency on target). This can be applied along several fronts:

- Given that flexibility will grow in importance, rewarding flexibility will incentivise the right behaviour and encourage new and existing generation plants to develop that capability.
- A feature of VRE rich systems is that they have a significant share of distributed energy resources. In addition to developing the right pricing in wholesale energy markets and ancillary services markets, retail tariff structures should be structured to encourage distributed energy resources. Transport is probably a newer arena for such applications but one that will grow in importance as the number of EVs grows. The importance of including EVs is underscored by the growing electricity consumption in the transport sector in the high RE scenarios (represented by the green bar in the middle left panel in Figure 64).
- Future networks are increasingly bidirectional, where power flows from the network to the consumer and can flow from the consumer connection point back into the network. Batteries and BTM generation provide this capability. It is important to develop policies and regulations that enhance the utilisation of this resource. As IT ability grows the system can become more sophisticated and allow innovation by, for example, introducing aggregators who can aggregate and manage smaller loads that otherwise would be excluded from participation.
- The collection of timely and accurate data and developing the capability to incorporate it into system modelling will enable valuation of system energy properly. This should apply to both energy and system services.

- Rewarding RE adoption can be accomplished by different means. A system that has been used successfully in many jurisdictions is introducing quotas accompanied by tradeable certificates commonly referred to as Green Certificates. Eligible generators are given rights to issue and certificates that can be traded and purchased by other parties who are obligated to meet a certain quota of RE generation in their portfolio. Another way of encouraging RE is to allow the development of a green tariff charged to consumers wish to support RE development by voluntarily paying the green tariff which includes a component of the price that supports RE.
- The Vietnamese government issued, in January 2022, the Decree No. 06/2022/ND-CP Providing Regulations on Reduction of Greenhouse Gas Emissions and Protection of the Ozone Layer. The scheme will establish regulations and operate a pilot exchange mechanism (2025) before moving to full operation in 2028. One ton of CO2 is equivalent to one carbon credit. Credits can be bankable and tradeable. A (10%) limit is imposed on the proportion of obligations that can be offset by a liable entity [18].

7.6 Transport sector

The transport sector is the second large\\st energy consumer and is responsible for a large portion of emissions in Vietnam. Electrification of this sector involves the shift to EV in passenger transport and freight. Modalities that cannot be electrified can shift from fossil fuel to renewable fuel. The modelling performed shows almost all land passenger traffic can be electrified while aviation and some areas of freight, mainly maritime, can be shifted to renewable fuels. Figure 71 shows that about half of the transport sector is projected to remain on renewable fuels by 2050 in the 100E scenario. In the 80 RE scenario this is reduced to 27% due to fossil fuels remaining in the system and (to a lesser extent) RE contributing a lower proportion of electricity. In order to reach high RE shares in the transport sector high EV shares (shown in Figure 71) need to be in place by the early 2040's. Policies to effect the shift away from fossil fuels in transport include:

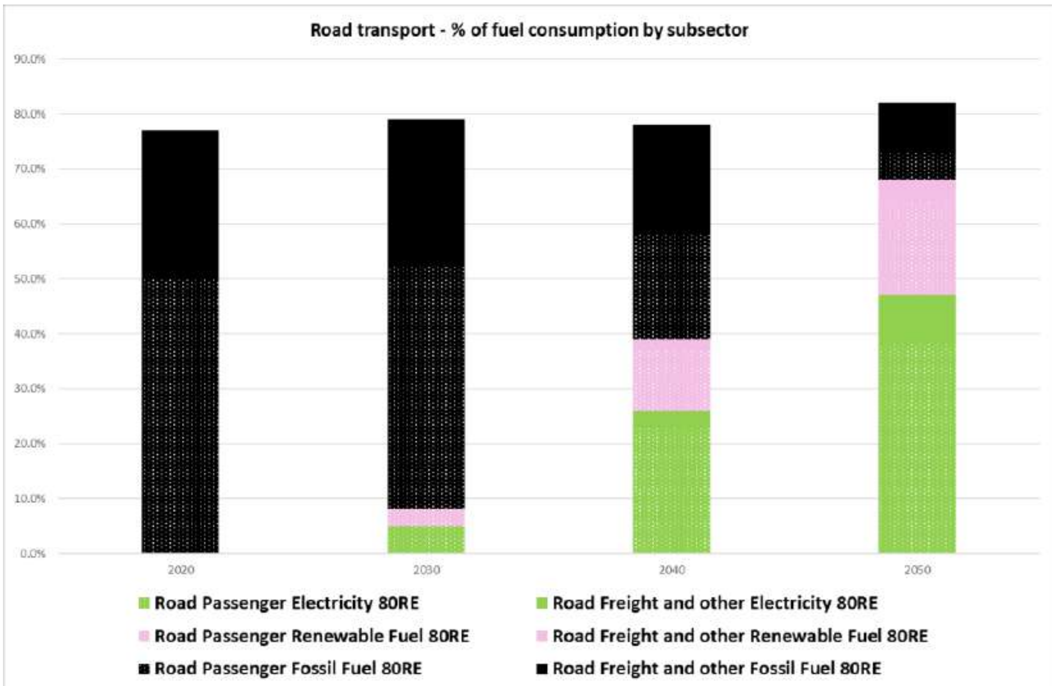
- Providing financial support to early adopters of EV. Particularly in the early period when the market share of EV is small, the cost of purchase and ownership is likely higher and an incentive can reduce the barrier to adoption of EV.
- Establishing sufficient public charging stations (for example at parking stations and shopping centres) and incentivising private charging stations (at residences and offices).
- Developing regulation and physical capabilities that allows EV owners from participating in both charging from and discharging into the network to benefit from opportunities of participating in the bidirectional network. This recommendation links back to the opportunity of incentivising flexible resources to participate in the

power system. This requires ability to identify and allocate the benefit to the owner of the vehicle rather than the owner of the connection point to which the EV is connected at a point in time, for example the state of California has regulation that facilitates this.

- Vietnam has recently approved the action plan for green energy in the transport sector, summarised in Section 2.1.10, which stipulates domestic manufacturing and import of ICE vehicles will cease by 2040 and all vehicles shall be using only electricity or green energy sources by 2050. Enforcement of the targets of this plan will make a significant contribution to the transition to RE.

To give a flavour of the pace of transformation required in the transport sector we use the example of road transport, by far the largest user of fuel in the transport sector (approximately 80% of the fuel usage in the transport sector). Figure 102 shows the 80RE scenario in which there is a remaining portion of fossil fuels. The green bars represent electricity as the fuel carrier, pink bars represent renewable fuels and the black bars fossil fuels. Within each category (colour)The solid colour represents freight while the dotted bars represent passenger traffic. The chart shows that the rate of switching to electrification and renewable fuels starts slowly in 2030, rises to a combined total of 40% of all energy consumed in the transport sector (not just road). By 2050 the green and pink bars represent approximately 68% of the total energy used in the transport sector and about 14% of usage remains as fossil fuel.

Figure 102 Percentage of fuel in the Transport sector by subsector – 80RE scenario



7.7 Climate, Health, and environment

- The achievement of RE targets results in benefits along several fronts. It decarbonises the economy, reduces pollution, improves energy security and reduces dependence on imported fuel. The achievement of benefits in several areas supports the need to develop an overarching planning framework that integrates climate policies, decarbonisation strategies and achievement of NDC targets. The economic cost of emissions from GHG, SOx, NOx and particulate emissions in the BAU scenario, is shown in Figure 55 and the reduced cost in the high RE scenarios is shown in Figure 99 for snapshot years and on an NPV basis accumulated over the entire study horizon in Figure 62.

8 Conclusions

The vision to have the Vietnamese economy supplied by 100% RE sources can be achieved by relying on **electrification** and converting difficult to electrify consumption to **renewable fuels**. **Industry and transport** are the largest consumers and some areas within these sectors, such as **maritime and aviation**, are the most challenging to electrify and convert either because of cost or technical limitations, although it is foreseen the latter can be resolved in future through advances in technology. **Road passenger transport** can be almost totally electrified providing the shift is facilitated by good infrastructure development and supporting policies.

Given **electrification** is a cornerstone of achieving the goal of high RE share in the economy, the **power sector** plays an important role. The task in the power sector can be summarised as firstly, **converting generation resources to be from renewable sources** supported by storage and secondly, **developing the network** to allow RE to be transmitted from resource rich areas to high demand areas. Success in integrating RE supported by storage into a reliable and secure power system will require technical, market and regulatory improvements. Improvements in system operation and grid codes are broad headings for technical areas that will need enablement through building technical operating capability and IT systems capability. With increased RE share flexibility will gain even more importance. Flexibility can be encouraged through creating instruments and mechanisms to reward behaviour that meets the technical needs of the power system. Creating markets for providing ancillary services is an important plank of encouraging investment in appropriate technologies. Energy and ancillary services markets should be inclusive and encourage participation of a wide section of resources including small-scale resources. This will be more important as EV numbers increase.

Transport is a key sector to achieving the high RE vision. Road transport can be almost entirely electrified and the more challenging areas within transport can be converted to renewable fuels. Adoption of EVs and phasing out ICE vehicles should be encouraged.

Energy efficiency is a low-cost mechanism that should be further encouraged through setting additional targets and mandating efficiency standards in the various sectors.

Adoption of RE can also be encouraged through the **green certificates** in addition to the announced **carbon credits market**.

Developing and enforcing improved data collection systems coupled with improving monitoring and analytical capability will enhance the ability to make informed decisions and policies. Strengthening monitoring and enforcement of standards and achieving goals is also needed.

The goal of achieving high RE shares in the energy system is consistent with reducing pollution and reducing reliance on imported energy, thereby improving energy security.

The BAU is the highest-cost scenario after accounting for the economic cost of externalities. The 80RE scenario has lower cost than 100RE because it avoids the highest cost conversions to renewable alternatives.

An overarching planning framework that integrates planning across networks, power system requirement, environment, and health will create improved outcomes.

Policies to support the achievement of the above have been proposed.

9 References

[1] Vietnam Ministry of Industry and Trade and GIZ, "Vietnam - National Energy Efficiency Program," GIZ, Hanoi, 2019.

[2] Vietnam Ministry of Industry and Trade, "Vietnam Energy Efficiency Program for the period 2019-2030 (Updated)," MOIT, Hanoi, 2021.

[3] IEA, "Viet Nam Balance Sankey Diagram," IEA, June 2020. [Online]. Available: https://www.iea.org/sankey/#?c=Viet%20Nam&s=Balance.. [Accessed 2022].

[4] Vietnam Ministry of Industry and Trade, "Power Development Plan VIII (draft)," MOIT, Hanoi, 2022.

[5] A. K. A. S. Abbas Rabiee, "Green hydrogen: A new flexibility source for security constrained scheduling of power systes with renewable energies," *International Jounral of Hydrogen Energy,* vol. 46, no. 37, pp. 19270-19284, 2021.

[6] Electricity and Renewable Energy Authority & Danish Energy Authority, "Fuel Price Projections for Vietnam. Background to the Vietnam Energy Outlook Report 2019," DEA, Hanoi, 2019.

[7] OECD - FAO, "Agricultural Outlook 2020-2029," OECD, 2020.

[8] P. a. H. L. Graham, "Electric vehicle projections 2021," CSIRO, 2021.

[9] I. Thermal, "Renewable Energy Options for Industrial Process Heat," The Australian Renewable Energy Agency (ARENA), 2019.

[10] N. Duong, "Rising cooking gas prices bring more financial pain," 07 March 2022. [Online]. Available: https://e.vnexpress.net/news/trend/rising-cooking-gas-prices-bring-more-financial-pain-4435017.html.

[11] SNV, "Goodbye Coal, Hello Rice Husks: Replacing coal-fired stoves with Biomass Cookstoves in Vietnam," November 2018. [Online]. Available: https://snv.org/update/goodbye-coal-hello-rice-husks-replacing-coal-fired-stoves-biomass-cookstoves-vietnam. [Accessed October 2022].

[12] IEA, "Energy Efficiency Policy Opportunities for Electric Motor-Driven Systems," IEA, France, 2011.

[13] IEA, “Energy Efficiency 2020,” IEA, 2020.

[14] Vietnam - National Energy Efficiency Program (VNEEP), “Energy Statistics - Viet Nam 2019,” VNEEP, Hanoi, 2019.

[15] World Population Review, “Vietnam Population,” World Population Review, 2022. [Online]. Available: https://worldpopulationreview.com/countries/vietnam-population. [Accessed 2022].

[16] Vietnam General Statistics Office, “Vietnam Population Data,” Vietnam GSO, Hanoi, 2021.

[17] Smarter House, “Replacing your Water Heater,” 2020. [Online]. Available: https://smarterhouse.org/water-heating/replacing-your-water-heater. [Accessed 2022].

[18] USAID, “Carbon Markets in Vietnam - Briefing Paper,” February 2022. [Online]. Available: https://pdf.usaid.gov/pdf_docs/PA00ZDT2.pdf. [Accessed October 2022].

[19] D. G. Goldmeer, “Power to Gas: Hydrogen for Power Generation, GEA33861.,” General Electric Corporation, 2019.

Appendix A Hydrogen for Power

This appendix provides analysis of the electric energy required to supply gas to a turbine for the purpose of generating electricity. General Electric published a paper on how natural gas turbines can be used to support lower emissions by burning hydrogen at various ratios in combination with natural gas [19]. We focus our discussion on burning 100% hydrogen where the hydrogen is produced by electrolysis powered by renewable sources (green hydrogen). We do not consider producing hydrogen from natural gas by reforming.

A large amount of energy is needed to produce sufficient hydrogen to fuel a generator running on hydrogen. This is an important consideration when deciding on the optimal use of energy. Table 25 shows the amount of energy needed by an electrolyser to produce enough hydrogen to power a generator that burns 100% hydrogen to run for 8,000 hours, equivalent to a utilisation rate of 91% of the power generator. The power output level (MW) is converted to energy output (GWh) by multiplying it by the assumed running time of 8,000 hours and dividing by 1,000.

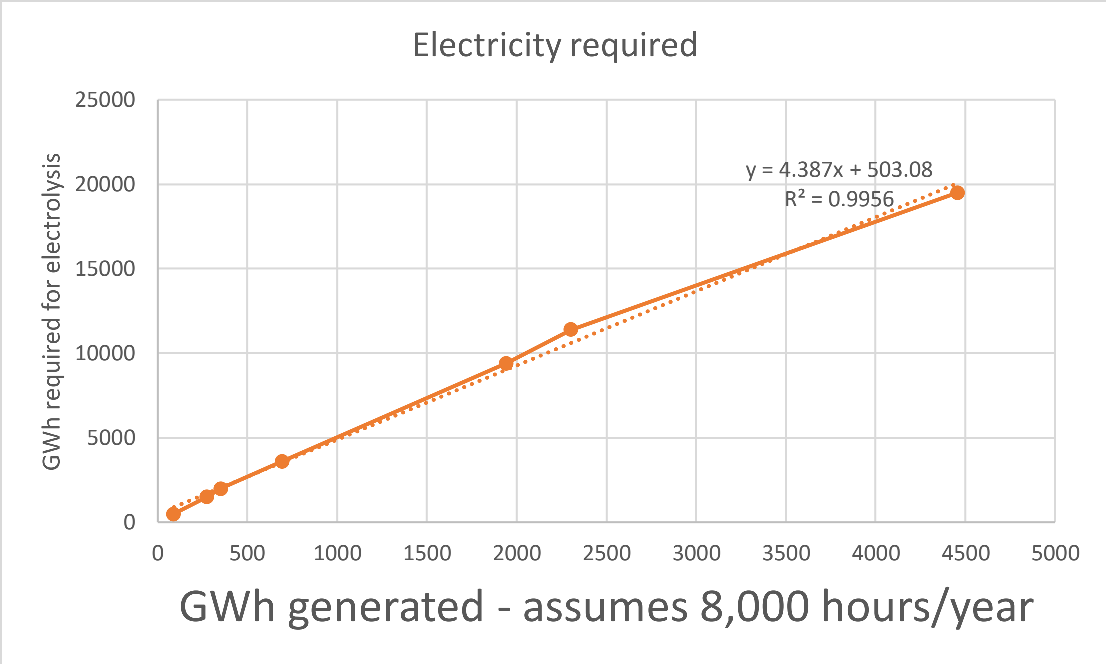
Table 25 Energy requirement for electrolysis to supply a gas turbine to operate on 100% hydrogen for 8,000 hours

Gas Turbine	Power Output (MW)	Energy Output (GWh @ 8,000 hours)
GE-10	11.2	89.6
TM2500	34.3	274.4
6B.03	44	352
6F.03	87	696
7F.05	243	1944
9F.04	288	2304
9HA.02	557	4456

Source: Adapted from GE, Power to Gas: Hydrogen for Power Generation [19, p. 5 Table 3].

We regress the data in Table 25, which incorporates generators with a wide range of sizes, from 11.2 MW to 557 MW. The charted data and regression equation are shown in Figure 103. There is a very strong linear relationship between the variables (coefficient of determination = 99.6%) and a highly significant coefficient of regression (t-statistic of 33.77 with 5 degrees of freedom giving a two-tailed p-value of 4.28×10^{-7}). The regression coefficient is estimated at 4.39 which indicates that 4.39 GWh of electricity are consumed in electrolysis to produce 1 GWh of electricity through a wide range of generator sizes. This represents an efficiency of 23%. The analysis did not take into account thermal energy needed by the process, water needed or the NOx emission from burning hydrogen. The energy requirement resulting from this analysis was used in arriving at the optimal power system portfolio.

Figure 103 Regression analysis of electricity needed by an electrolyser to supply hydrogen to produce electricity



Source: IES analysis based on data published in [19]

Appendix B Solar PV Note

This note relates to the key aspects of solar technology focusing on photovoltaic solar cells (or panels) with a brief reference to Concentrator Solar Power (CSP).

B.1 PV panels

Silicone is the predominant inorganic material from which PV cells are made. PV cells can be wafer-based or thin-film cells. Monocrystalline PV cells are cut from a single crystal while polycrystalline PV cells are cut from a block of crystals.

B.2 Bifacial panels

While solar cells started out as mono-facial types, bifacial panels have reached commercialisation stage. The increased output depends on the direct, diffuse and scattered light received by the reverse side of the panel. Economic viability cannot be generalised as the increase in power output depends on installation details and site characteristics. Among others, the study by Rodríguez-Gallegos et. al., 2018 provides a useful reference.

B.3 Tracking

To increase output from a PV panel, tracking systems alter the inclination of a panel to maximise the incidence of sunlight on it. Single axis trackers alter the inclination of a panel to follow the movement of the sun during the day. Double axis trackers have the additional ability of altering the inclination of a panel to track the movement of the sun across seasons. Most large-scale systems employ single-axis tracking as tracking the sun during the day typically produces a larger output gain than tracking across seasons.

B.4 Floating

Floating PV systems are used to take advantage of large water surfaces. Floating PV is typically designed for operation in relatively calm waters. It consists of a solar cell mounted on a floating platform. Floating PV can be mono-facial or bifacial and can be combined with tracking systems.

B.5 Concentrator Solar Power (CSP)

CSP technologies concentrate sunlight on a receiver and used to generate heat that can be used for heating or generating electricity through a turbine.

There are four primary types of CSP plants:

parabolic troughs

linear Fresnel systems

power towers

parabolic dishes

IEA's website https://www.solarpaces.org/how-csp-works/ provides a useful introduction to CSP. Large space requirement and current high capex are among the factors that detract from wider deployment of CSP.

B.6 Inverters

Solar systems require conversion of DC to AC current via an inverter. An inverter requires a controller for practical applications. Inverter controllers can be categorised into two broad categories, grid-following and grid-forming. Grid-following controllers are the most commonly used type. Such a controller relies on external resources setting the system voltage and frequency which the inverter then follows. Grid-forming controllers have been developed and deployed commercially based on a variety of strategies. Some of the more common types are droop controllers, virtual synchronous machines and virtual oscillator controllers. This area is constantly developing further and promises to deliver more innovative solutions in many areas including frequency control and inertia. The technoeconomic viability of such currently available systems and future innovation can only be determined by taking account of solar PV potential, solar PV cost trends for different variations of the solar PV technologies, type of connection to the network, hosting capacity of substations and other detailed engineered considerations. The considerations mentioned above for solar resources apply more broadly to all asynchronous renewable generation and batteries.

Appendix C Biomass Note

This note relates to the key aspects of biomass in Vietnam.

Several studies have dealt with biomass potential in Vietnam. Some studies considered a range of crops (see for example NL Agency's 'Biomass Business Opportunities Viet Nam', March 2012 and the World Bank's 'Biomass Resource Mapping in Vietnam', August 2018) while others focussed on a single crop, such as Cuong et. al. 2021 study of rice straw in Vietnam. The conclusions on the potential for electricity generation from biomass in Vietnam and on the ranking of the viability among crops vary among the studies. This is not uncommon. Electricity and heat from biomass are and will continue to be part of the energy mix in Vietnam. Biomass will likely be the optimal fuel in some instances. In this note we discuss key aspects of biomass in Vietnam based on the referenced studies and the experience of the consultant in biomass.

Biomass faces a number of challenges. Being geographically scattered combined with generally low energy density and bulk density makes transport costs challenging. Biomass resources are also subject to seasonality, degradation during storage, variability in energy content, contamination by foreign material, and incorporate compounds (such as silica and lignin) that present challenges (such as fouling and slagging) in energy applications. The value of biomass in alternative uses such as nutrient value or use in other products diminishes the net additional value from energy applications. Sustainability criteria include competition with food, biodiversity, alternative land use, competition for resources, environmental impacts, social and equity considerations. These considerations generally mean that not all of the theoretical potential can be exploited sustainably.

Harvesting methods influence residue potential, contamination by foreign material as well as cost (including capex and operating cost). Harvesting methods depend on factors such as crop type, size of land and topography.

The NL Agency study, released in 2012, set out to identify business opportunities in Vietnam's biomass sector and areas for cooperation between Vietnamese and Netherland organisations. The study estimated the potential of fourteen biomass resource types, including manure and municipal waste, and mapped them to potential conversion technologies.

The World Bank's study in 2018 assessed the potential of 18 biomass resources and produced a biomass atlas. The electricity generation potential on current sites was highest for sugar mills and municipal solid waste (MSW). The power generation potential of the 40 sugar mills studied, based on cogeneration technology and the 2016-17 milling season, was estimated at approximately 600 MW. A further 130 MW was estimated as the combined MSW potential. The study found limited potential in the surveyed rice mills (approximately 1,000 GWh/year from rice husk and additional biomass), wood processing mills (approximately 700 GWh/year from residue and additional biomass) and livestock farms (approximately 19 GWh/year). The study also assessed greenfield sites and assigned a suitability index to each.

Appendix D Renewable Fuels Note

This note discusses key aspects of renewable fuels characteristics and production.

Renewable liquid fuels can be produced by various processes to produce either early generation or advanced drop-in fuels. Early generation fuels such as ethanol and biodiesel are used blended with fossil fuels. Blends of up to 15% ethanol and 20% biodiesel are the most common blended fuels used in engines. Specially designed engines can take higher contents of ethanol, up to 83% ethanol depending on climatic conditions and season, and up to 100% (i.e. pure) biodiesel. Drop-in fuels are direct replacements to their fossil counterparts.

Ethanol is commonly produced by the fermentation of plant-based starches and sugars into alcohol (ethanol). Biodiesel is produced from vegetable oils and animal fats.

Drop-in fuels are produced from biomass through a number of processes. High temperature thermal processes include pyrolysis, gasification, and hydrothermal liquefaction. Pyrolysis involves rapid heating of the biomass feedstock in an oxygen starved atmosphere to produce bio-crude which is typically upgraded by further processing. Gasification subjects the biomass to higher temperatures to produce syngas. Hydrothermal liquefaction uses water and operates at lower temperatures and high pressures and is the preferred method for processing wet feedstock such as algae. Low temperature processes breakdown the tough outer structure of biomass feedstocks and expose the plant sugars (such as cellulose or hemicellulose) to the action of enzymes or chemicals to produce simple sugars.

The upgrading of bio-crude, syngas and sugars is accomplished through biological or chemical processes.[11]

The pre-processing of biomass feedstock is an important step that involves cleaning the feedstock, removing contaminants, and reducing it in size to suit the process. These steps can be carried out either in the field or in the processing plant. Pre-processing complexity, effectiveness and cost depends on the feedstock, harvesting method and the requirements of the production process (particularly with respect to cleanliness and particle size).

The treatment of liquid effluent and solid waste streams resulting from the production processes are an important consideration that can add cost and complexity to a process.

[11] Refer to this bioenergy technologies page for more details https://www.energy.gov/eere/bioenergy/biofuel-basics.

The yield, quality, and cost (capex and opex) of renewable fuel varies with the biomass feedstock, pre-production treatment, production process, upgrading, and effluent and waste treatment. Given the variability in these parameters the modelling has used a place holder for renewable fuels production.

NL Agency's 'Biomass Business Opportunities Viet Nam', March 2012 surveyed the biomass sector in Vietnam to identify business opportunities. The study identified the potential of biomass resources and linked them to potential conversion technologies. Table 3 of that study is duplicated below. It maps biomass resources in Vietnam to potential conversion technologies identified in the study.

Figure 104 Mapping of biomass resources to conversion technologies

	Pellets	Briquettes	Charcoal	Torrefaction	Combustion	Gasification	Pyrolysis	(An)aerobic (co-) digestion	Biodiesel Bio ethanol
Bamboo			X	?	X	X	X		
Cassava									X
Coconut (Coil and Pith)	X	X	X	?	X	X	?		
Coffee Pith	X	X			X	?	X		
Corn (Cobb and Stob)		X		?	X	?		?	
Jatropha									X
Manure								X	
Manure (poultry)					X	X	X	X	
OSW					X			X**	
Rice Straw				X	X		X	X*	
Rice Husk					X	X	X	X	
Sugar Cane Bagasse				X	X	X	X		
Sugar Cane Molasse									X
Wood	X	X	X	X	X	X	X		

* Not fermentable in a biogas plant without special pretreatment: Thermally / Chemically
**landfill MSW / digestion OMSW
Note: Energy efficient fermentation particularly of straw and leaves could make a substantial contribution to power supply.

Source: NL Agency,2012. 'Biomass Business Opportunities Viet Nam'. Table 3

A reference to a recent review of renewable fuels is provided in the footnote below. The authors use the term biofuel to refer to all renewable fuels made from bio feedstocks including drop-in fuels.[12]

[12] Teklit Gebregiorgis Ambaye, Mentore Vaccari, Adri´an Bonilla-Petriciolet, Shiv Prasad, Eric D. van Hullebusch, Sami Rtimi, 2021. Emerging technologies for biofuel production: A critical review on recent progress, challenges and perspectives. Journal of Environmental Management 290. https://doi.org/10.1016/j.jenvman.2021.112627

Appendix E Offshore Wind

The exploitation of offshore wind resources requires attention to issues relating to the various phases from surveying through to construction and operation. We focus here on the areas that are unique or more important to offshore wind projects rather than what is common to all power projects. The broad phases of survey (needed for prefeasibility), project evaluation and facilitation, and regulatory risk.

E.1 Surveying offshore wind areas

VN has approached the question of surveying offshore wind areas by granting permits to developers to survey large areas (this is not a permit to develop, just to survey). International experience shows that some jurisdictions opted for government to survey the areas while others opted to have developers undertake the survey at their own cost.

Clear criteria need to be developed of how survey areas are defined, the conditions to be included in survey permits and how proposals to survey areas will be evaluated.

E.1.1 Suitability factors

Many factors are involved in determining the suitability of an area to support an OWE project. The following list, expanded by IES, includes factors identified in Spyridonidou and Vagiona, 2020.[13]

- Proximity to local ports
- Power grid investment required
- Impact on local and national power system
- Geographic boundaries
- Wind speed
- Air density
- Water depth
- Seabed morphology and soil status
- Wave developments and patterns
- Hurricane/storm patterns

[13] Spyridonidou, S.; Vagiona, D.G. Systematic Review of Site-Selection Processes in Onshore and Offshore Wind Energy Research. Energies 2020, 13, 5906. https://doi.org/10.3390/en13225906

- Seismic hazards
- Relationship to
    - Shipping Routes
    - Submarine pipelines and cables
    - Military/Naval zones
    - Environmental Areas
    - Bird habitats and migration corridors
    - Marine life
    - Visual and acoustic disturbances
    - Fishing areas

It is clear from the above that suitability is not simply a function of the size of the area. Therefore, defining areas simply by reference to size is not ideal and other criteria would need to be taken into consideration. However, this may be limited by the availability of this information prior to undertaking the survey.

E.2 Release of permits and conditions

Should permits be issued in tranches over a period of time? Should the tranches be spread over geographies or concentrated?

Should the continued validity of the permit be tied to satisfying certain conditions, and milestones to be reached?

Consider prequalifying applicants based on criteria such as successful performance in previous similar projects within the last X years (for example the last five years), financial capability, ability to secure financing,

E.2.1 Evaluation framework

The evaluation framework should include how to resolve situations where competing survey applications nominate areas that overlap and how that might relate to potential award of development permits to competing developers.

E.2.2 Rules for project evaluation and facilitation

In addition to a clear timeline of project releases and mechanism for submission and award of projects, it is important to establish and publish clear rules of how projects will be evaluated including benefits to the local economy (new technology, skills, investment, jobs, etc) possibly ranking the importance of certain factors.

E.2.3 Project permits and evaluation rules

Establish a clear timeline and mechanism for project permit release, proposal submission, evaluation and award. Establish and publish clear rules for how applicants and projects will qualify and be evaluated. Considerations include whether the rules will:

- Favour technologies or be technology neutral?
- Specify a minimum or maximum size of project?
- Seek diversification of technology, investors and/or geographies?
- Specify a penalty for defective implementation or underperformance?
- Specify a penalty for delayed completion or incentive for early completion?
- What are the obligation and rules for decommission and what suitable guarantees will be required?

E.2.4 Establish project boundaries

Establish clear boundaries of responsibility for developer (for example, up to the point of connection to the grid) to enable them to assess the feasibility and risk of the project.

E.2.5 Facilitation

Government can play a major role in project facilitation along various fronts such as:

- Who will bear the cost of developing infrastructure needed for offshore wind development? In addition to shipyards, construction of offshore wind requires suitable ports and other infrastructure, such roads and power network investment.
- How to ensure on-going O&M activities will be carried out to the required standard?
- Can government agencies facilitate connecting international investors with local firms through establishment of forums or other means?
- How will the required skills in the workforce be acquired and developed along with the cost of training and regulatory oversight on certification?

E.2.6 Regulatory risk

Offshore wind is a capital-intensive investment with a high proportion of lifetime costs incurred before the start of operation. Add to that time to reach operation stage of 6 to

10 years, it becomes clear that a stable regulatory regime is an important pillar in facilitating investment.

Regulatory risk touches the areas of:

- Permitting framework including harmonising and coordinating requirements across agencies and levels of government;
- Route to market and PPA structure;
- Rules around curtailment, project termination, change in law and change in tax;
- Decommissioning rules, responsibility and guarantees; and
- Establishing and providing information about the pipeline of projects and its timeline should allow investors and suppliers to incorporate this into their decisions and commitments.

De-risking these areas for investors and finance providers will contribute to widening the field of applicants and reducing ultimate costs.

Appendix F Auctions

Auctions represent an instrument that has been applied successfully to achieve excellent outcomes. The advantage of competitive auctions is that they encourage competition and can assist in price discovery. The design of auctions needs to ensure competition is facilitated, and a diverse field of investors are attracted. Design parameters to consider include the quantity of renewable energy on offer in each round relative to the target and to the capabilities of the developers, and the products to bid on.

The entity that conducts the auction needs to have the capability or support, to design the auction, produce and distribute tender documents, conduct the auction, evaluate the offers, and finalise negotiations and procurement processes with the winners. Managing performance in the operation stage is also an important consideration associated with any instrument and not particular to auctions.

The design of competitive auctions for renewable energy is a vast topic. The following is intended to outline key auction design considerations:

- Bidder qualification requirements: If the level of experience of bidders to qualify for participation in the auction is set too high, relative to the available pool, it will limit the number of participants in the auction.
- Project qualification requirements: These can be set to include only projects that have secured access permits to the grid and do not require grid reinforcement all the way to not requiring a permit before the auction. For example, India's draft guidelines for competitive bidding for hybrid Wind and Solar projects requires the applicant to submit documents confirming technical feasibility of connectivity of the plant to the network, identification of the site, obtaining No Objection Certificates and, if applicable, Environmental Clearance. The risk of projects being delivered on time increases as the requirement is relaxed but the trade-off is that the cost will be lower and that there will be a larger field of participants. Other requirements can include project impact on the system, environment, and the economy.
- Technology differentiation: Will the entire volume be open to all technologies, or will the auctioned volume be divided between technologies? The latter can assist in ensuring that technologies at an earlier stage of development are included.
- Bid evaluation: The rules of selecting the winner need to be clear and carefully designed. Will the winner be determined based on price alone or will other criteria be used to calculate an overall score? In several jurisdictions an overall score weighted over relevant elements is used.

- On time delivery: Another important consideration is the mechanism by which to ensure that the auction winner delivers the entire capacity on time. Delivery may be delayed for any of a host of reasons – delays in obtaining project approvals, problems and delays with project design and execution, as well as commercial risks such as changes in the price of materials, exposure to inflation or changes in the rate of exchange. One solution is to a require bidders to post guarantees and be subject to penalties in case they fail to deliver the full quantity in the promised timeframe. Disadvantages of guarantees are that they raise costs and can discourage parties from participating in the auction. Moreover, they do not guarantee project completion.
- Operational performance: Beyond the construction and commissioning phases there are project risks during operation of the project. Considerations of performance in operation include the technical and commercial ability of the winner to operate the plant and deliver the promised production reliably.

These issues are applicable to power generation supply projects in general and should guide the principles to which Wind energy auctions are designed and commenced. Importantly, capacity could be auctioned off in technology-neutral renewable energy auctions, which allow for RE technologies to compete on a least-cost basis (or another basis, based on auction design), or technology-specific auctions.

Appendix G Just Energy Transition Partnership (JETP)

The establishment of the Just Energy Transition Partnership (JETP) was announced on 14 December 2022. The JETP is an agreement between Vietnam and the International Partners Group consisting of the European Union, USA, Italy, Canada, Japan, Norway and Denmark. The JETP will mobilise $15.5 billion of public and private finance over the next three to five years. The amount is made up of $7.75 billion in pledges, from the IPG in addition to the Asian Development Bank and the International Finance Corporation, and a commitment to facilitate a further $7.75 billion in private investment from private financial institutions coordinated by the Glasgow Financial Alliance for Net Zero (GFANZ) which includes an initial set of 11 major financial institutions.[14] The structure (grant versus debt) and terms of the funding is not known. The press release on the GFANZ website states it will work with the Vietnam Government to ensure continued improvement in the policy and enabling environment, availability of public finance to de-risk private finance, and securing a robust pipeline of competitive tenders for projects.[15]

The JETP targets published on the European Commission's site are:

- Bring forward the peaking date of GHG emissions in Vietnam by five years from 2035 to 2030.
- Reduce peak annual power sector GHG emissions by up to 30 percent (from 240 megatons to 170 megatons) and bring forward the peaking date of GHG emissions in Vietnam by five years from 2035 to 2030.
- Limit Vietnam's peak coal capacity to 30.2 GW (down from a current planning figure of 37 GW.
- Accelerate the adoption of renewables so that it accounts for a minimum of 47 percent of electricity generation by 2030 (up from the current planned generation share of 36 per cent).

It is estimated that the JETP will result in a cumulative reduction of around 200 megatons of greenhouse gas emissions by 2030, and a further 300 megatons by 2035, making a total of around 500 megatons.

[14] Available on the European Commission website https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7671

The full English text of the political declaration can be found on the UK Government website https://www.gov.uk/government/publications/vietnams-just-energy-transition-partnership-political-declaration/political-declaration-on-establishing-the-just-energy-transition-partnership-with-viet-nam

[15] Refer to the GFANZ website on https://www.gfanzero.com/press/gfanz-establishes-working-group-to-support-capital-mobilization-for-the-vietnam-just-energy-transition-partnership/

Vietnam is the third country to launch a JETP following South Africa (at COP 26) and Indonesia (at the 2022 G20 Leaders' Summit.

The JETP announcement and publicly available information is not sufficiently detailed to allow a precise estimate of its cost impacts to be made. We make some broad assumptions about the trajectory of change to arrive at high-level cost impacts in relation to the modelling output of our study.

The BAU scenario in this study estimates 45% of electricity to be generated from Hydro, Solar, Wind, and Biomass in 2030. This share is close to the November 2022 version of the draft PDP8 and the JETP target of 47%. Therefore, we do not expect the expansion of power generation from RE to significantly impact the power system related capex or power cost ($/MWh) estimated in our modelling of the BAU scenario. We note that the JETP uses a different base of 36% of electricity generated from renewables in 2030, which appears to be based on an earlier version of the draft PDP8.

The JETP estimates that limiting the maximum capacity of coal to 30.2 GW (from 37 GW) will achieve a cumulative reduction of 500 megatonnes of carbon emissions by 2035. At $40 per tonne of carbon the estimated cumulative cost of emissions in the JETP would be lower than the BAU by 20 billion dollars, around 5% of the BAU emissions costs.

Emissions peak at 243 megatonnes in 2029. Coal capacity in the BAU is 36.4 GW in 2030. It peaks in the period 2037 to 2039 before starting to decline from 2040.

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