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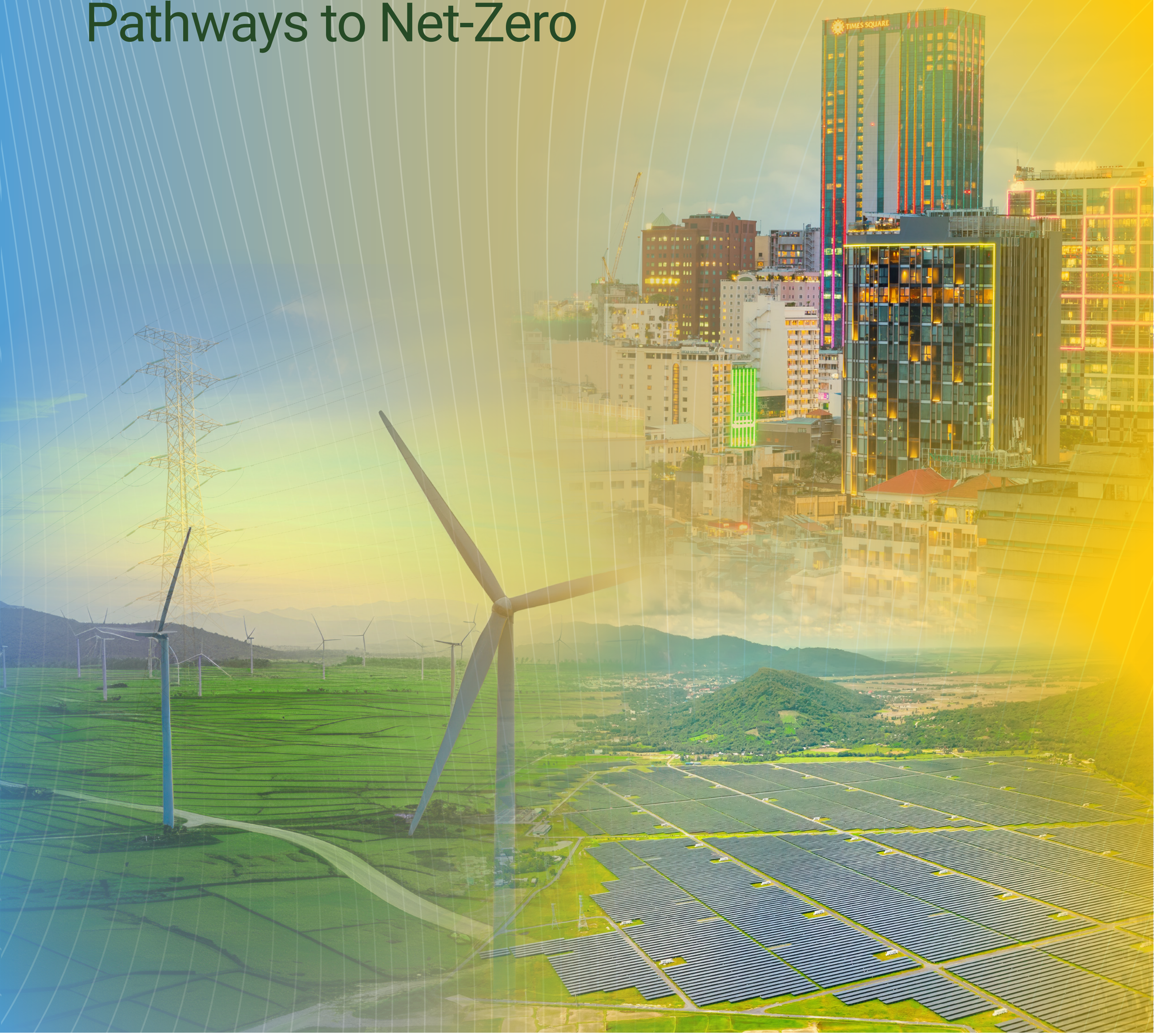
Viet Nam Energy Outlook Report

Pathways to Net-Zero



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"The energy partnership between Viet Nam and Denmark has yielded fruitful results and tangible benefits for both countries. The energy sector of Viet Nam is now facing critical challenges in meeting energy security and sustainable development targets. We always appreciate the support of the Danish government so far to help Viet Nam gradually realize the green and sustainable energy transition targets. I hope that, in the coming time, both sides shall continue our close collaboration to effectively implement energy cooperation programmes."

Nguyen Sinh Nhat Tan, Vice Minister, Viet Nam Ministry of Industry and Trade

"Viet Nam and Denmark both have ambitious climate goals. The 'Viet Nam Energy Outlook – Pathways to Net-Zero' is a result of our strong collaborative efforts addressing green transition and climate change. The report shows that Viet Nam has a remarkable potential for renewable energy, and illustrates how a green transition can drive growth, energy security and sustainable development for the Vietnamese society."

Kristoffer Böttzauw, Director General, Danish Energy Agency

Abbreviations and Acronyms

ASEAN	Association of Southeast Asian Nations
BESS	Battery Energy Storage System
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
COP26	26th UN Climate Change Conference of the Parties
DAC	Direct Air Capture
DEA	Danish Energy Agency
DEPP	Energy Partnership Program between Viet Nam and Denmark
EE	Energy Efficiency
EOR19	Viet Nam Energy Outlook Report 2019
EOR21	Viet Nam Energy Outlook Report 2021
EREA	Electricity and Renewable Energy Authority
EV	Electric Vehicle
EVN	Viet Nam Electricity
FEC	Final Energy Consumption
FLH	Full Load Hours
GDP	Gross Domestic Product
GHG	Green House Gas
GoV	Government of Vietnam
GSO	General Statistics Office of Vietnam
JETP	Just Energy Transition Partnership
LNG	Liquefied Natural Gas
LULUCF	Land Use, Land-Use Change and Forestry
MOIT	Ministry of Industry and Trade
MSW	Municipal Solid Waste
NCCS	National Climate Change Strategy
NDC	Nationally Determined Contribution
NEMP	National Energy Master Plan
PDP8	Viet Nam National Power Development Plan for the period 2021-2030, vision to 2050
$PM_{2.5}$	Atmospheric Particulate Matter with a diameter of less than 2.5 micrometers
PPA	Power Purchase Agreement
PtX	Power-to-X
PV	Photovoltaic
RE	Renewable Energy
SMR	Small Modular Reactor
TFEC	Total Final Energy Consumption
TPES	Total Primary Energy Supply
VNEEP3	Viet Nam National Program on Energy Efficiency and Conservation for 2019-2030
VRE	Variable Renewable Energy
WB	World Bank
WHO	World Health Organization

Executive Summary

Recommendations to achieve a cost-efficient and green development of the energy system

1. The green energy transition is cost-efficient for Viet Nam

Based on the analysis of cost-optimal pathways for the future development of the energy system of Viet Nam, the green transition is not only technically feasible, it is also economically viable. Even with no explicit GHG emissions reduction targets (Baseline scenario), total emissions peak in 2030 and decrease afterwards. Moreover, the projected annual GHG emissions in 2050 will be 21% lower than the emissions recorded in 2022.

To reach the net-zero target announced at COP26, Viet Nam needs to continue examining and implementing measures to significantly reduce emissions, especially in the power sector, already within this decade (Net-Zero scenario). Further emission reductions by 2050 are feasible (Net-Zero+ scenario) and are recommended to offset insufficient realization of the more uncertain emission reductions projected for the agriculture and LULUCF sectors, as outlined in the National Climate Change Strategy.

Recommendation: Incentivize CO_2 reductions through the planned market-based mechanisms.

- *The CO2 quota scheme (Emission Trading Scheme) should be aligned with ambitious targets already in 2030 and 2035 for the power and industry sectors, as it is an important economic instrument towards realizing short-term reductions.*
- *Consider strengthening the current ambitions to target peak emissions of the whole energy system before 2035, and in line with JETP targets for the power sector by 2030*[1]*. Moreover, consider to further increase ambitions for emission reductions in the energy sector in 2050, beyond the overall net-zero target for the whole society.*

2. A steady increase in renewable energy investments is required from today

The Power Development Plan for the period 2021-2030, vision to 2050 (PDP8) is particularly ambitious in the long-term development, with significant focus on renewable energy expansions after 2030. However, to reach Viet Nam's net-zero target in 2050 in a cost-effective way, Viet Nam should increase efforts to secure investments in renewable energy (RE) before 2030, with the growth in electricity demand to be covered mainly by RE from 2025.

Results from the Net-Zero scenario illustrate that, between now and 2030 Viet Nam needs to install 56 GW of renewable capacity (17 GW onshore wind and 39 GW solar) to be cost-effective in the long term. This is because the alternative to RE investments before 2030 are significant investments in thermal capacity that will only be operational for 10-15 years, before having to be phased out or operated at low loads to comply with the committed emission reduction targets.

Recommendation: Set ambitious short-term targets for RE deployment, and reduce risks and delays in approving renewable energy projects. The following steps can be taken to reduce the risk for investors and, thus, lower the capital cost of renewables:

- *Support early and selective prioritization of investments in renewable energy with focus on improved regulatory framework including tender mechanisms, direct power purchase agreement (DPPA), and PPA terms.*
- *Analyse and propose suitable support mechanisms when curtailing renewable-based generation.*

3. Transforming Viet Nam's economic structure towards a lower share of energy-intensive industries will help achieve green growth and be more cost-effective

In the Green Growth scenario, Viet Nam could achieve a more sustainable and cost-effective green growth by restructuring the economy and prioritizing service sector growth, reducing energy-intensive industries and increasing manufacturing sectors with high value-added and less energy-intensive products. This development

[1] Peak of emissions of no more than 170 Mt CO_2eq from electricity generation by 2030.

helps reduce total energy demand, thereby saving investments in the energy system, while still achieving economic growth and fulfilling climate goals.

Recommendations:

- *Consider amending the structure of Viet Nam's economic growth to guide the economy towards a higher economic growth from the service sector and less energy-intensive industries.*
- *Set sub-sectoral targets for the economic growth in manufacturing industries to prioritize the production of high-value products such as automobiles, electronics, batteries, photovoltaics, chips and semi-conductors, among others.*
- *Support the restructuring of the labour force by formulating a long-term training strategy and retrain skills of workforce by implementing programs for re-qualification of skills towards manufacturing of high-value products.*

4. Energy efficiency is a cost-effective option to reach the net-zero target

Between 2020 and 2050, the average industrial demand for energy will grow by a factor 4-7 depending on the scenario, with lower growth in energy demand achieved in the Green Growth scenario. For the residential and services sectors, the energy demand will grow by 150% in 2050, thus contributing to around 18%-24% of the total electricity demand. All existing processes will be replaced by new and more efficient processes and technologies by 2040 at the latest. Energy efficiency is therefore cost-efficient across industrial, residential and services sectors. However, investments to reach the full energy efficiency potential would require targeted incentives and solutions to improve policy compliance.

Recommendations:

- *Incentivize investments in more efficient processes in all sectors. Particularly, in the heavy industry like cement and steel sectors, investments in the most efficient processes are needed to reach the net-zero target.*
- *Analyse and quantify the non-financial barriers to investments in energy efficiency for industry, services and residential sectors to recommend appropriate policies.*

5. Integration of renewable energy in the power sector is a key pre-condition for the green electrification of the transport sector

According to the Green Transport Strategy (Dec. 876/QD-TTg, 2022), more RE is required to provide adequate green electricity for the transition of the transport sector already in the short term, thus increasing the electric vehicle fleet. However, if the power sector is not targeted by a similar ambitious and short-term focused plan on RE expansion and integration, then cross-sectoral synergies are not unlocked. This is seen in the Green Transport scenario, where a slower green development of the power sector combined with a rapid transition to e-fuels and other green fuels leads to a higher cost of reaching the net-zero goal in 2050.

Recommendation: Ensure coordinated pace of transition of power and transport sectors, by supporting the ambitious transport targets with similar ambitious targets for RE integration in the power sector.

Recommendations to achieve security of supply in the power sector, while transitioning to green energy

6. Further explore the potential for the use of land for onshore wind and solar power in line with the net-zero target by 2050

The Net-Zero scenario assumes a larger land area available for utility photovoltaics (PV), with double potential of solar PV capacity assumed compared to the Baseline scenario. While utility-scale PV are preferred in the cost-optimal scenarios, rooftop solar can be beneficial and competitive in some areas, due to, for example, local grid constraints or land use restrictions.

Recommendations:

- *Perform a study of usable land areas for multipurpose (agriculture and energy) use, with the goal of updating the potential areas available for onshore renewable energy while considering local aspects and agriculture needs.*
- *Develop standards and regulations to promote rooftop solar power connecting to the grid.*

7. Nuclear energy could play an important supporting role to renewable energy in the long term under high emission reduction scenarios

Ensuring the achievement of the net-zero emission target by 2050 entails a potential role for nuclear power, which could become part of the power mix by 2050 in the Net-zero scenario. Under more ambitious climate targets (NZ+ scenario), with consequent increase in the power demand, nuclear energy is developed starting from 2040, reaching up to 28 GW of capacity by 2050.

Recommendation: Further investigate the possible future role of nuclear energy in a largely RE-based power system, including the impact on diversification and robustness of the power system.

8. Accelerate the issuance of the regulatory framework to kick-start installation of offshore wind

In the Net-Zero scenario, offshore wind is projected to be in operation in 2035, with the offshore wind capacity expanding to 84 GW over the following 15 years until 2050. Developing the necessary framework to roll-out the planned pilot projects for offshore wind is therefore a prerequisite already from today to achieve the offshore wind targets stated in PDP8 and beyond, considering the long planning and construction time needed for offshore wind (6-10 years).

This includes developing and implementing adequate regulations and guidelines including marine spatial planning, a price framework, and a clear permitting process to ensure speed of implementation. At the same time, it is important to conduct an analysis of grid point connections, develop the needed seaport infrastructure and supply chains, as well as ensure the readiness of skilled workforce.

The offshore wind pilot projects, as outlined under PDP8, should be progressed as soon as possible in order to build the necessary experience; mitigate and minimize risks and costs; raise awareness for Vietnamese authorities and increase confidence for investors.

Recommendation: Accelerating the issuance of the legal framework and specific regulations and guidelines is the prerequisite for the effective roll-out of offshore wind projects.

9. Improve power system efficiency by enhancing and timely prioritizing flexibility

In order to meet the rapidly growing electricity demand in line with the projected economic development, and to live up to the commitment for net-zero emissions by 2050, a large expansion of generation capacity and transmission grid are required, with a high share of renewable energy contributing to the power mix. To accommodate the transition, flexibility is one of the key factors that enables increasing the efficiency of the system and allowing an effective and smooth integration of renewable energy. Some measures to ensure flexible operation of the power system include upgrading the transmission grid, investing in energy storage systems, and flexible operation of coal-fired power plants.

All these measures of flexibility are necessary and feasible to implement in Viet Nam, but priority should be given at different stages to achieve the highest economic efficiency. The analyses show that suitable grid investments in combination with measures to increase the operational flexibility of coal-fired power plants are the most cost-efficient options between now and 2035, after which also batteries will become cost-effective.

Flexible operation of coal-fired power plants can be achieved by enacting appropriate mechanisms to increase the effective operation of coal-fired power plants in synergy with production from renewable energy plants, hence reducing the overall cost of the system by saving investment needs in transmission grid and batteries, which are currently very costly. In addition, it is necessary to strengthen training programs for operators for improving power plant flexibility.

Recommendations:

- *Support measures enabling flexible plant operation will help ensure power system stability and efficiency. Consider to introduce support measures for supplying ancillary services to incentivize flexibility.*
- *Set standardized requirements for minimum load and ramp rates for existing power plants and units being planned to provide the legal basis and incentives for increasing flexibility. Perform pilot tests to gain experience and knowledge of the required costs and other barriers for increased power plant flexibility.*
- *Develop the regulatory framework to support large scale deployment of electric storage after 2030.*

10. Early and consistent expansion of the transmission system in Viet Nam is required

The analyses show that strengthening the inter-regional transmission capacity from 27 GW to 48 GW in 2030 is important and a pre-condition for ensuring security of supply with high shares of RE. In the Net-Zero scenario, investments of 1 GW of HVDC (High Voltage Direct Current) transmission lines from central regions to the North begin already in 2030. In the long term, HVDC connections become a pivotal part of the transmission system enabling the distribution of the high RE generation to the demand centres. By 2050, a tripling of inter-regional transmission capacity is expected, with HVDC lines playing a vital role.

Recommendation: Develop a plan for expansion and upgrade of the transmission grid, including HVDC connections to reach a tripling of the inter-regional transmission capacity by 2050 compared to today.

Recommendations to achieve synergy in the energy system by sector coupling of renewable fuels and hydrogen

11. The development of hydrogen production and infrastructure will be cost-efficient after 2035

A significant amount of green hydrogen will be needed in Viet Nam in the long term to decarbonize transport and industry, but other than this, the use of hydrogen is expected to be limited to around 1-5% of the total fuel consumption (depending on the scenario), due to high domestic production costs, and even higher import costs.

Hydrogen demands in the future are assumed similarly distributed to today's high demand regions, thus mainly in North and South regions. However, the analysis shows that it is more cost-effective to place hydrogen production near good RE sources and establishing an internal hydrogen pipeline system can be beneficial and therefore reduce the need for electricity transmission investments in the long-term.

Recommendations:

- *Establishing hydrogen infrastructure, namely production, transmission, distribution and storage, will be cost-effective from 2035.*
- *Analyse the potential location of hydrogen production sites close to RE generation and consumption facilities, and the possibility of hydrogen transportation by pipeline to reduce the need for transmission grid investments in the long-term.*

12. Prioritize hydrogen use in hard-to-abate sectors over use in the power system

Green hydrogen is expected to be necessary in large scale starting from 2040s, reaching production of 334 PJ of hydrogen in 2050 (Net-Zero scenario), up to above 573 PJ (Net-Zero+ scenario). The analyses show that application of green hydrogen and derivatives is only cost-efficient in hard-to-abate sectors, where direct electrification is not possible, such as heavy industry, shipping and aviation, and not as fuel for power generation. In industry sub-sectors such as iron, steel and cement production, hydrogen can contribute to achieving emission reduction targets, primarily from 2040, when technologies are expected to have matured. Moreover, domestic production of hydrogen through electrolysis can contribute to utilizing local RE-based generation, hence reduce reliance on fuel imports.

Recommendations:

- *Prioritize the use of green hydrogen in heavy industry sectors, i.e. cement, iron and steel production, as well as shipping and aviation through a combination of target setting and market-based measures, such as CO_2 tax or quota scheme and CO_2 credits.*
- *Implement pilot projects before 2035 in hard-to-abate sectors to build knowledge and experience before upscaling.*

13. Ensure sustainable utilization of biomass resources and biogas production

Sustainable biomass plays a crucial role in the industry to phase out coal where only few other feasible alternatives exist, such as high-temperature heating. Sustainable biomass is also utilized in the transport sector for the production of biomethanol through biomass gasification, synthetic natural gas and biodiesel for the heavy transport modes. Therefore, the use of biomass in the power sector is not cost-effective from a system's perspective, as sustainable biomass is a limited resource and less competitive than RE alternatives and nuclear for power generation.

The analyses consider a sustainable biomass potential of about 1,719 PJ in 2050; however, estimations on potentials and costs remain uncertain, as these are subject to changes in land use and climate change impacts, including water demand and rising sea levels, among other factors. These factors contribute to the increased risk of relying heavily on biomass for energy. Therefore, specific regulations and guidelines for the sustainable production, collection, processing and use of biomass should be developed.

Moreover, across all scenarios, the potential for biogas, with up to 176 PJ produced across scenarios in 2050, should be utilized to reduce emissions from agriculture and secure a reliable fuel supply in rural areas.

Recommendations:

- *Prioritize sustainable biomass use in industry and transport, rather than power sector.*
- *Develop regulations and guidelines on biomass resource production, collection, processing and use, including development of biogas production, where relevant.*

Recommendations to achieve green energy transition in the transport sector

14. Electrify the light transport modes rapidly and use of renewable fuels in the heavy transport segments to cost-effectively reduce climate and environmental impacts

Direct electrification of the light transport segments should be prioritized as it is cost-effective, even in the baseline scenario. A shift towards electric vehicles (i.e. electric cars and motorbikes, but also vans and busses) not only represents a measure for climate mitigation, but also holds the opportunity to diminish the health and environmental costs associated to air pollution, especially in urban areas. The whole car and motorbike fleet should be fully electrified by 2050, since it is the cost-optimal option across all scenarios, with a significant shift in the vehicle stock starting from 2030. However, a smoother and earlier introduction of Battery Electric Vehicles (BEVs) is recommended already from today, to consider factors like inertia and behaviour in private households' purchase decisions.

Recommendations:

- *Consider to formulate targets of 50% BEV by 2030 and 90% BEV by 2040.*
- *Consider short-term incentives (e.g. subsidy) on purchase of BEVs, especially 2-wheelers, as well as suitable tariffs for electricity price at EV-charging stations.*
- *Prioritize the use of hydrogen and e-fuels in the heavy transport segments (i.e. freight trucks, aviation and shipping).*

15. Plan the needed infrastructure for the electrification of the transport sector

Considering global technology development and projected cost reductions for BEVs, Viet Nam will witness a very rapid increase in consumers' demand for electric 2- and 4-wheelers in this decade. However, Viet Nam's local electricity grid infrastructure and urban planning are currently not prepared for the requirements that such transformation would entail. Demand for electricity to supply transport demands in the electrified modes will drastically increase in the future, with around 380 TWh of electricity needed in 2050 in the Net-Zero scenario, increasing to 408 TWh for the Green Transport scenario. Correspondingly, the electrification level, across all transport segments, drastically moves from a current 0.4% of the fuel mix in 2022 to covering 44% of the energy needs in transport in 2050 in the Net-Zero scenario.

Recommendations:

- *Develop an investment strategy for EV charging infrastructure based on international standards both at national and provincial level.*
- *Integrate EV charging infrastructure, including reinforcement of the distribution grid for charging stations, into national road planning as well as provincial, city and urban plans before 2030.*

16. Adequate infrastructure is necessary to enable the shift towards public transport and electric railways

Net-zero scenarios assume a key role for modal shift in reducing total energy needs to fulfil the passenger and freight demands in the future in Viet Nam. In particular, shifting from private vehicles to urban railway in the main urban areas for passenger transport, and moving part of demand from road, shipping and airplanes to railway for both passenger and freight transport can reduce the total fuel consumption in the transport sector by at least 9%, when comparing Baseline and Net-Zero scenarios. The modal shift is projected based on expected plans for railway infrastructure upgrades, with, among others, the introduction of a North-South high-speed railway system catering to passenger and freight transport. Such infrastructure investments require not only timely planning and implementation, but also setting the adequate incentives to promote the shift from current modes, differentiated respectively for passenger and freight transport.

Recommendation: Ensure timely investment roadmap for electric railway system is aligned with transport targets, both in scale and timing, accompanied with the necessary incentives to promote larger use of public transport.

17. Renewable fuels will play a major role for heavy-duty transport segments

Domestically produced green hydrogen becomes cost-competitive starting from 2040. The need for e-fuels including hydrogen and bio-based fuels to supply non-road transport segments that cannot be directly electrified, such as aviation and shipping, will increase to around 65-90 PJ in 2050 across net-zero scenarios. Moreover, methanol and ammonia could play a large role to supply maritime transport and heavy-duty vehicles, with up to 500 PJ needed in the Green Transport and Net-Zero+ scenarios in 2050.

Recommendation: Develop production and prioritize the use of e-fuels including hydrogen and bio-based fuels to supply shipping and aviation.

Recommendations to achieve cost-efficient and less energy-intensive industrial sector

18. Ensure electrification of all industrial processes where possible

In 2050, electricity could make up 58-73% of final energy consumption in industries, depending on the scenario. Using electricity is one of the cheapest solutions to improve efficiency and cut emissions, especially when it replaces traditional fuel sources. As the industry is rapidly growing, transitioning this sector should be prompt and targeted, concentrating on the sub-sectors with large energy consumption and potential for emission reduction. This can be achieved through use of electricity and biomass to replace coal.

Recommendations:

- *Analyse and develop policy mechanisms to support switching of all industrial processes to electricity, as soon as possible.*
- *Consider making use of electricity compulsory for specific processes, when switching to building new facilities or switching to new equipment. This could include the development of a roadmap for implementing the switch to electricity in industry from voluntary-based to compulsory.*
- *Ensure a phase-out of coal use for energy purposes in new industrial production investments no later than 2030, towards no new coal use at all in industries from 2040, unless CCS is implemented.*

19. Focus on transitioning the high-emission industrial sub-sectors

Heavy industrial sub-sectors such as iron, steel and cement represent a large share of the total energy consumption of the industrial sector in Viet Nam today. However, their share on the total industrial energy consumption can shift from the current 42% to 23-25% in 2050. Furthermore, these sectors also hold the largest share of GHG emissions, excluding process related emissions. The latter amount to 69 Mt in the Baseline scenario in 2050, whereas they are reduced to 20 Mt in the Net-Zero scenario.

Recommendation: Target the hard-to-abate industry sectors with measures to ensure energy efficiency, fuel switch to electricity and biomass, as well as promote alternative production routes and more sustainable construction materials.

- *Implement pilots for low-carbon cement or even zero-carbon cement production. From 2030, study and introduce support mechanisms for green steel production using electricity and green hydrogen rather than coal.*
- *Promote energy efficiency interventions in the cement sector, and consider to provide subsidies for switching to energy efficiency appliances.*
- *Develop and roll-out dedicated education programs targeting transition in the industries with highest GHG emissions.*

- *Support Vietnamese industries in meeting requirements of international carbon management mechanisms, i.e. the Carbon Border Adjustment Mechanism (CBAM), in a way that supports Viet Nam's long-term green transition.*

20. Prepare for the need of Carbon Capture and Storage (CCS) in selected industry segments

The Net-Zero scenario features investments in CCS to absorb almost 50 Mt of CO_2 in 2050. Therefore, to meet the net-zero target, CCS represents a technology solution in Viet Nam, albeit for use predominantly in the industry starting from 2040 (with an estimated 88% of the CO_2 captured in 2050), and not for application in power plants, where coal power with CCS is a very costly solution.

Recommendations:

- *Preparing local geological storage of CO2 should be starting soon, from 2030.*
- *CCS should be prioritized for industrial purposes, and possibly investigate the feasibility for waste incineration.*
- *All new cement and ammonia production industries from 2030 should be prepared for carbon capture facilities for the processing emissions.*

Recommendations to support a socially just transition and protect the local environment

21. The green energy transition requires skilled labour

To accommodate the increase in renewable energy, Viet Nam should incentivize expand the educational offer in clean energy technologies. Specifically, deployment and operation of renewables, considering the expected capacity of more than 590 GW for solar and wind in 2050 in the Net-Zero scenario brings an opportunity for creating new domestic jobs and requires a well-educated and skilled workforce. Educating and re-skilling the existing workforce in new technologies, such as wind, solar and batteries, as well as on power system flexibility is also an important part of preparing the workforce for the transition.

Recommendations:

- *Improve the education and skills of academics and workforce to meet the needs of the green transition and a sustainable economic growth.*
- *Establish and reinforce existing dedicated curricula on renewable energy and energy markets, including legal, technological, engineering, technical, and economic aspects.*

22. Accounting for air pollution in energy production and use to propose measures for improving public health and accelerating the green transition

Polluted air containing $PM_{2.5}$, SO_2 and NO_x emissions in excess of prescribed levels has been proven to have large negative impacts on human health, in turn with consequences on both economy and environment. Studies show that the largest air polluting sector is transport, followed by power and industry, i.e. sectors in which fossil fuels continue to be utilized even until 2050. Accounting for air pollution is needed to identify sources and levels of pollution thereby promoting mitigation solutions. The large electrification reduces the air pollution level and its negative consequences by more than 50% in 2050 compared to today. However, the decarbonization of the heavy transport sector does not necessarily decrease air pollution as some RE-fuels, e.g. biodiesel and biomethanol still contribute to air pollution.

Recommendation: Expanding the air quality monitoring network, as well as conducting further research and development of a detailed emissions inventory to account for air pollution levels and its impacts for each sector; further, proposing mitigation measures along with an implementation roadmap.

23. Waste-to-energy brings benefits to the society and environment

Waste disposal by landfilling causes serious social and environmental consequences, particularly considering the potential risk of soil and groundwater contamination. To utilise the waste resources and protect the environment, the amount of waste to landfills should be reduced to a minimum level, and at the same time an effective waste management system should be strengthened with priority given to waste collection and classification for recycling and electricity generation.

A modern waste-to-energy incineration plant is a measure to help improve public health, bring positive impacts on local environment, reduce GHG emissions compared to landfilling and effectively utilise resources for sustainable development.

Recommendation: Consider to revise existing legislation to prohibit landfilling of combustible and recyclable waste. Increase collection and classification of waste for recycling and electricity generation.

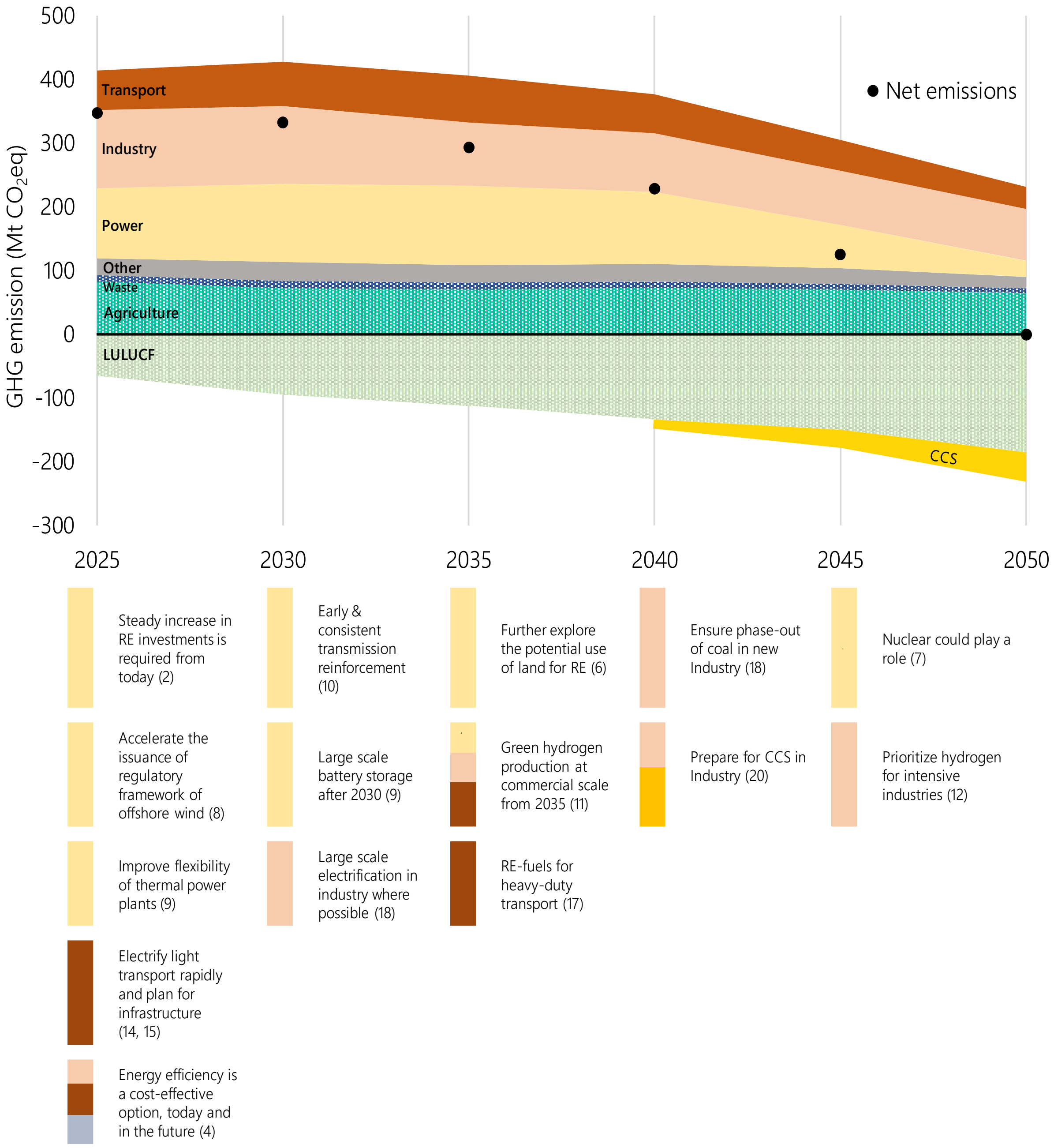

Figure 0.1 Summary of key findings on the timeline towards 2050, compared against the projected GHG emissions for the Net-Zero scenario. The emissions with patterns (Agriculture, LULUCF and Waste) follow the projections set out in the National Climate Change Strategy and are not included in the EOR framework. Only energy-related and process emissions are considered.

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Part A – Introduction and context

1. Introduction

1.1 The climate and energy policy landscape in Viet Nam

Viet Nam has experienced robust economic growth, increasing its GDP per capita by a factor of 3.6 over just two decades, reaching 3,700 USD by 2022[2], and emerging as one of Southeast Asia's fastest-growing economies. This upward trend is expected to continue, driving an increased demand for energy. The industrialization and urbanization processes are contributing factors, with a growing middle class and expanding manufacturing sector leading to higher energy consumption.

Viet Nam is among the world's 5 most vulnerable countries to climate change[3] and, as such, Viet Nam is increasingly and directly affected by the impacts of climate change, including rising sea levels, extreme weather events, and changing precipitation patterns. Initial calculations by the World Bank in 2022 suggest that already today, Viet Nam's economy suffers with losses of about 10 billion USD, corresponding to 3.2% of GDP annually, due to the impacts of climate change. The following dire statement underlines the need for urgent global and national action to reduce greenhouse gas emissions: "*Without proper adaptation and mitigation measures, it is estimated climate change will cost Viet Nam about 12 percent to 14.5 percent of GDP a year by 2050*" (World Bank[4]). Recognizing the vulnerability of its economy and population, the country is actively addressing climate change concerns in its policy landscape, with a focus on sustainable and resilient energy practices.

The architecture of Viet Nam's climate action framework is articulated in the National Climate Change Strategy to 2050 (NCCS), setting the goal of reaching a net-zero society by 2050 (with reference to Decision 896/QD-TTg, as well as Decision 888/QD-TTg on implementation of COP26). Moreover, in December 2022, Viet Nam joined the Just Energy Transition Partnership (JETP). This partnership will provide 15.5 billion USD in support until 2026-2028, from a group of donor countries and the private sector to help Viet Nam reach its net zero commitment by 2050. Key elements of the agreement include the 2030 targets of: peaking of power sector emissions in Viet Nam at 170 Mt CO_2eq, reaching a share of 47% of renewable energy generation and peaking of coal-fired plants capacity at 30.2 GW.

Building on the foundations of the NCCS, Viet Nam has incorporated sustainable transition into the latest Power Development Plan (PDP8) for the period 2021-2030, with a vision to 2050, as stipulated in Decision 500/QD-TTg and approved in May 2023, hereby setting targets for increasing shares of renewable energy for power generation and improving energy efficiency to support the country in achieving its 2050 net zero goals. Notably, no new coal-fired power plant investments are planned after 2030 and a gradual coal fleet reduction will follow after 2035.

Moreover, the National Energy Master Plan (NEMP) (Decision 893/QD-TTg) approved in July 2023 integrates the PDP8 into a broader roadmap for the energy sector, aimed at reaching Viet Nam's development goals while meeting its net zero target by 2050. At the same time, the NEMP plans for reducing reliance on imported energy sources and ensuring the efficient use of domestic resources.

On the sectoral plans, Viet Nam recently adopted a green energy transition roadmap (Decision 876/QD-TTg, 2022), with the overall objective to develop a green transport system, which will fully operate through electricity or green energy by 2050 in alignment with Viet Nam's net-zero target. Moreover, cross-cutting measures for mitigation of GHG emissions and protection of the ozone layer are also addressed in Decree 6/2022/ND-CP.

With a large technical potential for renewable energy, the share of solar and wind power in the electricity generation has grown rapidly in the past few years, from almost no renewable energy capacity in 2018 to 21% of solar and 5% of wind in 2022. This corresponds to over 16 GW of solar PV (including rooftop solar power) and 5 GW of wind power capacity installed. Looking ahead, PDP8 targets shares of 31-39% of renewable power

[2] Overview: Development news, research, data, World Bank: https://www.worldbank.org/en/country/vietnam/overview. Accessed on: 01.02.2024.

[3] According to USAID climate change fact sheet: Vietnam Climate Change Fact Sheet (usaid.gov): https://www.usaid.gov/sites/default/files/2023-07/2022-USAID-Vietnam-Climate-Change-Country-Profile.pdf

[4] Key Highlights: Country Climate and Development Report for Vietnam, https://www.worldbank.org/en/country/vietnam/brief/key-highlights-country-climate-and-development-report-for-vietnam

generation by 2030 (47% in the case of a "full and substantial implementation" of JETP) and 68-72% levels by 2050.

In this context, the objectives of this Viet Nam Energy Outlook Report, Pathways to Net-Zero (EOR-NZ) can be summarized as follows:

- Through quantitative analyses, compare and **evaluate impacts of different pathways** of the energy system on economy, fuel import dependency, GHG (greenhouse gas) emissions and health impacts from air pollution.
- Providing **technology and policy insights** on closing the gap on the net-zero target in the hard-to-decarbonize sectors, i.e. industry and transport.
- Explore **system-wide implications**, as well as sector-specific impacts and opportunities, of fulfilling the announced climate and energy targets.
- Foster a wide consensus and understanding of Viet Nam's energy challenges and opportunities in the mid- to long term, through stakeholder engagement throughout the outlook development process.

1.2 Structure of this report

The report is structured around two main parts:

1. The first introductory part (Part A) describes the scenario framework and assumptions, as well as key characteristics of the modelling methodology for this study.
2. The second central part (Part B) presents system-level results and key messages reflecting on the net-zero target by 2050, followed by sector-specific results encompassing: power system planning and operation, RE-fuel supply and use, transport, industry, and other demand sectors. Impacts of air pollution are also highlighted. Policy recommendations ensuing from the analyses are presented at the end of each relevant chapter.

2. Scenario framework

This report presents two main scenarios which, based on comprehensive energy system modelling, describe and compare a possible baseline development for Viet Nam compared to a sustainable development, with both portraying consistent, plausible and relevant long-term visions of the future energy system of Viet Nam (Figure 2.1). This approach is comparable to previous Energy Outlook Reports, although the EOR-NZ sets itself apart by the recent and firm commitment of Viet Nam's Prime Minister on the net-zero target by 2050, as announced at the COP26 conference in 2021, as well as the inclusion of such target in the National Climate Change Strategy and PDP8.

2.1 Scenarios analyzed

The purpose of the Baseline scenario is to provide a realistic pathway for the energy system development, if no further political action is taken towards reducing the greenhouse emissions to net-zero by 2050. This scenario is optimized towards the lowest possible total system cost while still meeting the high expected growth of energy demand toward 2050. The Baseline scenario, while lacking any climate targets, can still be expected to portray a system that requires a high rate of investments to meet the growing energy demand. The scenario itself can indicate whether and when it is cost-effective to introduce GHG reducing measures and technologies, such as renewables, energy efficiency and electricity storage, even when GHG reductions are not encouraged.

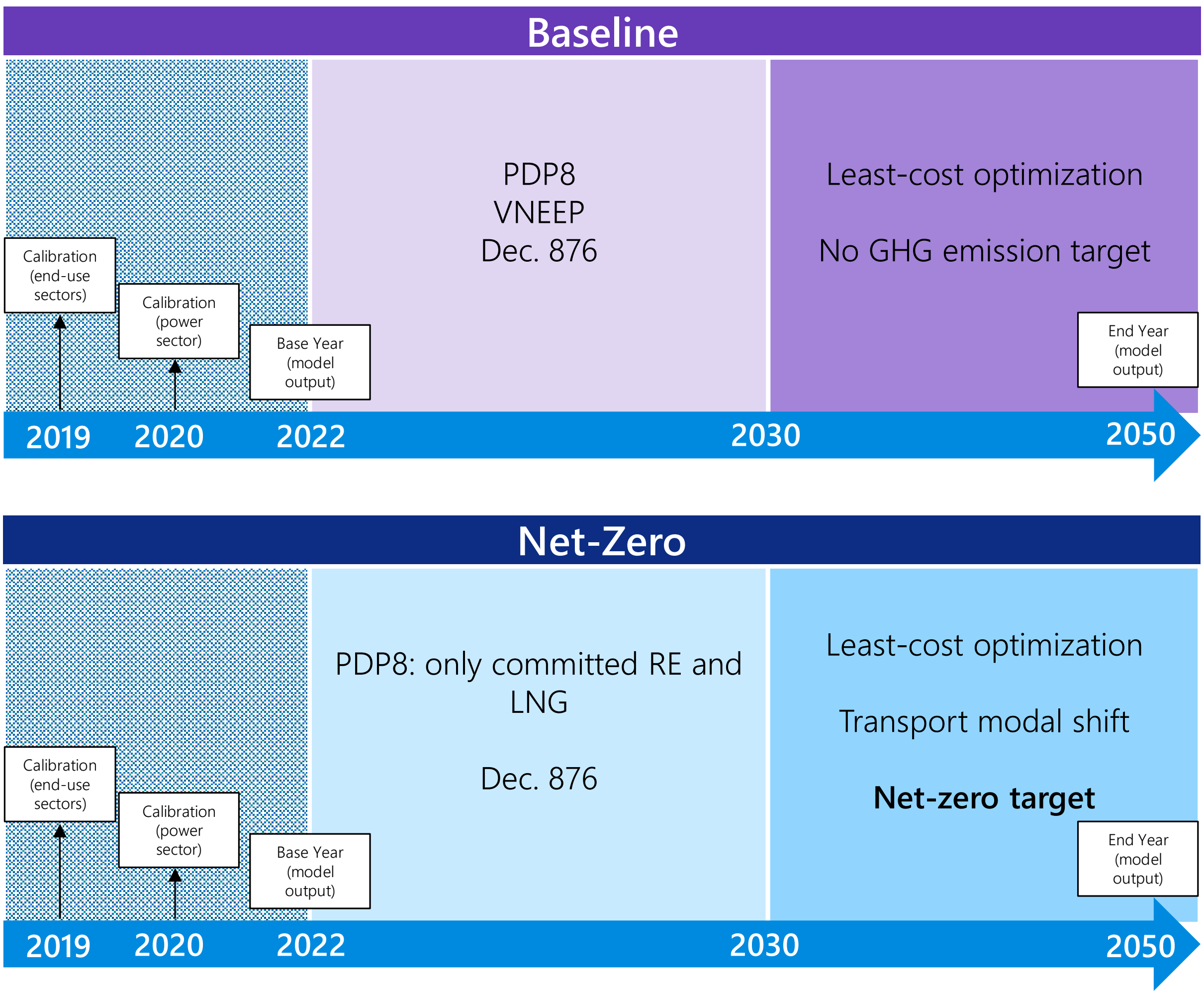


Figure 2.1 Key assumptions along the analysed time horizon for the two core scenarios.

The Net-Zero scenario provides a technically and economically optimized pathway to 2050, where Viet Nam's emissions reduction targets are met. As per the NCCS, this assumes a negative offset of GHG emissions from LULUCF of 185 million tons (Mt) per year by 2050. To reach net-zero emissions, the climate plan targets a maximum emission of 101 Mt per year from the energy sector, 56 Mt from agriculture, 20 Mt from industrial processes, and 8 Mt from waste handling. These upper bounds are adopted for the Net-Zero scenario. In order to assess any potential value of removing existing barriers and uplifting limitations, the inputs for the scenario assume an increased RE potential compared to the Baseline, as well as no limitations on possibly decreasing capacity of existing power plants. The scenario presents a development path that is economically optimized, but may naturally require measures to accommodate for important social issues that are not accounted for in the modelling, such as legal obligations, social issues connected to job transition, education requirements as well as environmental and planning issues.

The modelling set-up seeks to fulfil the constraints and goals set by the scenarios at the lowest possible cost. As such, one of the main parameters for comparing the different results will be any changes in socio-economic costs, including changes in total investments required.

Table 2.1 illustrates the storylines and model implementation of the core scenarios and the main net-zero variations. The differences between the Baseline scenario (BSL) and the Net-Zero scenario (NZ) focus on the following themes:

- Power plant technologies and fuel availability for Viet Nam: specifically, what is the role of the existing and committed gas and coal power plants in the future power system? How can a transition in the mid- and long-term (2030 and 2040) be optimized, and to what extent will alternative fuels such as hydrogen, ammonia and biomass play a role?
- To what extent is CCS in industry and power sector a feasible and cost-effective technology?
- What are technically-optimal utilization of onshore renewable potentials, when considering land availability and planned land uses?
- What are the impacts of different energy development pathways on security of supply, in terms of electricity supply, level of reliance on fuel imports for all sectors and diversification?
- What would be the needed investments for upgrades and reinforcement of the energy infrastructure, both for the power grid and for hydrogen, in the future?

In addition to the two main scenarios (Baseline and Net-Zero), three alternative variations for reaching the long-term goals of 2050 have been developed. These serve the purpose of investigating various fundamental approaches to the development of the Vietnamese society and the impact of this on the energy system and the fulfilment of Viet Nam's emission targets. The following questions have been addressed through the definition and modelling of the three main alternative net-zero scenarios.

1. Net-Zero+ (NZ+): If Viet Nam were to increase ambitions to push the energy sector to zero emissions by 2050, what would be the impact on additional investments required and possible new technologies? What would be the added costs of increasing the ambitions?
2. Green Growth (GG): What impact does the nature of Viet Nam's economic development have on the possibilities and cost of the green transition? Specifically, how will the investments and technology compositions be affected by a more rapid development towards an increase in the service sector economy, in combination with high-value industrial product manufacturing?
3. Green Transport (GT): Assuming a full implementation of Prime Ministers' Decision 876 for the transition of green transport in Viet Nam, how would this impact the development of the other energy sectors? Is such a scenario compatible with a more constrained power sector including restrictions on RE potentials?

Table 2.1 Overview of core scenarios and main net-zero variations.

	Purpose and application	Model implementation
Baseline scenario	This scenario illustrates a **reference development** to portray a hypothetical future, in which only existing policies and short-term plans are included, and no regard is put on avoiding the impacts of climate change for Viet Nam. The development of the energy system follows a pathway where GHG reductions are not prioritized, and the net-zero target by	• Based on the Baseline scenario (BSL) from EOR21, with the needed adjustments to include short-term plans and developments until 2030, considering PDP8, VNEEP and Dec. 876. • Restrictions on minimum operation of coal power plants are enforced. Retirement of plants before end of technical lifetime is not allowed. • Base RE potentials: solar land (excluding roofto floating) at 136 GW[5].

[5] Based on the land area allocated for energy purposes in Resolution 39/2021/QH15 on National Land Use Planning for the period 2021-2030, with a vision to 2050.

	2050 is not met. Comparison with the NZ scenarios can illustrate where transition is particularly needed to reach the net-zero target (e.g. which sectors/technologies/areas).	• The unconditional NDC (revised in 2022) is used to set the emission pathway to 2030, i.e. 15.8% emission reduction in 2030 compared to BAU.
Net-Zero scenario	The Net-Zero scenario illustrates how the net zero target can be achieved in a **cost-optimal way** from a techno- and socio-economic perspective, assuming that policies enabling the transition are timely implemented and that efforts are taking place ensuring that important barriers and inertia for the transition are overcome.	• The net-zero target for 2050 for GHG emissions for all sectors is included, equal to 101 Mt for the energy system, and an additional 20 Mt covering industrial process emissions (non-energy use). • Higher RE potentials: solar land (excluding rooftop and floating) at 272 GW[6]. • Coal power plants are allowed to be decommissioned before natural retirement. • Flexible power plant operation is allowed from 2030 (contractual requirements of minimum fuel use only enforced until this time). • Significant transport infrastructure development supporting modal shifts from private to public transport (both freight and passenger), as well as higher levels of electrification (especially for rail).
Net-Zero+ variation	This variation of the Net-Zero scenario is developed to enable further evaluation of the robustness of the Net-Zero scenario results, illustrating what a development path towards a **more ambitious 2050 target** will look like. The purpose is to investigate which technologies are applied, and in which sectors would be most cost-efficient to further reduce emissions, if, for example, the ambition of reaching 185 Mt of negative emissions from LULUCF by 2050 cannot be fully achieved.	The variation is identical to the Net-Zero scenario, except for increased emission ambitions for 2050. The emissions allowed for Viet Nam's energy sector alone in 2050 is reduced from 101 Mt, as per the National Climate Change Strategy (NCCS), to 0 Mt. This will correspond to reducing the total emissions for Viet Nam from 185 Mt to 84 Mt in 2050, with the residual emissions coming from agriculture, process emissions and waste handling, as per the NCCS.
Green Growth variation	This variation of the Net-Zero scenario investigates the impact of a different **economic development towards a less energy-intensive economic growth** on the energy system transition. The purpose is to gain an understanding of the impact of larger macro-economic decisions on possible energy system savings and emissions reduction. This variation only includes the energy system effects of the changed economic assumptions, and thus does not reflect on the potentially larger macro-economic effects, such as employment effects, educational requirements and import/export balance.	The Green Growth variation is applied to the economic structure of Viet Nam, while maintaining the same annual GPD growth rate. While the BSL and NZ scenarios assume a relatively slow development from Viet Nam's manufacturing industry to the service sector, this shift is significantly accelerated in this variation. Furthermore, within the manufacturing industry sector, a higher share of the economic growth is driven by high-value products such as electronics, and vehicles, at the expense of reduced growth in energy-intensive industry sectors (e.g. metal processing, textiles and plastics production). The overall contribution to GDP follows this structure in 2050: • Industry: 30% • Service: 60% • Agriculture: 10%

[6] Assuming increased land area available for energy purposes.

Green Transport variation	This variation of the Net-Zero scenario explores more ambitious goals for the transport sector, thereby analyzing the system-wide implication of **a full decarbonization of the transport sector by 2050**, while maintaining the overall net-zero goal for the energy system in 2050.	The Green Transport variation is built upon the Net-Zero scenario with the following variations: • Limit on transport-related GHG emission set at 1 Mt in 2050 based on full implementation of Dec. 876. • Base RE potentials: solar land (excluding rooftop and floating) at 136 GW.

2.2 Sensitivity analyses

A number of sensitivities (Table 2.2) are also performed in order to investigate the impact of certain developments, such as changes in global fuel prices and alternative cost developments for generation and storage technologies.

Table 2.2 Sensitivity analyses performed, on either energy system level (TIMES), power system (Balmorel) or both.

Sensitivity analysis	Focus and model implementation	Energy system	Power system
NZ - Lower discount rate	Discount rate: 6.3% (instead of 10%)	✓	✓
NZ - High GDP	Annual GDP growth rate from 2030 to 2050: 7.5% (instead of 6.5%)	✓	✓
NZ - High Battery cost	Higher BESS CAPEX based on Technology Catalogue (TC) upper limit (EREA & DEA 2023a)		✓
NZ - Low Battery cost	Lower BESS CAPEX based on TC lower limit		✓
NZ - High Solar cost	Higher PV CAPEX based on TC upper limit		✓
NZ – +50% LNG price	+50% increase in LNG price compared to NZ, from 2030		✓
NZ – +100% LNG price	+100% increase in LNG price compared to NZ, from 2030		✓
BSL - High fuel price	+25% increase in fuel prices (excl. nuclear) compared to BSL, from 2025	✓	✓
BSL - Low fuel price	-25% decrease in fuel prices (excl. nuclear) compared to BSL, from 2025	✓	✓
NZ - Reserves	Explicit modelling of operating and strategic power system reserves		✓
NZ – Limited thermal flexibility	Minimum fuel use for gas-fired plants until 2030		✓
BSL - Improved energy efficiency	Improved energy efficiency levels in residential and service sectors	✓	✓

Most sensitivity analyses consist in varying a single parameter to analyze the impacts on the energy and/or power system in terms of changes to the technology and fuel mix, as well as changes on the system costs. For example, a focused sensitivity analysis on power system reserves includes explicit modelling of strategic and operating reserves, in order to assess which technologies are best suited for meeting the reserve demand, and assess the additional costs of these.

Another example is the sensitivity of improved energy efficiency. This is developed to assess the potential impact of the adoption of more energy efficient technologies and appliances in the residential and service sectors, assuming that the targets set in the Viet Nam National Program on Energy Efficiency and Conservation (VNEEP) for 2030 are raised towards 2050.

2.3 Modelling framework and key assumptions

The aim of this section is to provide a general understanding of the model set-up, the system boundaries for the scenario analyses undertaken and key assumptions across scenarios.

The reported analyses are based on a least-cost socio-economic optimization of investments and operation of energy technologies with no direct accounting of taxes and subsidies, covering all sectors of the Vietnamese energy system (supply, transformation, demand) with a time horizon until 2050. More specifically, the modelled energy system covers the following sectors:

- **Upstream**: domestic resources, extraction infrastructure, fuel imports, refineries, existing and future energy transformations;
- **Power**: generation, transmission and storage.
- End-use sectors:
  - **Transport**: passenger and freight, excluding international aviation and shipping;
  - **Industry**: representing 14 different sub-sectors;
  - **Other demand sectors**: residential (rural and urban), agriculture and service.

The modelling framework comprises two main models, which are interlinked to complement their system coverage, time and geographical resolution:

- The **TIMES model** covers optimization of all sectors of the energy system under the assumption of perfect foresight, representing Viet Nam as a single region with 48 time-slices, and featuring high level of technological detail, thus making it well-suited for analysing resource and emission allocations across different sectors.
- The **Balmorel model** analyses the power system at higher level of temporal and geographical resolution: 624 time-slices are designed to capture seasonal, weekly, and daily variations in power supply and demand, as well as transmission and storage; moreover, the power system is divided into seven regions dynamically linked by transmission lines.

Additionally, a detailed model of the Vietnamese power grid (PSS/E) has been used to test grid-related results from the Balmorel power system analyses for the years 2025 and 2030, in order to identify potential voltage or transmission capacity violations at certain nodes. For more details, please refer to the report "Grid modelling of Net-Zero scenario" (Institute of Energy 2024).

For all scenarios, a GDP growth of 7% per year is assumed in the period 2021-2030, and GDP growth of 6.5% per year from 2030 to 2050. Moreover, a global interest rate of 10% is applied.

For more details on the modelling framework, input data (e.g. end-use demand and fuel prices) and other assumptions on the scenario analyses, the reader is referred to the EOR Technical Report (EREA & DEA 2024), and the Technology Catalogues for techno-economic parameters for power generation technologies (EREA & DEA 2023a)[7], storage technologies and renewable fuels (EREA & DEA 2023b)[8].

[7] Accessible at: ens.dk/sites/ens.dk/files/Globalcooperation/viet_nam_technology_catalogue_2023_-_power_generation_eng.pdf

[8] Accessible at: ens.dk/sites/ens.dk/files/Globalcooperation/viet_nam_technology_catalogue_2023_-_energy_storage_renewable_fuels_power-to-x_eng.pdf

Part B – Scenario results

3. Net-zero pathways to 2050

3.1 Overview and trends

This chapter presents the most relevant scenario results for Viet Nam's green transition towards 2050, with focus on emission reduction pathways and the transformation of the energy mix for both power and end-use sectors. The role of hydrogen and other RE-based fuels is also highlighted across the analysed scenarios.

As presented in Chapter 1, there are multiple government plans recently issued and under preparation, focusing on the transition of the energy system towards the net-zero goal in 2050. To set the context for the following analyses and findings presented in this chapter, the overview in Table 3.1 compiles the key energy strategies in Viet Nam and the corresponding targets of relevance for this study.

The reader should note that not all the listed strategies and plans are included in the analysed scenarios and should refer to Chapter 2 for an overview of the included plans and targets featuring in this study.

Table 3.1 Overview (non-exhaustive) of selected key energy and climate strategies and plans, with corresponding areas of focus and key targets set.

Reference	Focus area	Key targets
Orientation for National Energy Development Strategy, Resolution 55-NQ/TW (2020)	Orientation for development strategy of Viet Nam energy system until 2030, with a vision to 2045.	RE share in TPES: 15-20% by 2030; 25-30% by 2045. Emission reduction targets, energy-wide: 15% by 2030, 20% by 2045.
National Climate Change Strategy (2022)	Strategy for adaptation to climate change and reduction of GHG emissions, setting the goal of reaching net zero by 2050 through energy efficiency and clean energy technologies.	Emission targets, energy-wide: 457 Mt CO_2eq (2030) and 101 Mt CO_2eq (2050, including 20.8 Mt CO_2eq from transport); industrial processes: 89 Mt CO_2eq (2030) and 20 Mt CO_2eq (2050); agriculture: 64 Mt CO_2eq (2030) and 56 Mt CO_2eq (2050); waste: 18.2 Mt CO_2eq (2030) and 7.8 Mt CO_2eq (2050); LULUCF: -95 Mt CO_2eq (2030) and -185 Mt CO_2eq (2050). RE share in power generation: at least 33% in 2030 and 55% in 2050.
Nationally Determined Contribution (2022)	GHG emission reduction targets for whole of Viet Nam, as part of the Paris Agreement commitment.	Emission reduction targets, society-wide: unconditional 15.8% reduction (146.3 Mt CO_2eq), and conditional 43.5% reduction (403.7 Mt CO_2eq) in 2030 compared to BAU.
National Power Development Plan for the period 2021-2030, vision to 2050 (2023)	Sectoral plan for the power sector until 2030, with a vision to 2050	Emission level, power sector: 204-254 Mt CO_2eq (2030) and down to 170 Mt CO_2eq, if JETP commitments are implemented; 27-31 Mt CO_2eq (2050). Installed capacity, power sector: 150 GW (2030) and 490-573 GW (2050). RE share in power generation: 31-39% in 2030 (up to 47% if JETP commitments are implemented) and 67.5-71.5% in 2050.
National Energy Master Plan for the period 2021-2030, with vision to 2050 (2024)	Energy-wide plan for development on fuel mix until 2050, covering targets for coal, gas, and oil production, as well as production of alternative fuels and hydrogen, and CCUS.	Energy demand: 107 million t.o.e. (2030) and 165-184 million t.o.e. (2050). Emission targets, energy-wide: 399-449 Mt CO_2eq by 2030, and 101 Mt CO_2eq by 2050.
Hydrogen Strategy (2024)	Strategy for development of Viet Nam's hydrogen economy based on renewable energy, including production, storage,	Hydrogen production targets: 100,000-500,000 t/year by 2030, and 10-20 Mt/year by 2050

	transportation, distribution, for both domestic use and export.	
Green Transport Strategy (2022)	Strategy for the development of a green transportation system towards the goal of net-zero GHG emissions by 2050.	Increase share of electricity and green energy across transport modes, with targets starting from 2025.
Just Energy Transition Partnership (2022)	International support to Viet Nam to deliver on its net-zero 2050 goal and 2030 targets, and accelerate and reduce the peaking of its GHG emissions and transition away from fossil fuels to clean energy.	Emissions, power sector: 170 Mt CO_2eq (2030) RE share in power generation: 47% (2030) Coal capacity: 30.2 GW (2030)
Viet Nam Energy Efficiency Program (2019)	National master plan on energy efficiency, saving, and conservation of energy resources.	Energy savings, energy-wide: 8% to 10% of total national energy consumption in 2030 (compared to 2019); industry: 5-25% in 2030, depending on sub-sector; transport: 5% of fuel consumption in 2030.

3.2 Key results

In light of Viet Nam's net-zero target by 2050, as well as the different sectoral targets for both the short and long term (Table 3.1), alternative pathways for the development of the energy system have been explored (Figure 3.1). GHG emissions from the energy system (excluding LULUCF, agriculture and waste sectors) peak in 2030 across all scenarios, albeit within a large range, with 338 Mt CO_2eq for the Green Growth and 406 Mt CO_2eq for both the Baseline and the Green Transport scenarios in 2030.

Moreover, even with no explicit emission reduction targets for the long term (Baseline scenario), GHG emissions reach 239 Mt in 2050, well below today's levels, with emissions for the energy system standing just above the 300 Mt mark in 2020. This overall finding indicates that a green transition of the energy system is cost-effective and technically feasible for Viet Nam, even without considering climate targets (Baseline scenario). Since all scenarios show cost-optimal emission trajectories consistently projecting a peak by 2030, this highlights the urgent need to change the course towards a sustainable development trajectory within this decade.

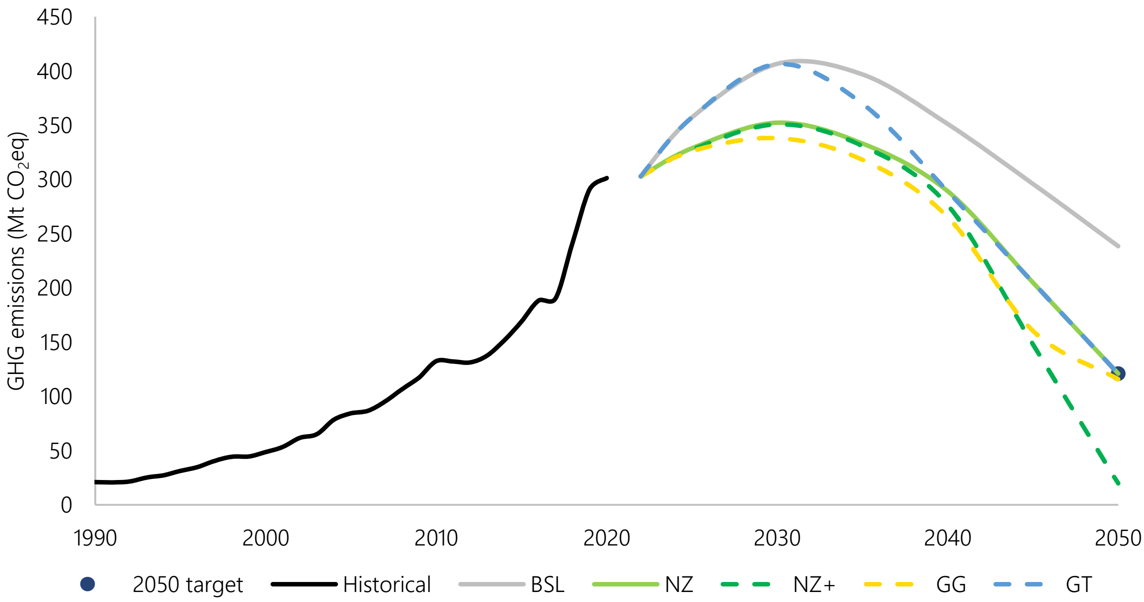


Figure 3.1 GHG emission trajectories (2022-2050) for the key scenarios analysed (energy-wide), as compared to net-zero target in 2050 for Viet Nam. Historical emissions (1990-2020) (IEA 2024b).

Looking towards 2050, the emission limit at 101 Mt CO_2eq for the energy system and 20 Mt CO_2eq for industrial process-related emissions can be reached through different sectoral developments (Figure 3.2). Green transition in the power sector will be fundamental in reaching the overall energy system targets, as decarbonization of the power sector is a pre-condition to the green electrification of other sectors. GHG emissions from the power sector peak at 173 Mt CO_2eq in 2030 in the Baseline scenario, thus within reasonable range compared to the agreed targets for the power sector set within JETP (i.e. 170 Mt CO_2eq for the year 2030). For comparison, power sector emissions peak in 2035 at 124 Mt CO_2eq in the Net-Zero scenario, through more accelerated development of renewable energy.

Starting from 2040, deeper emission cuts will be required in the power sector to reach the net-zero goal, mainly through phasing out of coal-fired generation and a significant reduction in gas-fired thermal plants.

Electrification of the end-use sectors, especially high-emitting transport and industry, will be key in the decarbonization of end-use demands towards 2050. Despite the electrification trend, residual emissions will be present across all scenarios in 2050, mainly from those industrial sub-sectors and transport segments that cannot be fully electrified and for which renewable fuel alternatives remain expensive.

Reaching the net-zero emission target for the energy system alone by 2050 (NZ+ scenario) is also technically feasible. However, the residual emissions mainly from the heavy industry will need to be compensated through Carbon Capture and Storage (CCS) starting from 2035 (with 30-46 Mt of captured CO_2eq in 2050 across net-zero scenarios) and Direct Air Capture (DAC) in the NZ+ scenario, with 10 Mt of captured CO_2eq in 2050.

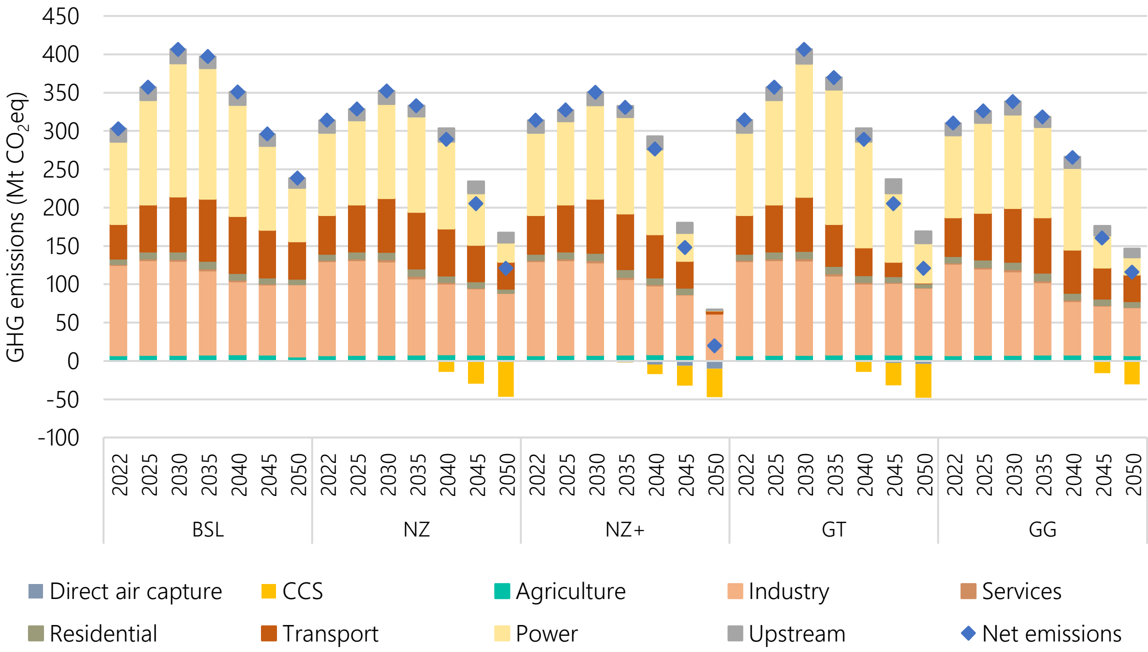


Figure 3.2 GHG emissions by sector and net emissions from the energy system. LULUCF, agriculture and waste emissions are not included. Only emissions related to fuel combustion in agriculture sector are included.

Emission reductions can also be achieved through different economic developments in the industrial sector. Industry-related emissions, excluding process emissions, are reduced to 63 Mt CO_2eq in 2050 in the Green Growth scenario, down from the 81 Mt CO_2eq projected in the Net-Zero scenario, under the assumption that Viet Nam will rapidly develop towards a service-based and less energy-intensive economy starting from 2030.

Cumulative GHG emissions for the whole period from 2022 to 2050, as a global metric to assess climate ambitions across scenarios beyond year-based targets, are consequently 21% and 6% lower in the GG scenario, compared to BSL and NZ scenarios, respectively (Figure 3.3). The scenario with the most ambitious climate target at 0 Mt CO_2eq in 2050 from the energy system (NZ+ scenario), reduces cumulative emissions by 6% (476 Mt CO_2eq) compared to the NZ scenario. On the other hand, when introducing advanced green transport policies not in sync with the pace of decarbonization of the power system and other sectors (GT scenario), cumulative emissions increase by 7% (600 Mt CO_2eq) compared to the NZ scenario.

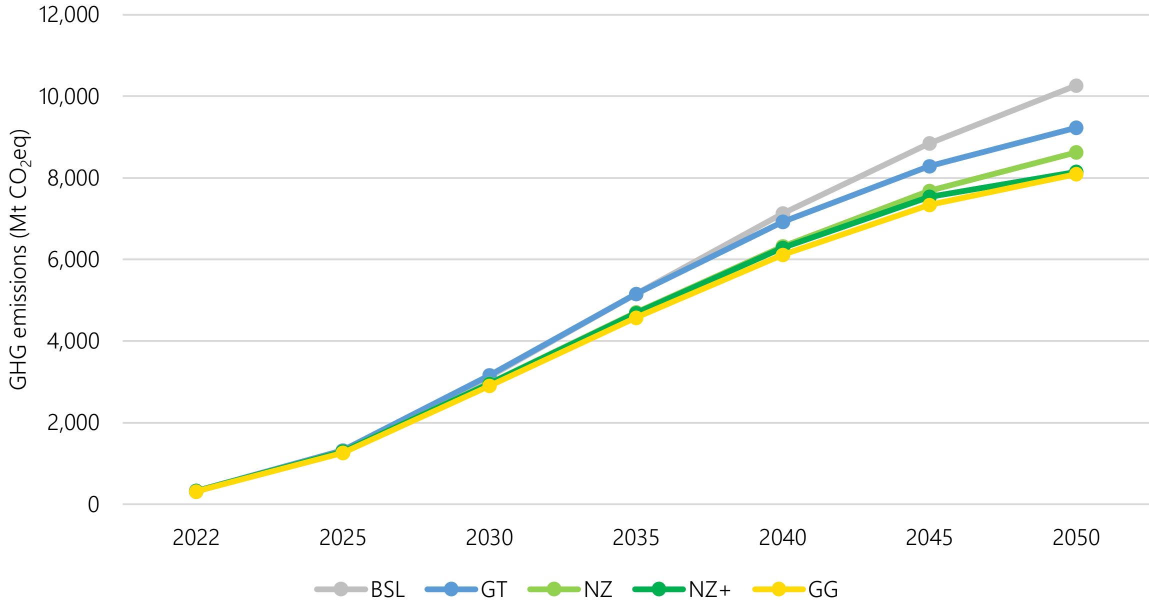


Figure 3.3 Cumulative GHG emissions (2022-2050) from the energy system for key scenarios.

The transition of the energy system towards 2050 will entail significant changes in the fuel supply mix (Figure 3.4), with an increasingly larger role for renewable energy, especially solar and wind, and consequently lower reliance on imports of fossil fuels. The Total Primary Energy Supply (TPES) almost doubles from currently 3.9 EJ in 2022 to 7.4-8.1 EJ in 2050, with the exception of the GG scenario where the projected large role for low energy-intensive industries will reduce the growth of TPES reaching 6.1 EJ in 2050.

Across all scenarios, the phasing out of coal and the increasing role for domestic resources in the energy mix, especially renewables and wind in particular, reduces the overall dependence on imports. In 2022, imports of coal and oil (crude and refined) represented 40% of the TPES. However, while LNG and oil (products) will still be imported, the share of imports on TPES reduces to 17% and 10% in 2050 for the Baseline and Net-Zero scenarios, respectively, and down to 1% in the NZ+ scenario.

Wind and solar energy combined constitute 50% to 54% of the TPES in 2050 across net-zero scenarios, while in the Baseline case the figure corresponds to a still high contribution (40%), up from the current limited share (4%) in 2022. The increase in renewable energy across scenarios illustrates that Viet Nam's future growth in energy demand should ideally be covered primarily by solar and wind, regardless of GHG emission targets. To meet the net-zero target in 2050, the growth in renewables would facilitate an accelerated phase-out of coal, oil and gas (in this order).

With a full decarbonisation of the energy system (NZ+ scenario), even more RE will be required, pushing wind and solar to a combined supply of over 4,420 PJ in 2050. This corresponds to 1,228 TWh of electricity generation. Nuclear energy might enter the supply mix in the long-term to reach the net-zero target, and more prominently under a more ambitious emission reduction scenario (NZ+).

Biomass resources are also central in enabling the achievement of the net-zero goal, with the assumed total biomass potential of 1,719 PJ being almost fully utilized across scenarios in 2050. The main biomass resources in Viet Nam are rice husk, bagasse, wood waste, animal waste, and the organic fraction of municipal solid waste. The total biomass potential has been derived from the "Viet Nam Green Energy Handbook" (MOIT, VEA, VESC 2021), with the application of assumed collection rates for each type of biomass. Biomass is used for production of RE-fuels needed in the transport sector (mainly biomethanol, synthetic natural gas and biodiesel), as well as in the industry sector.

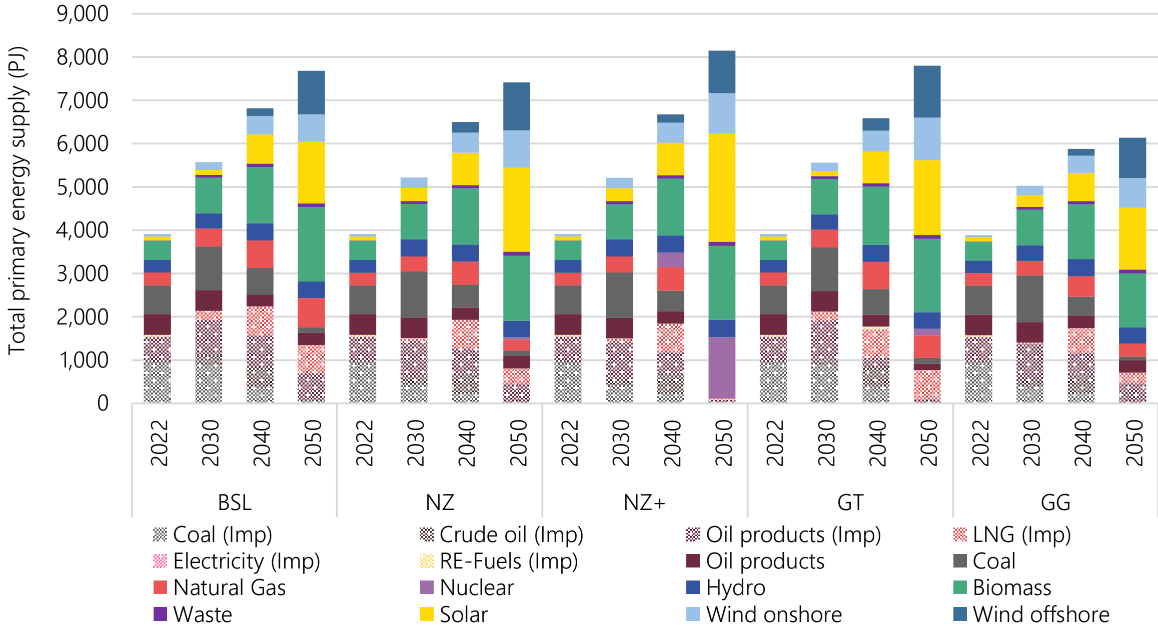


Figure 3.4 Total primary energy supply (TPES) across key scenarios. Imports are reported with shaded bars.

The fuel mix in the Final Energy Consumption (FEC) presents a similar picture, with a significantly reduced role of oil and gas, and an almost phase-out of coal in the energy system by 2050 in the NZ scenario (Figure 3.5), with residual coal used in industry sub-sectors in 2050. This will be in favour of a higher share of electrification, reaching 61% and 69% in 2050 in the NZ and NZ+ scenarios, respectively. Around 60% of the electricity will be consumed by the industrial sector in 2050 across scenarios, with 705 TWh in the Net-Zero scenario (and 809 TWh in the NZ+) in 2050, up from the current 136 TWh in 2022. The distribution of the remaining electricity demand in 2050 differs depending on the scenario: in the Net-Zero scenario, 16.5% will be consumed in the transport sector through full electrification of the private modes (cars and motorbikes), followed by residential with 14.5%, services at 5.5% and agriculture sectors.

Reaching the net-zero goal in 2050 will also require hydrogen and other renewable fuels in the future energy mix (Figure 3.5 and Figure 3.6), with the need drastically increasing from 2040. Hydrogen will be needed for decarbonization of industry and transport as direct use across net-zero scenarios, with a total of 334 PJ and 573 PJ of hydrogen produced in 2050 in the NZ and NZ+ scenarios, respectively. Moreover, under the most stringent emission limits, hydrogen will also be used for production of renewable fuels, with 97 PJ of hydrogen used in 2050 in the NZ+ scenario for ammonia production and 63 PJ in 2050 in the GT scenario for production of RE-jet fuel and RE-LPG. Renewable fuels will be required to decarbonize the heavy-duty transport segments and will play a significant role particularly under ambitious climate targets (NZ+ scenario) and green transport policies (GT scenario), with projected production of RE-fuels (excl. hydrogen) respectively at 817 PJ and 833 PJ in the GT and NZ+ scenarios in 2050.

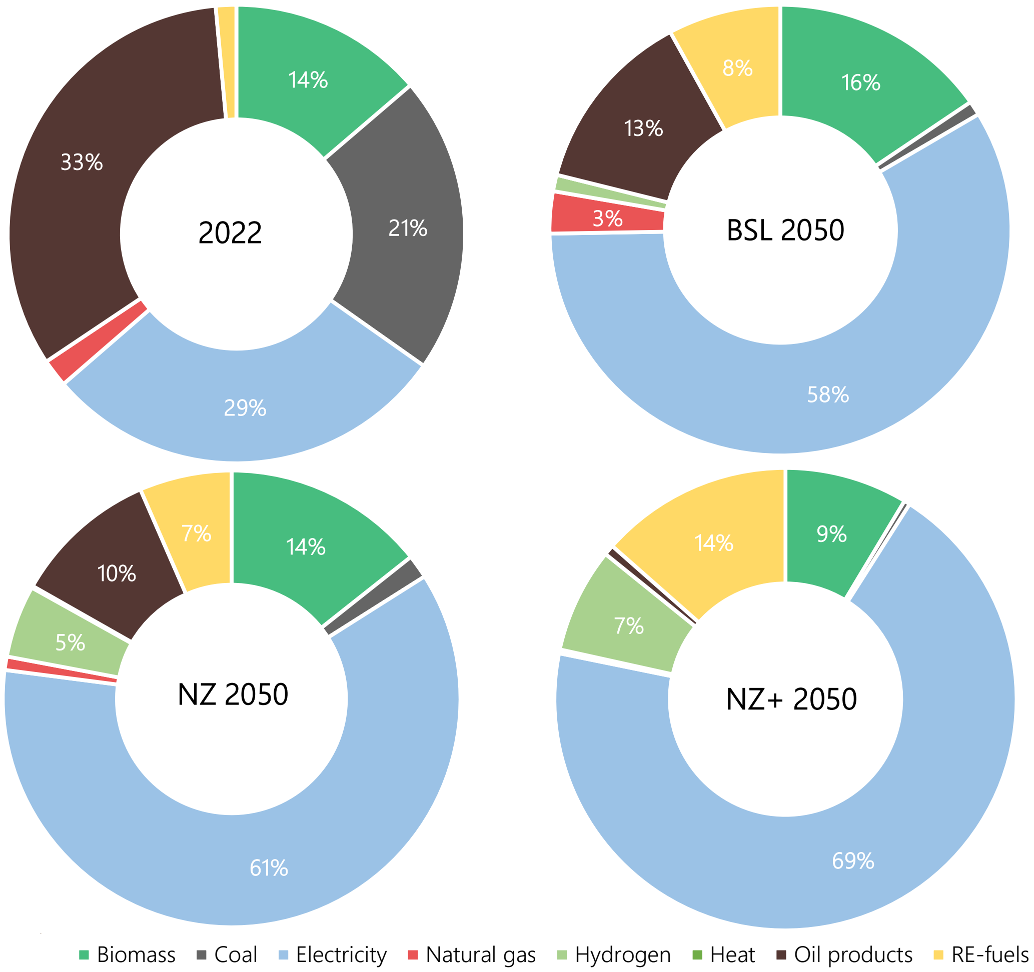


Figure 3.5 Final energy consumption by fuel, as comparison between current system and future system (2050) across key scenarios.

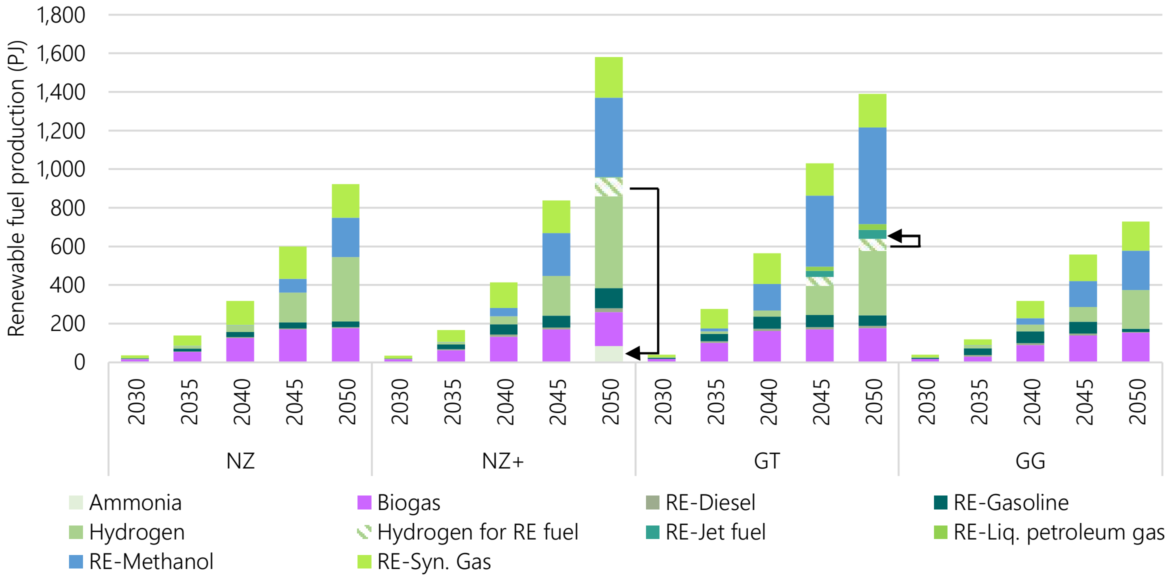


Figure 3.6 Production of renewable fuels by scenario. The share of hydrogen used for RE-fuel production is reported in the shaded bar, with the arrows indicating the corresponding hydrogen use in the production of other RE-fuels.

The reported future development of the energy system drives an increase in annual system costs over time across all analysed scenarios, in line with the need to supply an increasing energy demand (Figure 3.7). The reported costs cover the whole energy system, and are undiscounted for each modelled year.

Capital expenditures (CAPEX) increase over time across all scenarios, making up for 68%-77% of the total system costs in 2050, as an effect of the growing vehicle stock in the transport sector and the increasing need for investments in the power sector. Fuel costs are reduced by 33% in 2050 in the Net-Zero scenario compared to the Baseline, at the expense of an increase in CAPEX and Operation and Maintenance (O&M) costs. Air pollution costs represent the costs associated to the impact of air pollution emissions (NO_X, SO_2 and $PM_{2.5}$) on human health. Total annual air pollution costs are increasing over time across scenarios, despite the decrease in air pollution emissions following the GHG emission trajectory, due to the assumed relative increase in health costs based on GDP growth. A net-zero trajectory can reduce air pollution costs in 2050 by 18% compared to the Baseline scenario, and even further to 34% with a more ambitious GHG emission target (NZ+ scenario).

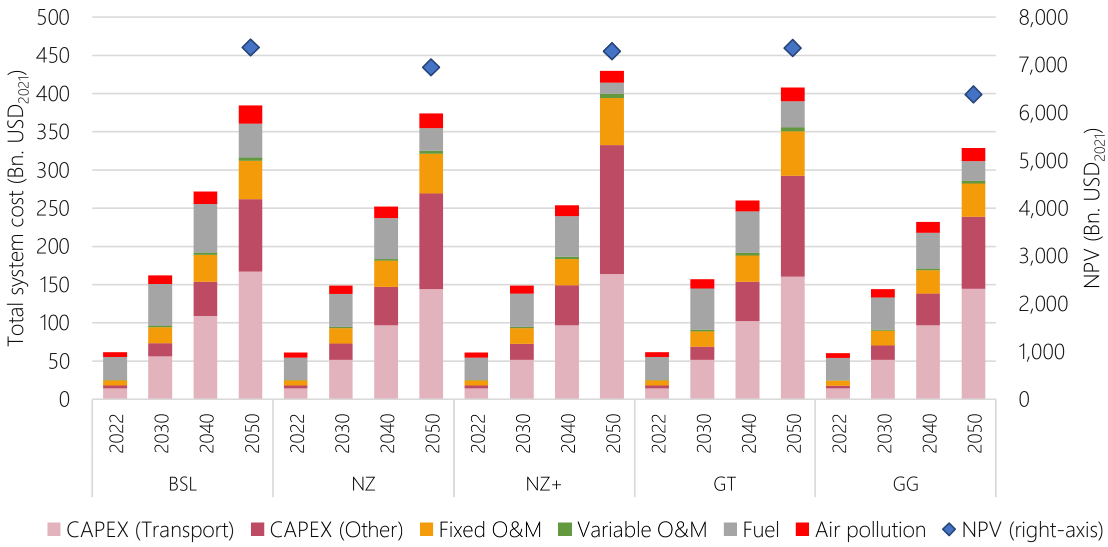


Figure 3.7 Total energy system costs by year (undiscounted annual costs) and net-present value for the period 2022-2050 for key scenarios.

To take account of the different value of money at present and in the future, future costs are discounted back to today, using an annual socio-economic discount rate of 10%. The sum of annual discounted costs of a given scenario represents the Net-Present Value (NPV), or the total energy system cost for the considered period, as reported in Figure 3.7.

The Green Growth scenario reduces total system costs by 13% compared to the Baseline scenario, mainly due to the savings in the total energy demand, thus reducing investments needs. It is worth noting that the analyses do not account for the costs, as well as potential benefits, that the transition to a greener economy would entail, including incentive measures and other mechanisms to support the transition of the industry, as well as programs for re-skilling of workforce, among others.

The Net-Zero scenario also presents a relatively lower (5%) total system cost compared to the Baseline scenario, with the main reason being the reduced energy demand for both passenger and freight transport, following from the assumed shift towards increase use of railways. Annual system costs in 2050 are highest for the Net-Zero+ scenario, due to the needed more expensive technological solutions to achieve the more ambitious emission target. However, from a total system cost perspective (as in the NPV), costs are similar for BSL and NZ+ scenarios, due to two opposing trends: lower energy demand for transport achieved through modal shift in the NZ+ scenario, coupled with higher investment needs in NZ+ compared to BSL, especially in the power sector and new transport technologies based on RE-fuels, to reach the 0 Mt target in 2050. Once again, the cost comparison bears the limitation that system cost accounting does not comprehensively include the needed fuel infrastructure (with only aggregated representation of the fuel transportation costs and storage), as well as transport infrastructure upgrades (e.g. new roads or railways).

3.3 Key messages and recommendations

The green energy transition is cost-efficient for Viet Nam

Based on the analysis of cost-optimal pathways for the future development of the energy system of Viet Nam, the green transition is not only technically feasible, it is also economically viable. Even with no explicit GHG emissions reduction targets (Baseline scenario), total emissions peak in 2030 and decrease afterwards. Moreover, the projected annual GHG emissions in 2050 will be 21% lower than the emissions recorded in 2022.

To reach the net-zero target announced at COP26, Viet Nam needs to continue examining and implementing measures to significantly reduce emissions, especially in the power sector, already within this decade (Net-Zero scenario). Further emission reductions by 2050 are feasible (Net-Zero+ scenario) and are recommended to offset insufficient realization of the more uncertain emission reductions projected for the agriculture and LULUCF sectors, as outlined in the National Climate Change Strategy.

Recommendation: Incentivize CO_2 reductions through the planned market-based mechanisms.

- *The CO_2 quota scheme (Emission Trading Scheme) should be aligned with ambitious targets already in 2030 and 2035 for the power and industry sectors, as it is an important economic instrument towards realizing short-term reductions.*
- *Consider strengthening the current ambitions to target peak emissions of the whole energy system before 2035, and in line with JETP targets for the power sector by 2030[9]. Moreover, consider to further increase ambitions for emission reductions in the energy sector in 2050, beyond the overall net-zero target for the whole society.*

A steady increase in renewable energy investments is required from today

The Power Development Plan for the period 2021-2030, vision to 2050 (PDP8) is particularly ambitious in the long-term development, with significant focus on renewable energy expansions after 2030. However, to reach Viet Nam's net-zero target in 2050 in a cost-effective way, Viet Nam should increase efforts to secure investments in renewable energy (RE) before 2030, with the growth in electricity demand to be covered mainly by RE from 2025.

Results from the Net-Zero scenario illustrate that, between now and 2030 Viet Nam needs to install 56 GW of renewable capacity (17 GW onshore wind and 39 GW solar) to be cost-effective in the long term. This is because the alternative to RE investments before 2030 are significant investments in thermal capacity that will only be operational for 10-15 years, before having to be phased out or operated at low loads to comply with the committed emission reduction targets.

Recommendation: Set ambitious short-term targets for RE deployment, and reduce risks and delays in approving renewable energy projects. The following steps can be taken to reduce the risk for investors and, thus, lower the capital cost of renewables:

- *Support early and selective prioritization of investments in renewable energy with focus on improved regulatory framework including tender mechanisms, direct power purchase agreement (DPPA), and PPA terms.*
- *Analyse and propose suitable support mechanisms when curtailing renewable-based generation.*

Transforming Viet Nam's economic structure towards a lower share of energy-intensive industries will help achieve green growth and be more cost-effective

In the Green Growth scenario, Viet Nam could achieve a more sustainable and cost-effective green growth by restructuring the economy and prioritizing service sector growth, reducing energy-intensive industries and increasing manufacturing sectors with high value-added and less energy-intensive products. This development helps reduce total energy demand, thereby saving investments in the energy system, while still achieving economic growth and fulfilling climate goals.

Recommendations:

- *Consider amending the structure of Viet Nam's economic growth to guide the economy towards a higher economic growth from the service sector and less energy-intensive industries.*

[9] Peak of emissions of no more than 170 Mt CO_2eq from electricity generation by 2030.

- *Set sub-sectoral targets for the economic growth in manufacturing industries to prioritize the production of high-value products such as automobiles, electronics, batteries, photovoltaics, chips and semi-conductors, among others.*
- *Support the restructuring of the labour force by formulating a long-term training strategy and retrain skills of workforce by implementing programs for re-qualification of skills towards manufacturing of high-value products.*

Energy efficiency is a cost-effective option to reach the net-zero target

Between 2020 and 2050, the average industrial demand for energy will grow by a factor 4-7 depending on the scenario, with lower growth in energy demand achieved in the Green Growth scenario. For the residential and services sectors, the energy demand will grow by 150% in 2050, thus contributing to around 18%-24% of the total electricity demand. All existing processes will be replaced by new and more efficient processes and technologies by 2040 at the latest. Energy efficiency is therefore cost-efficient across industrial, residential and services sectors. However, investments to reach the full energy efficiency potential would require targeted incentives and solutions to improve policy compliance.

Recommendations:

- *Incentivize investments in more efficient processes in all sectors. Particularly, in the heavy industry like cement and steel sectors, investments in the most efficient processes are needed to reach the net-zero target.*
- *Analyse and quantify the non-financial barriers to investments in energy efficiency for industry, services and residential sectors to recommend appropriate policies.*

Integration of renewable energy in the power sector is a key pre-condition for the green electrification of the transport sector

According to the Green Transport Strategy (Dec. 876/QD-TTg, 2022), more RE is required to provide adequate green electricity for the transition of the transport sector already in the short term, thus increasing the electric vehicle fleet. However, if the power sector is not targeted by a similar ambitious and short-term focused plan on RE expansion and integration, then cross-sectoral synergies are not unlocked. This is seen in the Green Transport scenario, where a slower green development of the power sector combined with a rapid transition to e-fuels and other green fuels leads to a higher cost of reaching the net-zero goal in 2050.

Recommendation: Ensure coordinated pace of transition of power and transport sectors, by supporting the ambitious transport targets with similar ambitious targets for RE integration in the power sector.

The green energy transition requires skilled labour

To accommodate the increase in renewable energy, Viet Nam should incentivize expand the educational offer in clean energy technologies. Specifically, deployment and operation of renewables, considering the expected capacity of more than 590 GW for solar and wind in 2050 in the Net-Zero scenario brings an opportunity for creating new domestic jobs and requires a well-educated and skilled workforce. Educating and re-skilling the existing workforce in new technologies, such as wind, solar and batteries, as well as on power system flexibility is also an important part of preparing the workforce for the transition.

Recommendations:

- *Improve the education and skills of academics and workforce to meet the needs of the green transition and a sustainable economic growth.*
- *Establish and reinforce existing dedicated curricula on renewable energy and energy markets, including legal, technological, engineering, technical, and economic aspects.*

4. Power sector

4.1 Overview and trends

Over the last decade, the Vietnamese power sector has grown and evolved remarkably, driven by the country's economic expansion and a substantial increase in electricity demand. During this period, the power system primarily relied on coal, gas, and hydropower plants (Figure 4.1).

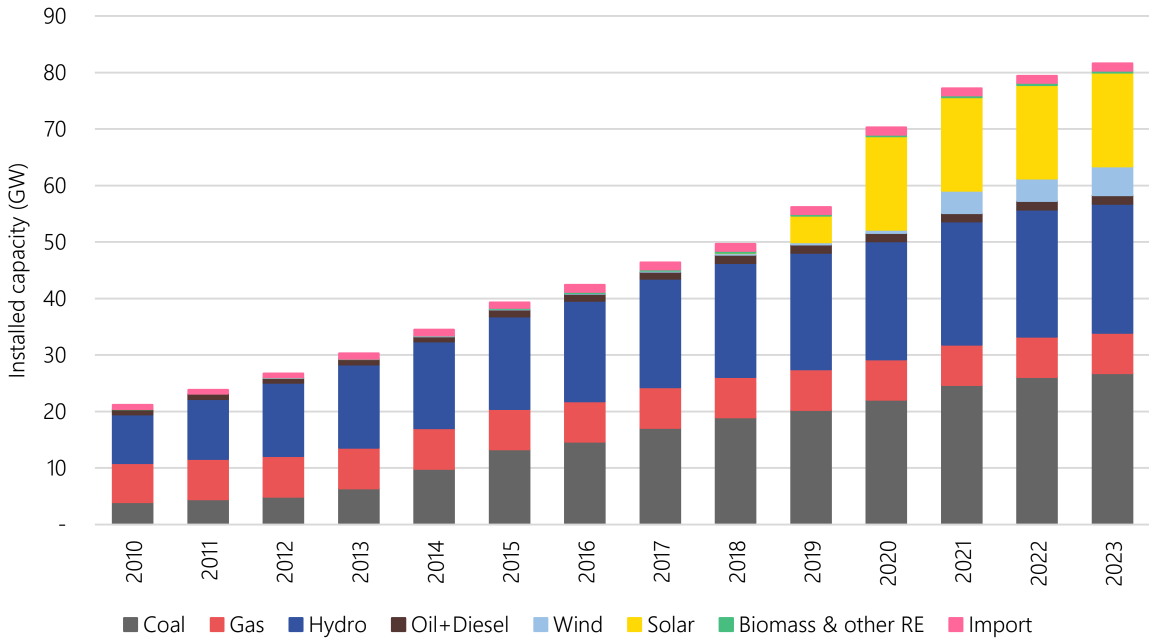


Figure 4.1 Historical installed capacities in Viet Nam (Institute of Energy 2024).

Both hydropower and coal-fired power plants have been extensively installed across Viet Nam reaching capacities of 22.8 GW and 26.7 GW, respectively, in 2023 (Institute of Energy 2024). Solar and wind power have not contributed significantly to the capacity mix until recently. Development of solar power has grown rapidly in 2019-2020, while onshore wind power also took off from 2021. As of 2023, 16.5 GW solar and 5.1 GW onshore wind were installed across the country.

The government of Viet Nam has issued several energy and climate strategies and plans (Table 3.1), whereof the PDP8 from May 2023 outlines a detailed plan for the future development of the power sector for the period until 2030 with a vision to 2050 and the net-zero target. Additionally, the Just Energy Transition Partnership (JETP) has been established in December 2022, to mobilise international resources to support the green and just transition of Viet Nam's power sector in the short term. The JETP sets targets for 2030 of maximum emissions at 170 Mt CO_2eq from the power sector, a coal capacity peak of 30.2 GW and a RE share in power generation of 47% (GoV 2022). The PDP8 projects that the total installed generation capacity in the power sector reaches 150 GW by 2030 and 490-573 GW by 2050, with a RE generation share of 31-39% in 2030 (or up to 47% if the JETP is implemented) and 67.5-71.5% in 2050 (GoV May 2023). In April 2024, the Implementation Plan of PDP8 has been issued, which, among other things, lists in more detail planned power generation projects until 2030 (GoV April 2024).

Renewable energy potentials

Viet Nam has large renewable energy resources, as illustrated in Figure 4.2. The largest RE potential in Viet Nam, as assumed in this EOR, is solar power with up to 500 GW, combining utility PV, floating PV panels and rooftop solar.

The instalment of land-based (utility scale) solar panels requires a large area of land, which in return excludes that land area from other uses, such as agriculture, residential and afforestation purposes. Following the land-use planning in Resolution No. 39/2021/QH15, which revised the amount of land available for energy purposes, the land-based solar potential is assumed at 136 GW in the BSL and GT scenarios, and 272 GW in the NZ, NZ+ and GG scenarios, the latter assuming an increased land availability (272 GW of utility scale solar requires about 3,000 km^2, or 0.9% of Viet Nam's total land area). Good solar power potential can be found across the entire country, with the very best solar resources located in the South and South Central. However, following the land area allocated for energy purposes, the largest available potential for utility scale solar is in the North. Further description on regional potentials of RE can be found in the Technical Report for this EOR (EREA & DEA 2024).

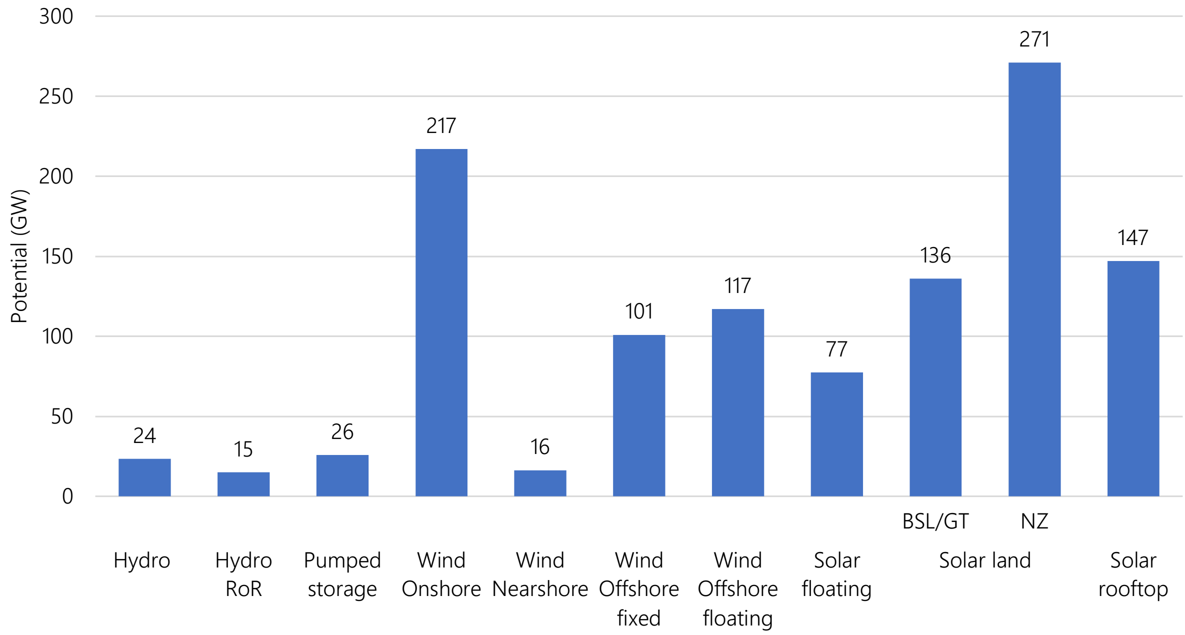


Figure 4.2 Renewable energy potentials assumed in the analysed scenarios.

Wind power provides the second largest renewable energy source in Viet Nam. Onshore wind is considered with a potential of 217 GW, with the majority located in the Highlands, South West and South-Central regions, and 16 GW of nearshore wind, mainly located in South West. While there are no offshore wind power projects in operation as of 2024, the PDP8 has a target of 6 GW of installed offshore wind capacity by 2030 (fixed foundation), with additional capacity option for electricity export and/or green hydrogen production. Towards 2050, this capacity is expected to increase at least tenfold based on targets set in PDP8. Along the coast line of Viet Nam, great conditions for offshore wind can be found, especially in South Central region, where 75% of total offshore wind potential is located; to a lesser extent the South West and Northern regions have suitable conditions for offshore wind. For this study, a potential of 101 GW offshore wind with a fixed base and additional 117 GW floating offshore wind are assumed. The assumed potential for offshore wind covers only areas with a distance to shore between 6 nautical miles and 150 km, outside of shipping lanes and with average wind speeds >7 m/s.

The estimated potential of large and medium hydro power plants (>30 MW) is 23.5 GW, including 2.5 GW expansion of existing plants. Today, 77% of this is already utilized. A total of 11 GW of small hydro plants and run-off-river plants are considered as potential, with 4 GW in operation today.

More details on RE potentials can be found in the accompanying EOR Technical Report (EREA & DEA 2024).

Assumptions on generation based on fossil fuels

For fossil-based thermal plants, an increase of fossil-based capacities until 2030 is projected across scenarios, except for three net-zero scenarios (NZ, NZ+ and GG), where only 2.8 GW out of 11 GW of new LNG power plants (as planned in PDP8) are committed to be installed. The maximum LNG fuel consumption is based on the maximum expected LNG fuel import, based on projections set out in the Energy Master Plan at 18.2 bn m^3, corresponding to 650 PJ (Vietnam Briefing 2023). In net-zero scenarios NZ, NZ+, GG, early decommissioning of thermal plants (i.e. before technical end-of-lifetime) is allowed.

4.2 Key results

Electricity demand

Viet Nam has experienced rapid growth in electricity demand, with 8% average growth per annum over the past 10 years, reaching an electricity demand of 251 TWh in 2023. Figure 4.3 illustrates the end-use sector electricity demand up to 2050 for the core scenarios and main variations. The electricity consumption developments are the result of detailed analyses of the growth in energy consumption across sectors, given the assumed development in more than 20 different economic sectors.

Continuous growth in electricity demand is expected in future years, with very similar development in BSL and NZ in the next two decades, reaching 425 TWh[10] in 2030 and around 740 TWh in 2040, which correspond to average annual growth rates of 7.8% in the period 2023-2030 and 5.6% in the period 2030-2040. The NZ+ and GT scenarios have slightly higher demand in 2040 (around 20 and 40 TWh higher, respectively), while the demand projections for GG in 2040 reach only 650 TWh. In comparison with PDP8, the results for the cores scenarios project a final electricity demand that is about 75 TWh less in 2030 (PDP8 assumes about 500 TWh electricity demand in 2030).

After 2040, the end-use demand for electricity develops differently across scenarios. The BSL reaches 1,127 TWh in 2050, a 4.5-fold increase compared to today. The electricity demand increases further when the NZ target is achieved, given additional electrification of end-use sectors, as well as electricity needed for hydrogen to RE-fuel production. The NZ scenario reaches around 1,271 TWh and the highest electricity demand occurs in the NZ+ scenario with around 1,500 TWh, a 6-fold increase compared to today's levels. In contrast, the GG scenario, assuming a structurally changed macro-economic development for Viet Nam, consequently shows an alternative net-zero pathway with lower electricity demands than the BSL scenario, reaching around 1,010 TWh in 2050, a 20% reduced demand compared to the core NZ scenario.

The continuous growth in electricity demand is driven by GDP growth expectations, additional electrification of those processes and technologies that were conventionally fossil-fuel based, as well as new demand types for the production of synthetic fuels to supply end-use sectors. The industrial sector remains the main electricity consumer with 49-61% of the demand share in 2050 in the core scenarios (Figure 4.4).

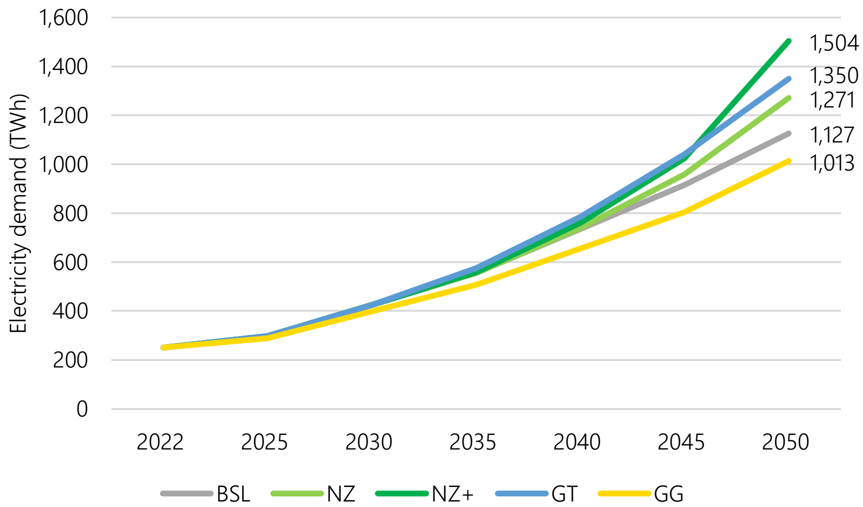


Figure 4.3 Electricity demand development (TWh) for the period 2022-2050.

The relative share of electricity consumed by households decreases, while the electrification of the transport sector (mainly electricity-based road and rail transport) will increase significantly and require in 2050 as much electricity as households. Additionally, the electricity required for production of e-fuels (shown as "Upstream", i.e. hereafter also Power-to-X, PtX) becomes a large demand driver in the range of 8-15% share on total electricity demand in the net-zero scenarios. The PtX demand comprises mainly the generation of hydrogen for domestic industrial purposes and methanol for the shipping sector. No hydrogen or other e-fuels such as ammonia is used for power production, as that is not competitive with other options.

[10] Including assumed distribution losses of 5%, excluding transmission losses.

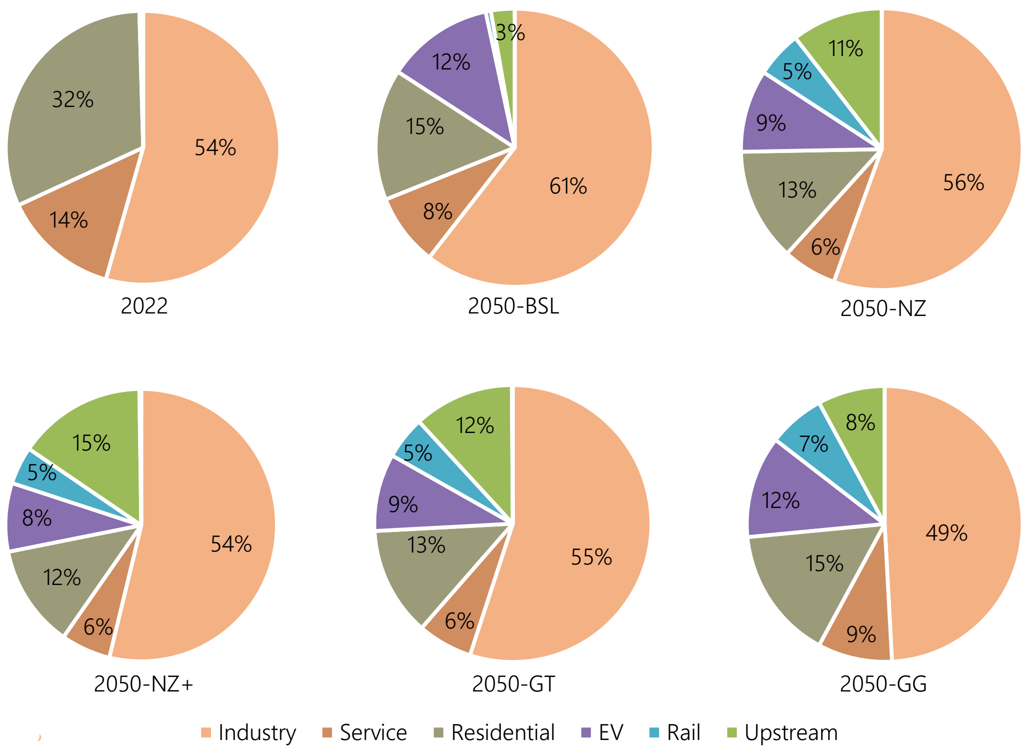


Figure 4.4 Electricity demand share by sector.

Power capacities and generation mix

To secure a stable, reliable and affordable power supply that supports Viet Nam's rapid electricity demand increase, extensive investments in power generation technologies and grid network are necessary. These following sections present the required installed capacities to enable a cost-efficient expansion of the power sector to meet future electricity demands under different net-zero pathways.

The installed power capacity in Viet Nam amounted to 77.7 GW in 2022, with a share of 13.9% VRE (solar and wind) in power generation (EVN 2023).

Figure 4.5 illustrates the optimized growth in power capacity in order to meet the future electricity demands across scenarios. By 2030, power capacities are expected to double from today's levels, reaching between 124 and 150 GW in the BSL and NZ/NZ+ scenarios, respectively. By 2050, these capacities are projected to expand to between 522 GW and 789 GW, with lower capacities in the BSL scenario due to a slower transition to electrification, a reduced demand for PtX technologies, and a greater reliance on fossil fuel-based generation, with higher full load hours (FLH). Despite these differences, all scenarios, including the BSL, predict a significant increase in solar and wind power, with renewable energy comprising 85%-94% of the total installed capacity across scenarios by 2050.

Specifically, to adhere to a net-zero pathway and supply the projected power demand of 1271 TWh in 2050, a total generation capacity of 673 GW is necessary (NZ). Of this, 591 GW comes from solar and wind power, contributing to a total renewable energy capacity, including hydro and biomass, of 627 GW in NZ. By 2050, 1.3 GW of nuclear power and 0.7 GW of LNG with CCS are invested in, with the remaining fossil capacity at 44 GW in 2050, of which 30 GW are LNG power plants.

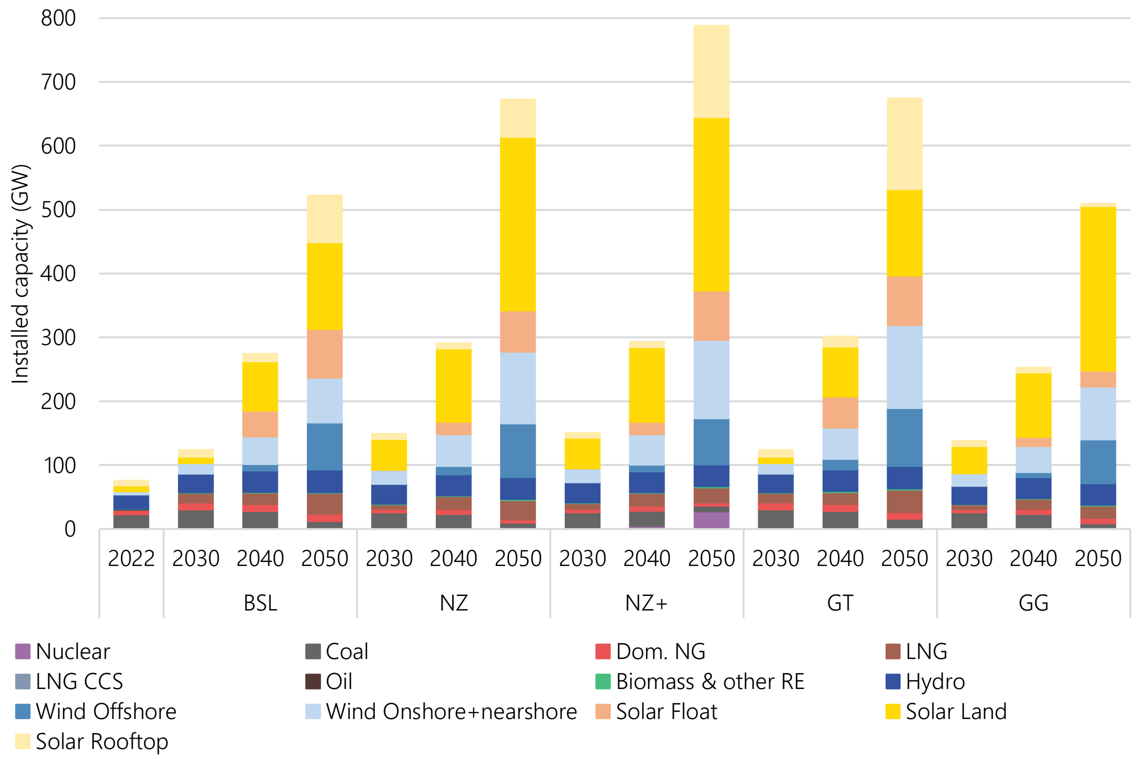


Figure 4.5 Installed power capacity for key scenarios.

With increased net-zero ambitions (NZ+ scenario), RE capacity reaches 723 GW in 2050. The additional RE capacity consists of mainly solar rooftop, which is the next cheapest RE technology in combination with storage after the solar land potential is fully utilized, and partly onshore wind power installations. Furthermore, a total of 28 GW of nuclear power is contributing to the power system in 2050, while LNG capacity is never exceeding 23 GW and an additional 1 GW of LNG with CCS is needed to reach the increased emission target.

In the Green Growth scenario, the total installed capacity only reaches 509 GW in 2050, with solar energy constituting 56% of the installed capacity by 2050. RE capacity reaches 473 GW and given the diminished energy demand, nuclear power is not required to play a role in the cost-optimal transition of the power sector. Further, to reach the net-zero target in a cost-optimal way, investments in LNG reach maximum of 19 GW in the GG scenario due the significantly lower electricity demand, thus 11 GW below LNG investments in the NZ scenario. Beside the increase in generation capacity, significant investments in electricity storage in form of pumped hydro and batteries, as well as significant reinforcements of the transmission grid, occur across all scenarios, as described in Chapter 5.2.

The short-term development trajectories for the power sector diverge significantly in the Baseline and Net-Zero scenarios (Figure 4.6), with 56 GW of fossil capacity in place in 2030 in the Baseline scenario, against more significant investments in RE in the Net-Zero scenario, substituting 18 GW of fossil-based capacity.

The Baseline scenario, with a coal capacity at 30.5 GW and domestic gas capacity at 11 GW in 2030, resembles to a large extent the projected fossil capacity planned in PDP8 (30.1 GW and 15 GW, respectively for coal and gas). The domestic natural gas capacity comprises the planned investments in gas plants of 7.2 GW and the conversion of 4.8 GW of existing plants from domestic gas to LNG in the period 2024-2029.

The Net-Zero scenario indicates that an early transition with progressive integration of RE in the power system is cost-efficient on the path to reach the net-zero target (Figure 4.6). The coal capacity is peaking at 28 GW before 2030 and the gas-based power plant capacity is reduced (reaching 8.1 GW domestic gas and only 9 GW LNG in 2035). Consequently, a total of 78 GW wind and solar power are installed by 2030, of which 22 GW of onshore wind (which is similar to PDP8) and 48 GW of land-based solar power (37.5 GW more than planned in PDP8). This development corresponds to an annual deployment of 7.4 GW solar between 2025 and 2030.

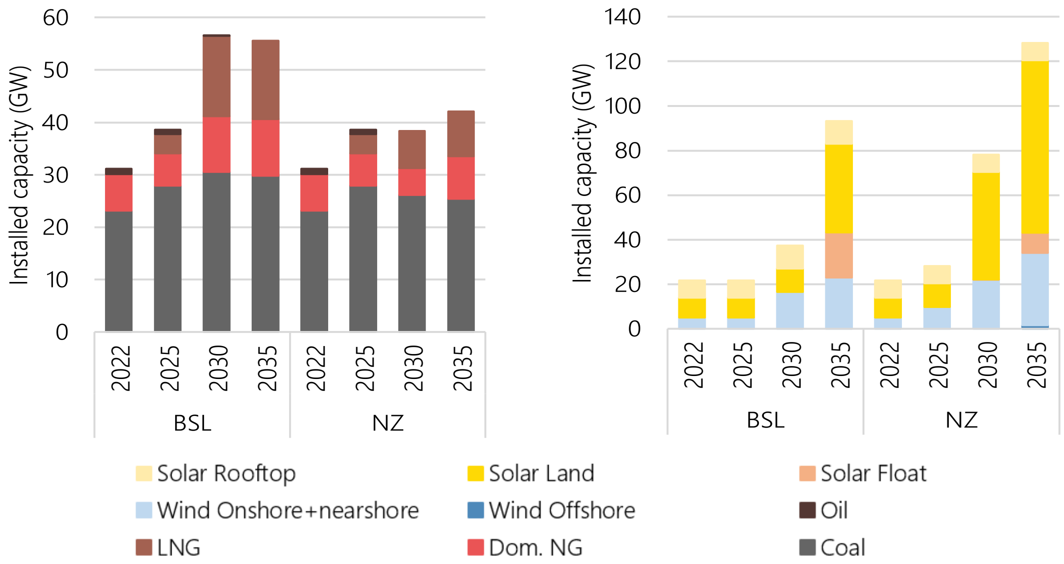


Figure 4.6 Installed capacities displayed separately for solar, wind and fossil fuels in Baseline and Net-Zero scenarios from 2022 to 2035.

When comparing the BSL scenario to the NZ scenario, it becomes clear that in order to reach the net-zero target in a cost-efficient way, it is crucial to expand the RE capacity starting already before 2030, thereby avoiding lock-in effects in fossil investments which can prove costly for Viet Nam to phase-out later.

Following the development of power capacities, the future mix of power generation will undergo similar significant changes (Figure 4.7), with a continuous increase in RE share reaching a level between 85% and 94% in 2050 across scenarios and conversely a rapid and steady phase-out of coal power generation after 2030. For the Net-Zero scenario, up to 1,203 TWh are generated from hydro, biomass, solar and wind power, and only 61 TWh derived from fossil gas (LNG and domestic gas), 8 TWh from LNG with CCS and 7 TWh from nuclear power in 2050. The different levels of total electricity generation among scenarios is driven by the demand (Figure 4.3). In the GG scenario, the reduced energy demand can be met predominantly through renewables, resulting in a diminished need for LNG and no need for nuclear generation in 2050. This is reflected in a RE share of 94%, the highest together with the NZ scenario among all considered scenarios.

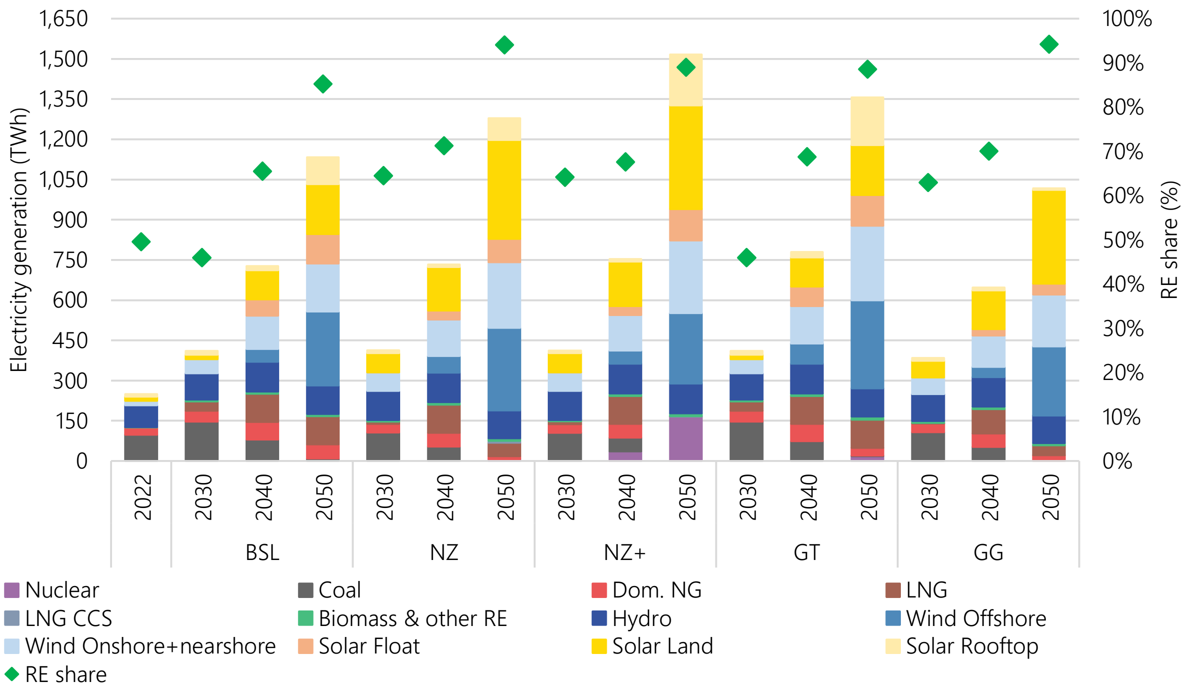


Figure 4.7 Electricity generation and renewable energy (RE) share for key scenarios in milestone years.

Coal power generation, currently the largest power source in Viet Nam's power mix, is expected to decrease after 2030 in all scenarios and is eventually phased-out by 2050. Until 2030, coal generation only increases in the BSL and GT scenarios, while the coal output is kept relatively constant in the NZ, NZ+ and GT scenarios at 100-107 TWh annually until 2030. This is in line with the development of coal capacities described above.

Domestic natural gas and LNG become a relevant fuel source in Viet Nam in the medium term, with a combined generation share of 18% and 10% in 2030, for BSL and NZ scenarios respectively. In absolute terms, the gas consumption is reaching its peak in 2040, generating 170 TWh in the BSL and 156 TWh in the NZ and NZ+ scenarios, whereof 105 TWh is from LNG. To align Viet Nam's power mix with the net-zero target, the gas-based power generation decreases from 2040 towards 2050 to 61 GWh in the NZ scenario and is fully phased out in the NZ+ scenario.

The share of RE on power generation in the Baseline scenario is 46% in 2030, which is in line with Viet Nam's JETP target. The Net-Zero scenarios show that an even higher share of 64% can be reached (corresponding to 267 TWh of RE generation). This illustrates that it is cost-efficient to increase RE shares significantly within this decade, which reduces GHG emissions from the power sector. Moreover, the increasingly higher share of RE-based electricity contributes to the decarbonization of end-use sectors, for which electrification rates progressively increase in the future.

Regional capacity differences in the power system development

Viet Nam's extensive power system is represented in seven regions, with each region having distinct generation capacities, RE potential and generation profiles, electricity demand, and transmission capabilities. The installed capacities given in Figure 4.5 are distributed by regions, as seen in Figure 4.8. By 2050, the largest installed capacity is in the North, composed of a large share of solar and wind power, and the remaining are LNG and hydropower.

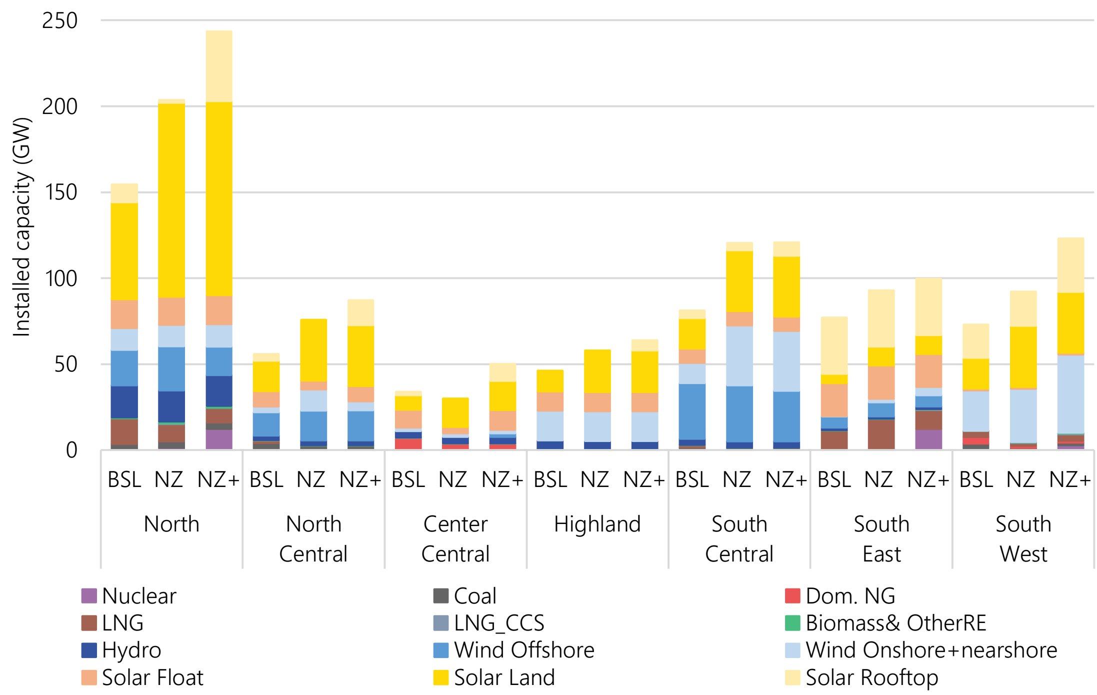


Figure 4.8 Installed generation capacity per region for the BSL, NZ and NZ+ scenarios in 2050.

While the solar capacities are distributed over the entire country, accounting for the majority of the capacity share in most regions, wind power is distributed differently across Viet Nam, with the South-Central region having the highest share of wind capacity (35 GW onshore and 33 GW offshore). Notably, the South-Central region functions as a key supply centre, distributing its significant renewable energy generation through extensive interconnections with other regions (as described in more detail in Chapter 5). LNG plants are installed to support high demand areas, with LNG only appearing in North and South East regions, and to a small extent in South West.

With even higher climate targets (NZ+ scenario), a greater degree of electrification is cost-effectively unlocked, which requires a larger capacity build-out, consisting mainly of solar rooftop across all regions, with the highest additions to be found in the North, and nuclear power (SMR) mainly in North and South East with 12 GW in each region (and 3 GW in South West), to support power supply in high demand regions, where no further development of solar or onshore wind is techno-economically viable.

Renewable energy development and potentials

Renewable energies will become the main source of Viet Nam's future power system to fulfil the net-zero pledge and its expansion will happen at a rapid pace. As visible from the presented development in capacity build-out, solar power will be the main contributor, followed by onshore wind power and offshore wind, which will become equally important, reaching equal shares in the long-term, followed by hydro power.

Solar power will double its share in the power mix by 2030, reaching 20% in the Net-Zero scenario at 56 GW installed capacity. This will increase rapidly until 2050, when the generation share will reach 42% and total capacity of solar will reach around 406 GW (NZ scenario) and around 500 GW (NZ+ scenario). In turn, solar build-out rates should reach on average 7.5 GW/year in the period 2025-2030, up to 9 GW/year in 2030-2040, reaching as high as 27 GW/year (NZ scenario) and 35 GW/year (NZ+ scenario) for the period 2040-2050.

Even though the capacity factors are intrinsically lower for solar than other technologies, due to the technological specifications and the dependence on day time, solar power is the favoured technology, due to the low investment cost and distributed location. In the long term, integration of large amounts of solar power affects the system dynamics, requiring a larger degree of flexibility and storage needs. A distinct build-out of storage in correlation with increasing VRE, especially solar power, is further descripted in Chapter 5.2. Solar power is distinguished between utility/land, rooftop and floating technologies, where the land solar is the cheapest with the largest potential, and thus land solar is dominating the in Baseline and Net-Zero scenarios (Figure 4.5 and Figure 4.6). Rooftop solar is comparatively more expensive than land solar (EREA & DEA, 2023a), but can provide additional benefits where limited land is available as well as it reduces grid investments, yet these effects are not captured in the modelling. However, Viet Nam had by the end of 2020 more than 100,000 rooftop solar systems and a total capacity of 9.6 GW into operation (EREA & DEA, 2023a). The analysis illustrates, that in the long-term, additional solar rooftop investments of 48 GW (NZ scenario) and up to 135 GW (NZ+ scenario) are installed by 2050. Floating solar rooftop is assumed to have a potential of 76 GW across Viet Nam, which is fully utilized across all scenarios, except for the GG scenario.

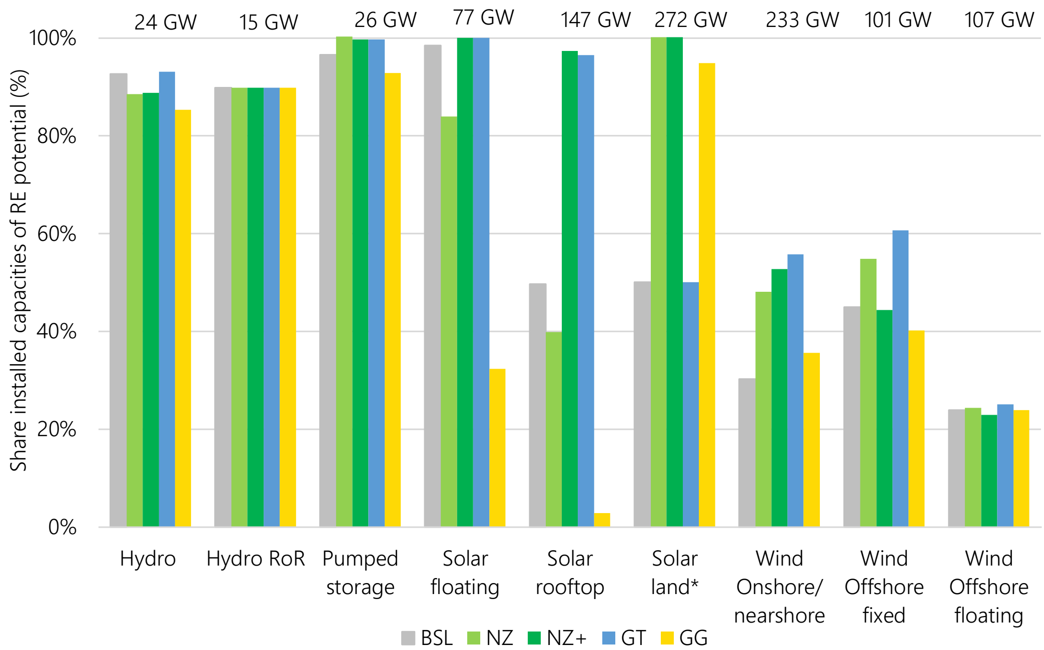


Figure 4.9 Percentage level of RE potential reached for each scenario in 2050 and the maximum assumed potential for each RE technology indicated on top of each bar (*the maximum allowed investments in land solar is 136 GW for BSL and GT scenario, and 272 GW for NZ, NZ+ and GG scenarios).

Under a less optimistic development for the investment costs of solar power (CAPEX 70% higher compared to core scenario costs), while still reaching the net-zero target (NZ-High Solar), solar power will still hold the largest share of installed capacity in the future. However, the capacity level in 2050 will only be at 250 GW. The remaining solar power is substituted by 12 GW of combined onshore and offshore wind, 9 GW of gas power (whereof 6 GW are equipped with CCS) and 15 GW of nuclear power.

Onshore wind power will increase its share in the power mix from today's 3.4% to 16% in the Baseline scenario, and to 19% under net-zero pathways by 2030, keeping a stable long-term share of 18-20% from 2030 to 2050. The onshore wind capacity develops in the net-zero scenarios to 22 GW by 2030 and will be reaching around 50 GW by 2040 and 112-130 GW in the NZ, NZ+ and GG scenario, while only 83 GW in the GG scenario. The development can be reached with average annual build-out rates of 2.4 GW/year from today towards 2030, 2.7 GW/year in 2030-2040 and increasing towards 6.3 GW/year in the NZ scenario in 2040-2050 and 7.3 GW/year in the NZ+ scenario for the same period. Despite slightly higher costs compared to solar power, onshore wind power is the second biggest contributor the reach Viet Nam's transition, as it provides higher FLH, with its production possible all-day round, thus requiring lower need for daily storage compared to solar.

The long coastline of Viet Nam offers great **offshore wind** areas, with regulatory frameworks currently being developed to enable this new industry to take off. Offshore wind is to enter the Viet Nam power sector across all scenarios only starting from 2035 (NZ and NZ+ scenario) or 2040 (BSL and GG scenario), but will, within one decade, become an integral part of Viet Nam's power sector. In 2040, the investments in offshore reach from 9 GW in the BSL scenario to 14 GW in the NZ scenario. The late penetration of this technology is due to higher investment costs compared to solar and onshore wind power in early years. The projected future cost reductions and good wind resources in a number of areas along the Vietnamese coastline, combined with the limited solar potentials assumed, contribute to the considerable capacity installed and large role for offshore wind in Viet Nam in the future. By 2050, the offshore wind instalments reach 70-90 GW across all scenarios, including the BSL scenario with 73 GW, and NZ scenario with 84 GW. Around 2/3 of the capacity is fixed-bottom based and the remaining capacity is floating offshore wind.

Such development requires establishing an adequate regulatory framework, including plans for large-scale allocation of marine areas, procurement through offshore wind tenders, and a transparent permitting process. Moreover, the projected scale of offshore wind development requires also adequate grid planning and analysis of grid point connections, as well as timely development of port infrastructure, supply chain, and a skilled workforce.

Hydro power is the most important RE source in Viet Nam today with 73% of all renewable power coming from hydropower and a total generation of 81 TWh in 2023 (EVN 2023). The increase in capacity for hydro power is more limited compared to solar and wind power, with a maximum of 38.5 GW, including expansion of existing plants (2.5 GW) and new small hydro power (11 GW). A continuous development of hydropower from today's 23 GW until reaching a stable capacity of 34 GW in 2045 can be observed, resulting in a production of 106 TWh. The comparable small increase in hydropower results in a large reduction of its share in the power mix to 8-11% in the net zero scenarios.

By 2050 RE potential will be largely utilized across scenarios. Despite the vast potential of renewable energies in Viet Nam, the electricity demand increase by a factor of 4.6-6 (depending on scenario) requires the commissioning of 90-100% capacity potential of the generation technologies land-based solar[11], floating solar, large and small hydro power across BSL, NZ, NZ+ and GT scenarios, as well as rooftop solar in the case of the NZ+ and GT scenarios (Figure 4.9). Further, pumped storage is fully utilized by 2045 in all scenarios, as it is the cheapest form of storage technology and of great need as solar and wind capacities are expanding.

By 2050, 2/3 of the total assumed RE potential is utilized in the Net-Zero scenario, 73% in the NZ+ while it is only around 50% in the GG scenario. The remaining unutilized RE potential comprises partly solar rooftop in BSL, NZ and GG scenarios, and mainly wind power, with 98-106 GW onshore wind and 134-146 GW offshore, in the NZ+ and NZ scenario, respectively.

The remaining onshore wind potential is located in low wind areas (FLH < 1800), which decreases the economic competitiveness, and in regions (Highlands and South West) where additional grid infrastructure would be required to utilize this remaining RE potential to supply high demand centres.

The high untapped offshore wind potential highlights that there is good potential to increase RE generation further in the future, in case of additional demand increase or for the generation of renewable fuels. However, the

[11] The assumed land-based solar potential in the BSL and GT is 136 GW, which corresponds to 50% of the assumed 272 GW land solar potential in NZ, NZ+ and GG. The land-based solar in BSL and GT is fully utilized by 2050.

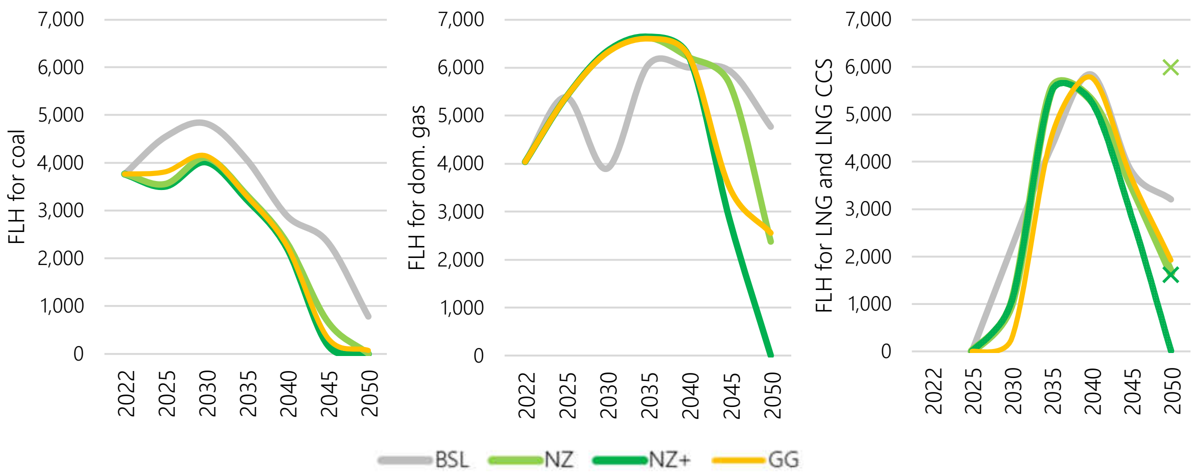
remaining potential can probably be first used in the long term, considering the already high expansion rates for offshore wind by 2050.

The role of thermal power plants

In 2022, the total fleet of thermal power plants, primarily consisted of coal and domestic natural gas, with the two sources contributing to 33% and 9% of the total installed capacity in Viet Nam, respectively (EVN 2023). The production from coal and gas contributed to 36% and 11% of the total electricity generation. Following a net-zero pledge, the generation of these conventional fossil thermal power plants will reduce, as described in the following section.

Operation of coal and gas power plants

Coal generation peaks in 2030 across all scenarios (Figure 4.7), but the maximum use of coal in the net-zero pathways is around 253% below the BSL consumption peak (around 1,050 PJ in NZ scenario). After 2030, the generation of coal power plants is continuously decreasing and by 2040, the remaining coal capacity runs with only 2300 Full Load Hours (FLH) in NZ scenario and NZ+ scenario, and below 3000 FLH in BSL scenario (Figure 4.10a). The coal phase-out is reached by 2050 in NZ scenario and an almost phase-out in 2045 in NZ+ scenario, where FLH are as low as 190 hours.



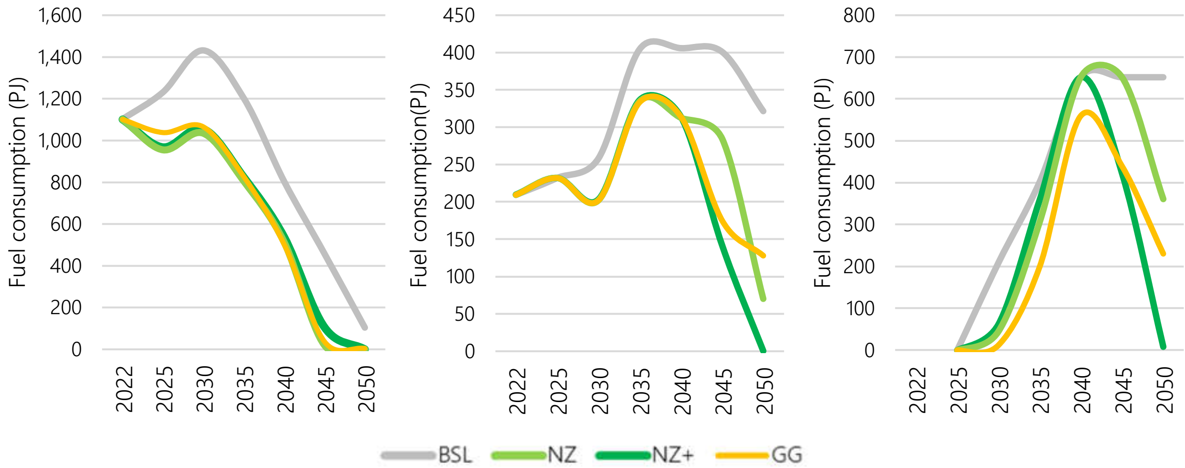
(a) Coal *(b) Dom. NG* *(c) LNG (line), LNG+CCS (cross mark)*

Figure 4.10 Full Load Hours for (a) coal, (b) domestic natural gas and (c) imported LNG.

The utilization of domestic **natural gas** plants increases up to 2035 and remains at high levels up to 2040 in all scenarios with FLH above 6000. **LNG** becomes part of the Vietnamese power mix by 2030, where it mainly runs to supply peak demands with low FLH, at about 1000-2200. In the period 2035-2040, LNG is largely used across all scenarios with high FLH between 4300 and 5800. From 2040-2050, FLH are decreasing back to 1700 and 1900 in NZ and GG scenario, respectively, and a phase-out of conventional LNG in NZ+ is observed. Thus, LNG will only have high utilization rates in the medium term to serve the growing electricity demand, but in the long-term, LNG plants are only functioning as support during peak residual demand.

The maximum LNG fuel use (650 PJ) is reached in 2040 in all scenarios (Figure 4.11). However, in order to follow a net-zero pathway, the LNG consumption has to decrease again towards 2050, as shown by the FLH development. In GG and NZ scenarios, LNG use is halved by 2050 compared to 2040, while LNG is no more present in the power mix in the NZ+ scenario.

Due to the lower emissions and its higher flexibility, natural gas stays a decade longer at a higher level of utilization compared to coal, but for both fuel technologies, the challenge of phase-out/down of existing plants remains, as well as ensuring the needed plans/frameworks to be established to secure economic feasibility of plants running on low load.



(a) Coal *(b) Dom. NG* *(c) LNG*

Figure 4.11 Fuel consumption (PJ) for (a) coal, (b) domestic natural gas and (c) imported LNG.

Cost of LNG and risk of increasing fuel prices

As with any fuel, the cost of importing LNG depends on the development of the international prices, as well as the investment costs associated with the infrastructure. Significant investments into LNG infrastructure, as well as the power plants using LNG, are required to obtain the production profiles shown in Figure 4.10. A peak consumption of 650 PJ per year corresponds to about 13 million tonnes per annum (MPTA) of LNG. This is a substantial amount of imported LNG, which will require the construction of several terminals, possibly including so-called FSRU's (Floating Storage Regasification Units). The cost of infrastructure in Viet Nam is assessed to correspond to about 10% of the total price of LNG, received at the power plant (Institute of Energy & TEDIPORT 2019).

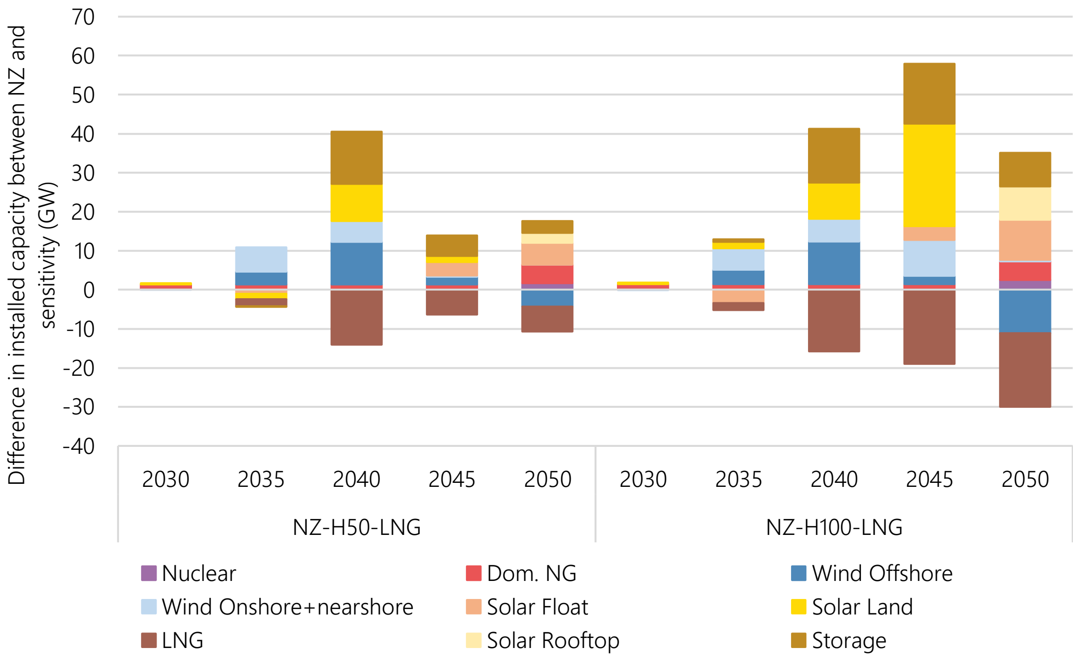


Figure 4.12 Difference in installed capacity between NZ and NZ-H50-LNG / NZ-H100-LNG.

LNG markets in Europe and Asia have shown to be closely linked (IEA 2024a). As such, any international disruptions in the LNG market can be expected to have direct repercussions on the cost of fuel in Viet Nam. The long-term fuel price for LNG used this report is 12.5 USD/GJ, which corresponds to about 13.2 USD/MMBtu. However, uncertainties surround the long-term fuel prices for LNG, which is assessed by analysing the effect of a 50% and 100% increase of the LNG fuel price from 2030 to 2050. Figure 4.12 highlights the difference between the installed capacities for NZ and 50% / 100% LNG fuel prices, starting from 2030. In NZ, LNG plants reach an installed capacity of 30 GW by 2050, however for the mentioned higher LNG price sensitivities (described as NZ-H50-LNG and NZ-H100-LNG, respectively) investments of 23.7 and 11.1 GW are instead observed by 2050.

With the higher prices, both capacity and operation the LNG power plants are reduced, as these are only used as peak plants throughout the period. In NZ scenario, the LNG power plants operate with higher utilisation rates in the period 2035-2045, and then only in 2050 operate as peak plants. With the lower LNG plant operation and capacity, peak fuel consumption declines to 454 PJ and 93 PJ for NZ-H50-LNG and NZ-H100-LNG, respectively. To make up for the reduced LNG capacity and utilization, more and earlier investment in RE and storage is necessary (Figure 4.12).

The future of the thermal power fleet

Viet Nam has committed to a coal capacity peak in 2030, which is reached in BSL at 30.5 GW. However, all net-zero scenarios, except GT, show that a peak of 28 GW before 2030 is cost-efficient. This can be achieved by decommissioning of old/inefficient plants and/or limiting the build-out of new plants. Decommissioning of coal power plants is expected after the end of lifetime of 40 years, leading to a maximum residual capacity of 12.8 GW (9 GW in net-zero scenarios) in Viet Nam's coal fleet by 2050. The remaining capacity is not operating in 2050, neither are retrofits with CCS or co-firing a cost-efficient solution, as discussed below. Therefore, the remaining coal capacity is not contributing to normal power system operation, and further decommissioning or potential support as backup/reserve capacity could be considered.

Viet Nam's gas fleet using domestic natural gas has a net increase in the BSL scenario of 3.6 GW to 10.6 GW by 2030, as a result of 7.9 GW new instalments and a fuel switch towards LNG of 4.3 GW. But, similar to coal power, a high increase in fossil capacity within this decade is to be avoided for a cost-efficient net-zero pathway (NZ scenarios). The long-term capacity of gas power plants using domestic gas is at 11 GW for the Baseline and 8 GW for net-zero pathways, which is reduced by further decommissioning to only 5 GW in 2050.

Among the fossil fuels, only LNG plants have a high capacity in 2050 across all scenarios, reaching as high as 30-35 GW in BSL, NZ and GT scenarios, and 19-23 GW in the GG and NZ+ scenario. However, these are only used to a limited extent in the normal operation of the power sector providing peak capacity (Figure 4.10). As for coal power plants, retrofit with CCS or co-firing is not a cost-efficient use to keep gas plants in the regular power mix when net-zero emissions are to be achieved.

While transitioning away from coal and natural gas, and approaching the net-zero target, different options for the development of the thermal power plant fleet in Viet Nam are currently discussed. The possible changes in regards to the thermal power fleet that are currently considered in Viet Nam are:

1. CCS implementation to conventional coal and gas plants;
2. Co-firing of hydrogen, ammonia or biomass as substitute to the coal or gas;
3. Extending the thermal fleet by nuclear power;
4. Expansion of biomass plants and incineration of municipal solid waste.

In the following sections, the results from this study in relation to these possible changes are discussed more in detail.

1. *Carbon Capture and Storage for conventional coal and gas power plants*

CCS provides the option to capture the released CO_2 emitted from power generation plants, such as coal, natural gas, LNG, biomass or municipal solid waste, allowing fossil plants to continuously play a role when emission reduction targets have to be achieved. However, CCS is costly in terms of both investments, which triple compared to a conventional LNG power plant, and operation on the power plants (EREA & DEA 2024). Additionally, CCS requires large carbon storage capacities, such as deep geological formations, as well as transportation of CO_2. Moreover, the maximal feasible efficiency of the CCS process is considered around 90% (EREA & DEA 2023a), thus it is not a fully carbon-free alternative. The scenarios show that CCS in the power sector will only play a marginal role, with only 0 1.3 GW and 1 GW LNG with CCS invested in the NZ and NZ+ scenario, respectively, by 2050. As the power sector is easier to decarbonize compared to end-use sectors, it is more cost-efficient to replace fossil-powered plants with renewables, rather than retrofit base-load power plants with CCS in large scale.

2. *Co-firing and conversion of gas and coal power plants with hydrogen and ammonia*

Co-firing and eventually a full fuel switch of coal and gas plants with ammonia, biomass and hydrogen, respectively, is another option discussed for the future Viet Nam's thermal power plants and considered in PDP8. PDP8 projects that by 2050 a capacity of 4.5-9 GW of LNG power plants are co-fired using hydrogen, a full conversion of the coal fleet of 25-32 GW to biomass or ammonia, and a full fuel conversion of 7 GW of domestic gas power plants and up to 20 GW LNG plants to hydrogen is reached (GoV May 2023).

Co-firing strategies are very costly and not competitive with a large increase in RE combined with storage according to the analysed scenarios. Hydrogen or ammonia co-firing/fuel-switch is not present at a significant level across the key scenarios, due to the costly generation of domestic H_2 or NH_3 production. In addition, it is unlikely that green hydrogen or ammonia can be imported from other countries in the ASEAN region at price levels that will make co-firing a feasible alternative (see Chapter 6 for more details on hydrogen). By 2050, only minimal biomass-cofiring of 0.4 GW can be observed in the GT scenario and 2.9 GW co-firing of LNG power plants with hydrogen. However, these only act as peak power plants with FLH as low as 100 h. This result illustrates that the usage of hydrogen or ammonia for reserve purposes, where the power plant is not running on a regular basis, thus does not have high fuel consumption costs, may be considered, which is discussed further in Chapter 5.2.

3. *Extending the thermal fleet: option of nuclear power*

Nuclear power provides an emission-free alternative for power generation. Nuclear power is not part of the projected power mix in the BSL and GG scenarios, and only small investments in nuclear power of 1.3 GW and 3 GW are cost-optimal the NZ and GT scenario, respectively. Only the NZ+ scenario, which projects the highest electricity demand and most ambitious emission reduction target, leads to a considerable large share of nuclear of 28 GW by 2050. The investments consist in small medium reactor (SMR) technologies, an emerging technology option, providing the benefit of shorter construction periods and more regional distribution.

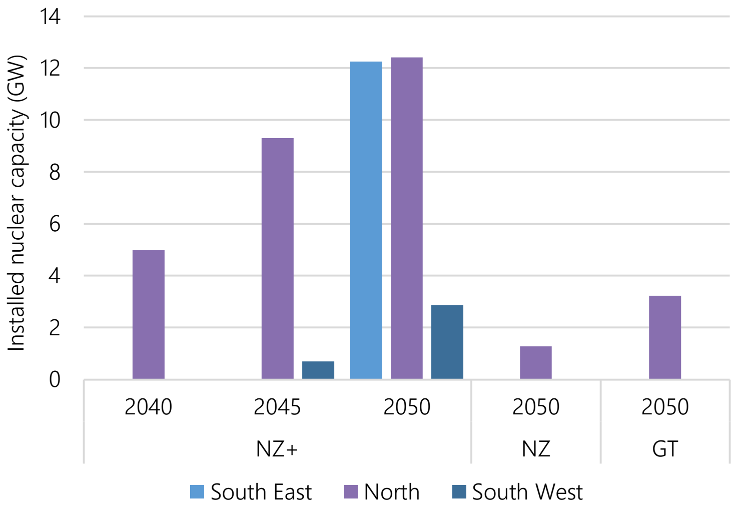


Figure 4.13 Nuclear power investments by region (there are no nuclear investments before 2040 in any scenario).

The regional location is of relevance when considering the potential role of nuclear in Viet Nam. Conventional nuclear power plants are assumed available for investment only in North Central and South-Central regions, which, however, results not being cost-efficient in any scenario. Instead, the SMR investments are cost-optimal predominantly in the North or South East regions (Figure 4.13) to supply the large demand centres without additional need for interregional transmission investments. Nuclear power could therefore become regionally cost-competitive, when cheap RE technologies like land-based solar power are fully exploited in high demand regions.

As nuclear power is not present in Viet Nam today, the development of required infrastructure and know-how to introduce this highly specialized technology is related to high uncertainty, both in terms of cost and required development timelines. Furthermore, the integration of nuclear in a system largely based on RE-powered generation challenges a continuous operation of nuclear on high loads. Nuclear is a very costly technology to introduce in the power system: in the NZ+ scenario nuclear only takes up to 3.5% of the installed capacity, but contributes to 10% of the investment needs between 2025 and 2050. This underlines that the choice for nuclear technology should be carefully taken, while prioritization of domestic renewable technologies together with storage is recommended. At the same time, further investigation of the possible role of nuclear energy in the future power system, particularly in diversifying the power mix, is necessary.

4. *Expansion of biomass and municipal solid waste*

Viet Nam's biomass potential is used for energy purposes outside the power sector, such as biofuel generation for the transport sector or industrial purposes, as described in Chapter 6, 7 and 8. Therefore, there are no additional biomass power plants beyond the existing 0.3 GW.

Only few waste incineration power plants are in operation in Viet Nam today. By 2050, Waste-to-Energy plants will generate up to 7.1 TWh electricity based on 31.2 million ton of waste in the net-zero scenarios, to be provided by 1.2 GW waste incineration plants. The waste potential is based on analyses from the World Bank (World Bank Group 2018). While the contribution to Viet Nam's future power mix is modest, waste incineration provides also environmental and social benefits compared to conventional landfills. Waste-to-energy plants help improve public health, bring positive impacts on local environment, reduce GHG emissions compared to landfilling and effectively utilise resources for a sustainable development.

Diversification

In planning the power system, diversification plays a crucial role in ensuring reliability, safety, and resilience of the system. Relying heavily on a single technology could leave the system vulnerable to disruptions if there are supply issues related to that technology. This is especially a concern for fuel-based technologies that rely on continuous import of fuels. To estimate the diversity within a power system, the Herfindahl-Hirschman Index (HHI) is commonly applied. This index measures the diversification across installed fuel capacities, with a lower HHI indicating a more varied capacity mix. The index offers insights into the system's diversity based on fuels, but does not account for the origin of technology (domestic versus imported) and accessibility of the fuels.

Figure 4.14 illustrates the installed capacity shares for BSL, NZ and NZ+ alongside their respective HHI-score, depicting a transition from coal and hydropower to a predominance of solar and wind energy. However, the HHI score trends downward into the future, suggesting a broader diversity of the power mix, dominated by solar and wind. In 2050, the HHI scores are 0.12 for BSL, and slightly higher at 0.16 for NZ and 0.14 for NZ+, attributed to heavier reliance on imported LNG in the Baseline scenario. Notably, the NZ+ scenario, with its significant inclusion of nuclear capacity, demonstrates a lower HHI score compared to the NZ scenario, highlighting nuclear energy's potential to enhance Viet Nam's energy mix diversity. However, the reliance on imported nuclear fuel must be considered.

It is critical to recognize that the HHI score does not fully capture the advantages of renewable energy sources. Renewables, being domestically sourced and accessible throughout Viet Nam, reduce the dependence on imported fuels and support a more geographically dispersed power capacity, underlining their integral role in achieving a resilient and sustainable energy landscape in Viet Nam.

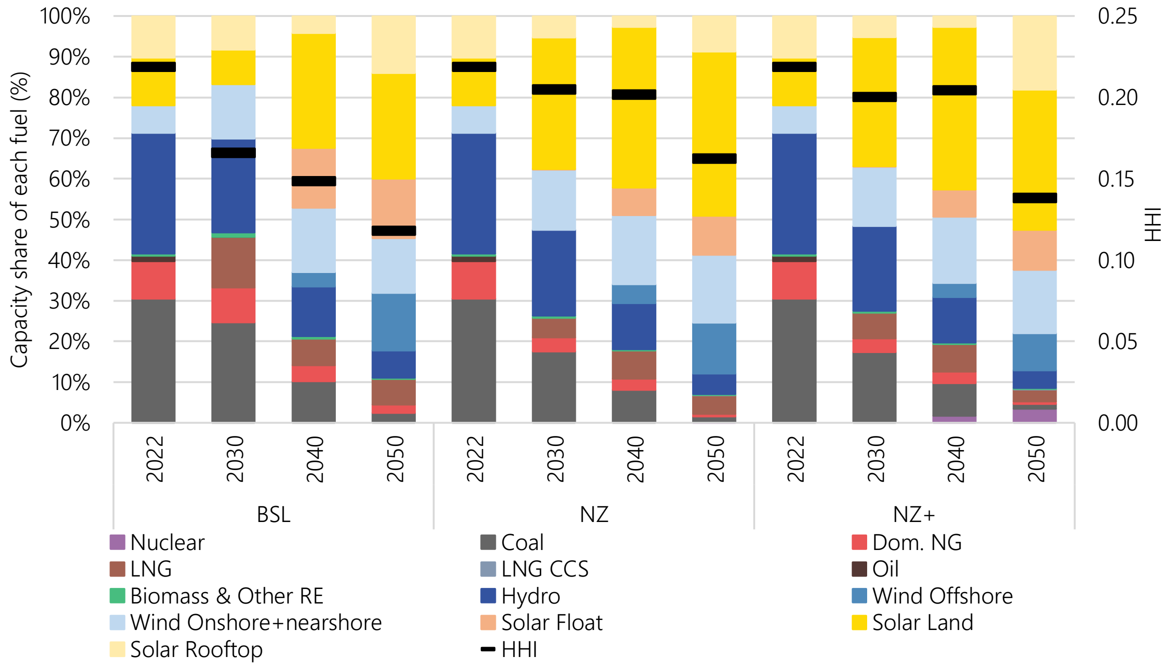


Figure 4.14 Capacity share and diversification metric (lower HHI values indicate more diversity in the power supply).

Power system costs

The power system serves as the critical infrastructure for the green transition, enabling the decarbonization of other sectors, representing over 14-31% of the total energy system costs between now and 2050. The increasing electrification trend with ensuing growing power capacity over time results in significant increase in power system expenses. This shift is evident when comparing the BSL with NZ and NZ+ scenarios. Initially, fuel costs comprise roughly one-third of the system costs in 2025. However, with increasing electricity needs as well as investments into primarily RE capacity, the power system changes towards a more capital-intensive system (Figure 4.15).

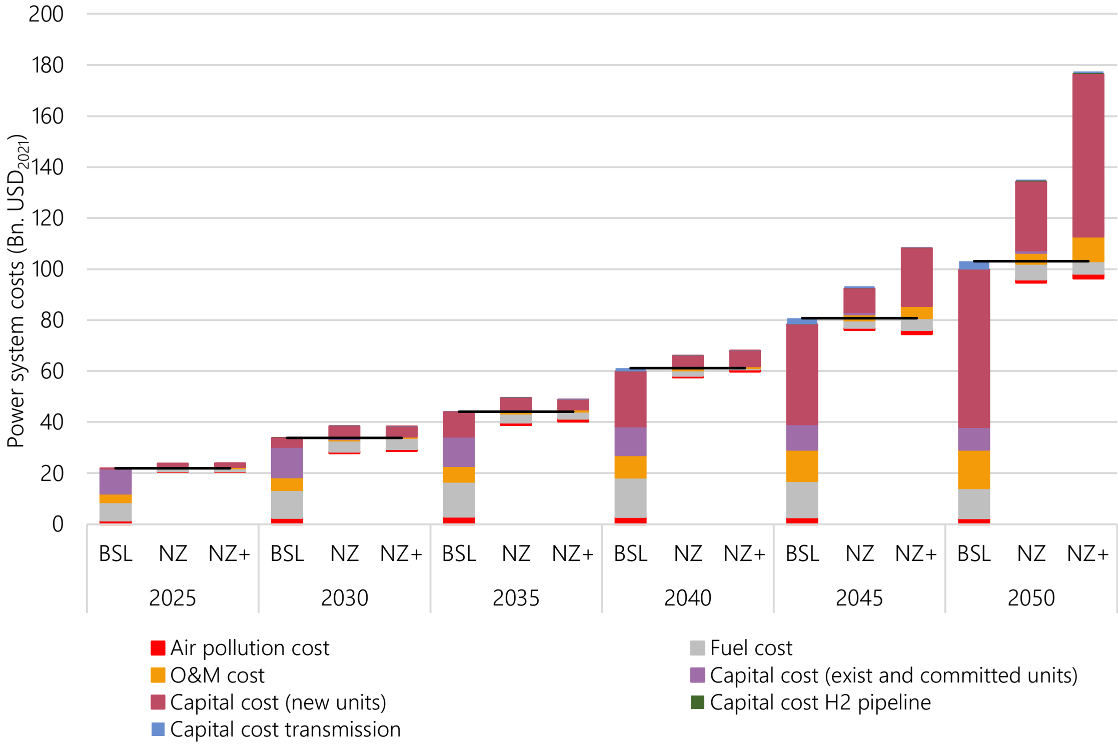


Figure 4.15 Annual power system costs for BSL, NZ and NZ+, presented as cost differences between BSL and NZ/NZ+.

Most expenses are tied to new power capacity rather than power infrastructure. The investment costs in the transmission grid remain relatively minor in comparison to those for generating capacity, which are depicted in more detail in Figure 4.16. Moreover, investments in electricity transmission represents a significantly higher total cost than that for hydrogen grid infrastructure (as further detailed in Chapter 6).

Investment needs[12] for generation and storage technologies (excl. transmission investments) over the period from 2025 to 2050 (Figure 4.16) reveal that investments are predominantly directed towards solar and wind power, accounting for 65%, 69%, and 58% of investments in the BSL, NZ, and NZ+ scenarios, respectively. Despite the late deployment of battery and pumped hydro (with large-scale electricity storage appearing after 2035, see Chapter 5), 8-12% of the investment need is related to storage technologies. The 28 GW nuclear power investments in the NZ+ scenario account for 10% of the total CAPEX, illustrating the very large capital required related to this technology. For scenarios where the net-zero target is achieved, investments in hydrogen production and storage account for 1%-3%. This detailed breakdown highlights that, regardless of the scenario pathway, investments in wind and solar power should be prioritized and are crucial for a cost-efficient development of Viet Nam's power sector. Considering the strategic importance of prioritizing domestic renewable energy, quickly developing the needed regulatory frameworks can enable incentives and create stable investment environments.

[12] Total investment need discounted to 2025 with a discount rate of 10%.

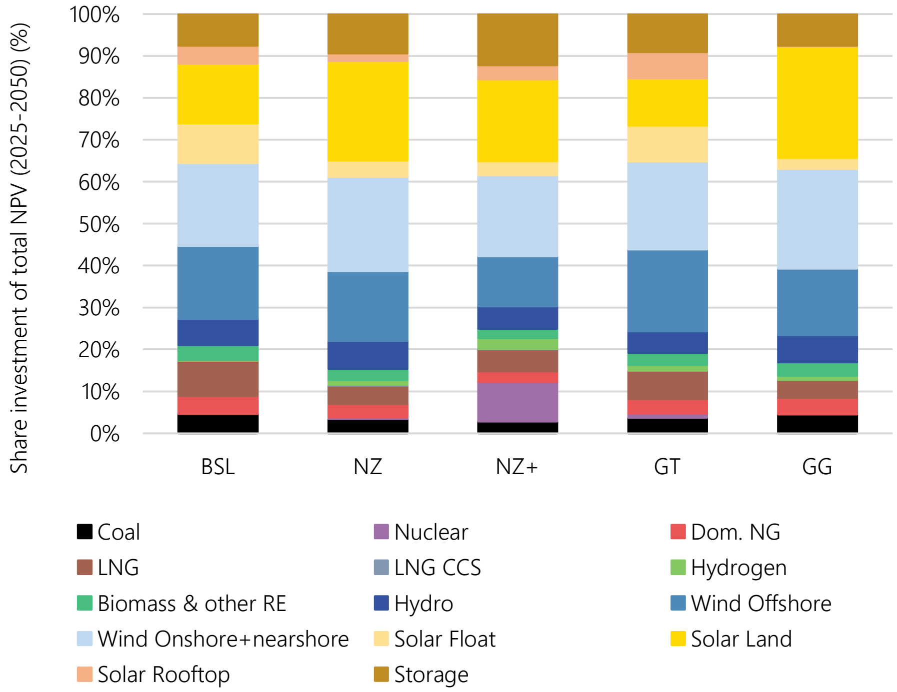


Figure 4.16 Investment need by generation and storage technology for key scenarios in the period 2025-2050.

4.3 Key messages and recommendations

Further explore the potential for the use of land for onshore wind and solar power in line with the net-zero target by 2050

The Net-Zero scenario assumes a larger land area available for utility photovoltaics (PV), with double potential of solar PV capacity assumed compared to the Baseline scenario. While utility-scale PV are preferred in the cost-optimal scenarios, rooftop solar can be beneficial and competitive in some areas, due to, for example, local grid constraints or land use restrictions.

Recommendations:

- *Perform a study of usable land areas for multipurpose (agriculture and energy) use, with the goal of updating the potential areas available for onshore renewable energy while considering local aspects and agriculture needs.*
- *Develop standards and regulations to promote rooftop solar power connecting to the grid.*

Nuclear energy could play an important supporting role to renewable energy in the long term under high emission reduction scenarios

Ensuring the achievement of the net-zero emission target by 2050 entails a potential role for nuclear power, which could become part of the power mix by 2050 in the Net-zero scenario. Under more ambitious climate targets (NZ+ scenario), with consequent increase in the power demand, nuclear energy is developed starting from 2040, reaching up to 28 GW of capacity by 2050.

Recommendation: Further investigate the possible future role of nuclear energy in a largely RE-based power system, including the impact on diversification and robustness of the power system.

Accelerate the issuance of the regulatory framework to kick-start installation of offshore wind

In the Net-Zero scenario, offshore wind is projected to be in operation in 2035, with the offshore wind capacity expanding to 84 GW over the following 15 years until 2050. Developing the necessary framework to roll-out the planned pilot projects for offshore wind is therefore a prerequisite already from today to achieve the offshore wind targets stated in PDP8 and beyond, considering the long planning and construction time needed for offshore wind (6-10 years).

This includes developing and implementing adequate regulations and guidelines including marine spatial planning, a price framework, and a clear permitting process to ensure speed of implementation. At the same time, it is important to timely conduct an analysis of grid point connections, develop the needed seaport infrastructure and supply chains, as well as ensure the readiness of skilled workforce.

The offshore wind pilot projects, as outlined under PDP8, should be progressed as soon as possible in order to build the necessary experience; mitigate and minimize risks and costs; raise awareness for Vietnamese authorities and increase confidence for investors.

Recommendation: Accelerating the issuance of the legal framework and specific regulations and guidelines is the prerequisite for the effective roll-out of offshore wind projects.

Waste-to-energy brings benefits to the society and environment

Waste disposal by landfilling causes serious social and environmental consequences, particularly considering the potential risk of soil and groundwater contamination. To utilise the waste resources and protect the environment, the amount of waste to landfills should be reduced to a minimum level, and at the same time an effective waste management system should be strengthened with priority given to waste collection and classification for recycling and electricity generation.

A modern waste-to-energy incineration plant is a measure to help improve public health, bring positive impacts on local environment, reduce GHG emissions compared to landfilling and effectively utilise resources for sustainable development.

Recommendation: Consider to revise existing legislation to prohibit landfilling of combustible and recyclable waste. Increase collection and classification of waste for recycling and electricity generation.

5. Securing and balancing the power system

5.1 Overview and trends

The energy system in Viet Nam must ensure continuous balance and stability, a task growing in complexity with increasing power demand and share of variable renewable energy. With the primary challenge of keeping up with significant annual increases in demand, while also managing daily and seasonal fluctuations, Viet Nam has prominently succeeded in ensuring that its power system develops in line with the country's economic development. The challenge of meeting the increasing demand is expected to persist, and the required investments in new generation and transmission capacity are projected to meet these increases in demand, as described in Chapter 4. In this chapter, focus will be on describing the challenges associated with ensuring that the power system is balanced effectively, not only to meet variations in demand, but also to make the best use of the new variable energy production primarily from the future wind and solar capacities.

Figure 5.1 illustrates how the national power system is balanced today. In a typical day in 2023, coal supplies the base-load, natural gas provides the medium demand range and hydro flexibly adjusts its output to respond to the daily variations in demand and renewable generation. This adjustment is particularly noticeable around noon, when hydro generation is reduced to align with the lower demand at lunch break. Similarly, hydropower is used during the afternoon to accommodate for the abrupt reduction in solar generation and demand, leading to a required net increase from other units – today, hydropower.

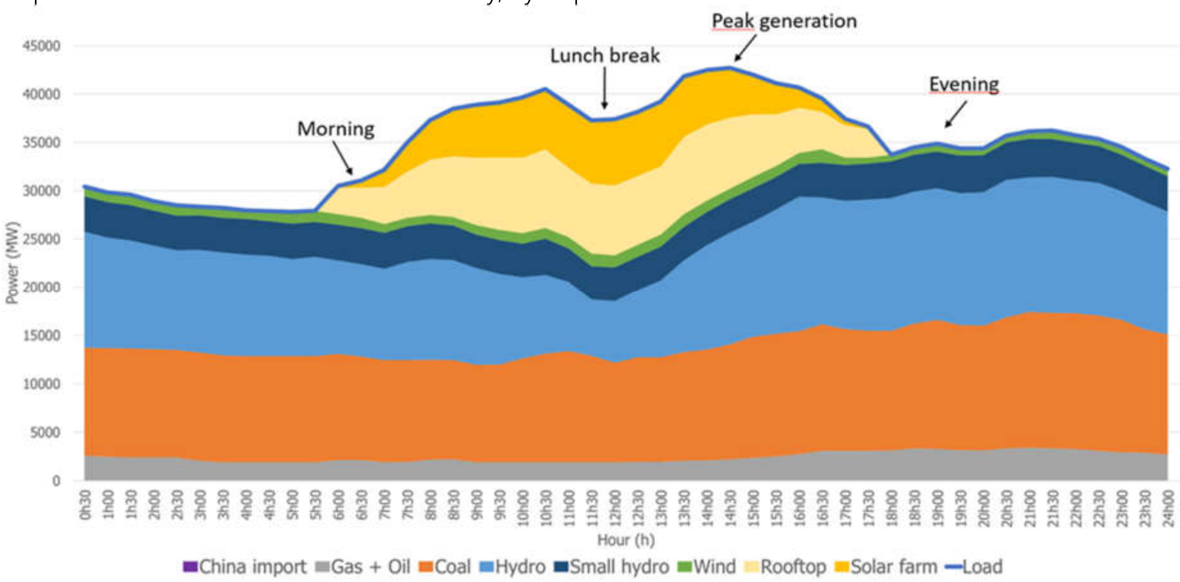


Figure 5.1 Power generation and demand on a summer day in 2023 (NLDC).

As can be seen from Figure 5.1, the current thermal power plants of Viet Nam (coal, gas and oil) are not generally assisting with the intra-day balancing of the power system, although there can be instances where local constraints can require contributions from thermal power plants, which is not visible in Figure 5.1. Any significant increases in renewable generation will naturally challenge this current mode of operation, as there are limits and technical requirements to the balancing capacity of Viet Nam's hydropower plants.

5.2 Key results

Variability and power system dynamics

The integration of increasing amounts of renewable energy into the Vietnamese power system introduces complexities not only due the variable nature of the demand load, but also the intermittency of variable renewable electricity (VRE) generation. Consequently, the future system will be driven by the changes in both the renewable generation and demand, i.e. residual demand[13], rather than adjusting solely to overall demand level. Figure 5.2 illustrate the evolving challenge of balancing the power system, based on the VRE shares projected in the Net-Zero scenario. On a specific day in June in the year 2030, electricity demand is projected to peak at 64 GW during

[13] The residual power demand is defined as the remaining power demand after deduction of VRE-based power production.

the morning at 8 AM, while the lowest residual demand in the same day drops to 21 GW at 11 AM when the sun is at its highest (Figure 5.2a).

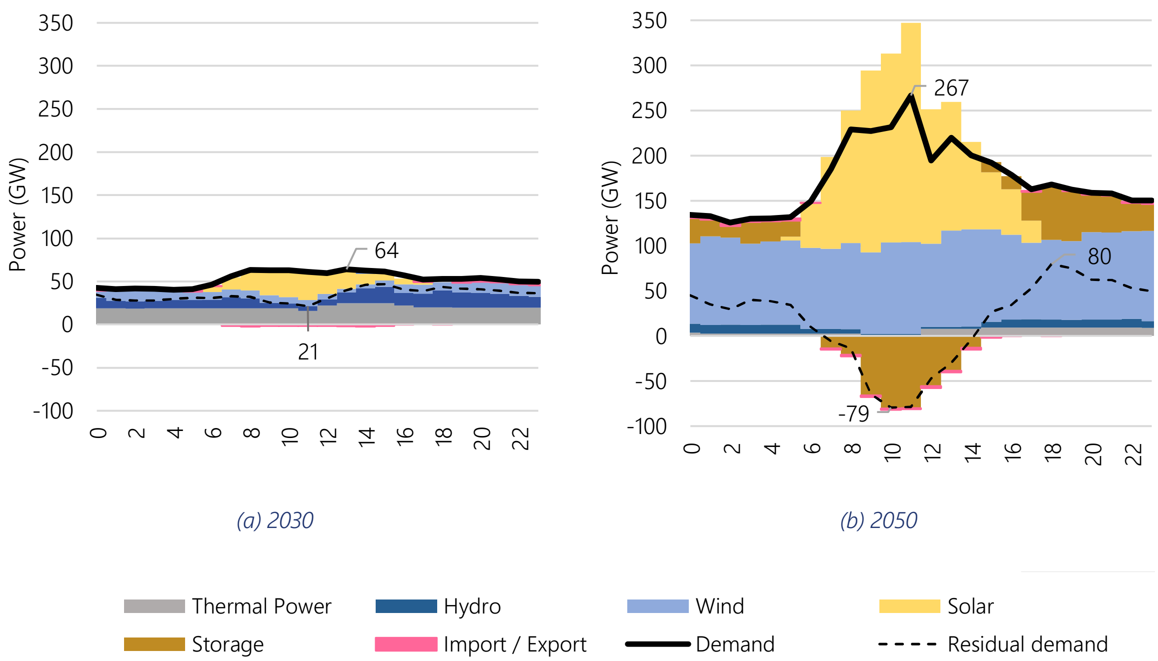


Figure 5.2 Demand and residual demand in Viet Nam for the 17th of June in 2030 (left) and 2050 (right) based on the Net-Zero scenario.

By 2050, the annual power demand increases by more than 460% in 2050 compared to 2022. The growing trend corresponds to a higher demand peak for a typical day in June for the year 2050 (Figure 5.2b), reaching 267 GW. Moreover, the large expansion of wind and particularly solar generation in the Net-Zero scenario results in a residual demand of -79 GW. The power system will be significantly challenged by this shift from a large overproduction (negative residual load) during the midday hours, to a relatively large positive residual load (need for added generation) only 6-7 hours later during the meal preparation period (around 6 PM), where the residual demand reaches 80 GW, as seen in Figure 5.2b.

Such drastic daily changes challenge the balancing and increase the risk of curtailment, therefore requiring a high degree of flexibility from all generation units, not the least from thermal power plants, as well as flexibility from other sources such as electric cars, batteries and hydro storages, and industry demand. A similar development can be observed in the Baseline scenario, although to a lesser extent, due to a lower VRE capacity.

Figure 5.3 represents a more diversified power system (compared to today) with greater shares of renewables and flexible technology mix, showing the balancing of supply and demand in a given week in 2050 for the whole Viet Nam when reaching the net-zero target. While such a VRE-based system is more challenging to operate efficiently, significant gains can be expected in reduced fuel costs and fuel import dependencies.

Large excess production of electricity from wind and PV plants are accommodated by flexible sources such as storage and flexible demand, while hydro and LNG play an important role in making up for the afternoon and evening deficits in power generation. Even nuclear can be required to shut down, during specific times. These flexibility sources are all crucial for distributing energy during the periods when solar power is not available, ensuring a consistent and reliable energy supply throughout the day and night.

To reach the adequate flexible power supply in 2050, and ensuring the system operates efficiently, at low cost and ensuring a safe and reliable operation, several measures need to be developed and implemented, starting already from today.

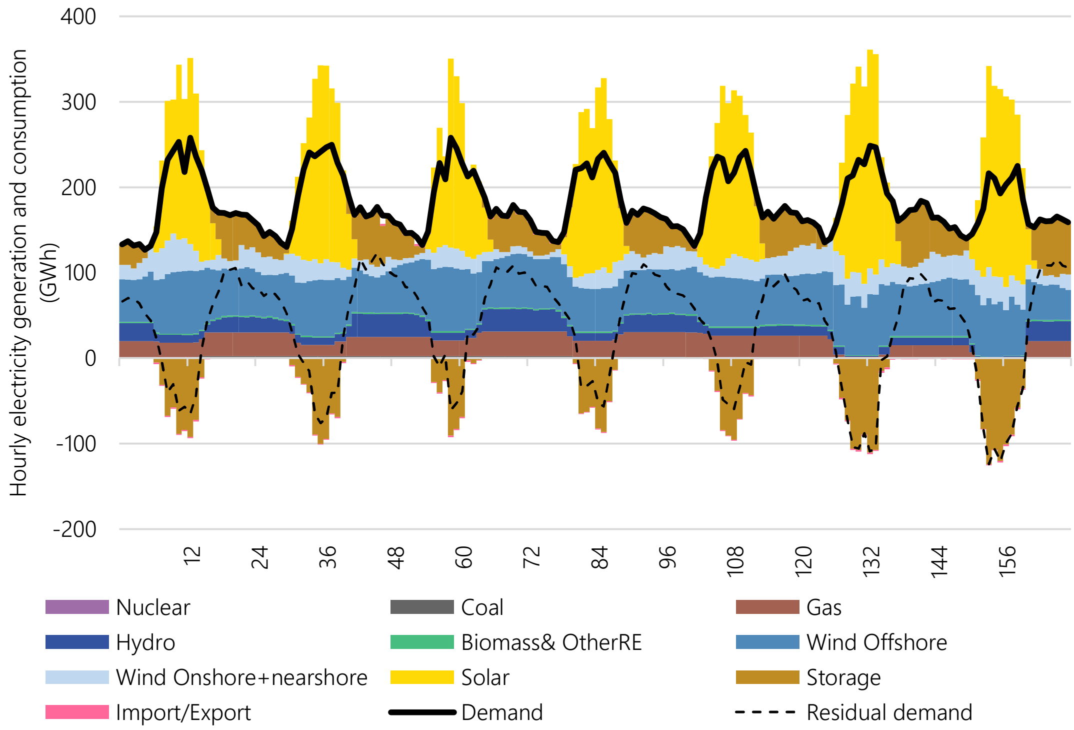


Figure 5.3 Hourly dispatch for the whole Viet Nam for a week in June of 2050 for the Net-Zero scenario.

Flexible measures and improving the systems efficiency

Viet Nam faces a significant risk in regards to security of supply if integration of RE is delayed, and if flexible measures to accommodate RE are not implemented in time. This could lead to greater degree of curtailment, higher system costs and possibly higher dependency on import of fuels. An overview of such flexible measures including the relevant timing for the implementation of the technology or solution is depicted in Figure 5.4.

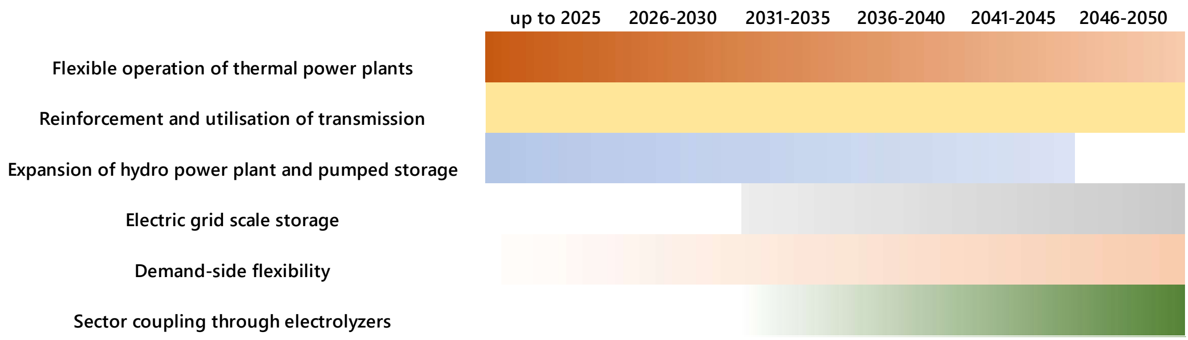


Figure 5.4 Development of flexible measures to reach the net-zero target in 2050.

Some measures will benefit the Vietnamese power system already today, such as improving the flexibility of existing and new thermal power plants, expanding hydropower and reinforcing the transmission system. Other measures are equally important, but as the scenarios show, they are not cost-efficient to be deployed until after increased flexibility in power plants have been implemented. Eventually, though, it will become necessary to use electric storage, demand-side flexibility and sector coupling with green hydrogen production (electrolysers). Up until the mid-2030s, these technologies would however only be developed at a test or pilot-level, due to high investment and operational costs.

All the above measures, as listed in Figure 5.4, are important actions to improve the power system’s ability to withstand critical situations, such as low reservoir level of hydro plants, high prices for imported fuels, outages of power plants and exceptionally large or low demands. In other words, to improve the power systems efficiency, flexible measures are necessary to increase the pool of active resources the National Load Dispatch Centre can resort to, in order to balance the system. The flexible measures in Figure 5.4 are therefore not able to stand alone and are highly dependent on the design of suitable regulatory frameworks, grid connection requirements for producers and consumers, compliance of such and developing incentives for all actors to take part in increasing the efficiency of the power system.

While there are plans in Viet Nam's Energy Master Plan and PDP8 to transition Viet Nam's power coal power plants to run on ammonia, and LNG power plants to use hydrogen, this development is not supported by the scenario results herein reported. While production of green hydrogen and ammonia are options available in the modelling set-up, both of these options are too costly for use as fuel in power plants. Instead, LNG is used in the NZ and BSL scenarios for generation during periods of high residual demand. Green hydrogen and e-fuels are almost exclusively used in the transport sector, with a small share used in industry as well (see Chapters 7 and 8).

Flexibility potential of existing thermal power plants

In Viet Nam all thermal power plants are incentivized to operate at highest possible load and heat rate (plant efficiency), which leaves little room for flexible operation. As a result, the coal thermal power plants primarily act as base load, with the hydropower and, to some extent, gas power plants meeting most of the system's balancing needs. While this approach in theory maximises the production efficiency of each individual plant, this mode of operation will effectively hinder integration of variable renewable energy, such as wind and solar. The economic efficiency of the whole power system is therefore not optimised when each power plant is running more efficiently at high load.

With higher shares of renewables, inflexible thermal power plants may lead to curtailment of the renewable energy production, which in turn results in a higher cost for the whole power system, as well as increasing risks – and thereby cost – for investors in renewable energy.

Figure 5.5 illustrates the consequence of inflexible operation of coal and natural gas for an example week in February 2030, where solar production is curtailed in the middle of the day for more than 10 GW, even though coal or gas plants could have operated at a lower load and saved the curtailed power.

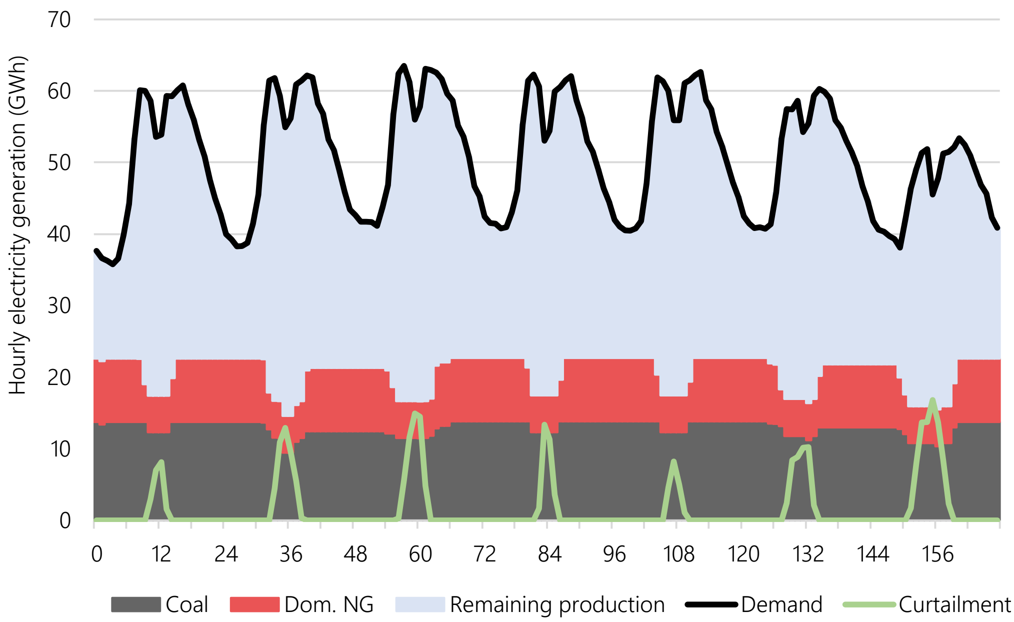


Figure 5.5 Hourly dispatch from gas and coal plants for the Net Zero scenario in week 8 in 2030, along with demand and curtailment (the total curtailment in week 8 amounts to 284 GWh).

Based on experiences from Germany (Agora Energiewende 2017), Denmark (DEA 2021) and India (Government of India 2023), it is assessed that significant benefits from improving power plant flexibility can be gained. Low to no cost options are available merely by training the staff and educating on how to operate the power plant differently (ERAV & DEA 2023) and could be activated by improving incentives for power plant operators. Depending on the specific power plant, different retrofit options are available in order to lower the minimum load, increase ramp rate and lower start-up time.

However, while solutions exist for flexible operation, there are barriers which have to be addressed before thermal power plants can operate flexibly. The possible barriers are given in Table 5.1.

Table 5.1 Possible barriers and solutions for limited flexible operation of thermal power plants.

Barriers for flexible operation of thermal power plants	Possible solutions to overcome barrier
PPAs and other contracts promote high minimum load, and constant operation	Revise existing PPAs and ensure that power plants benefit from providing system services.
Domestic coal is promoted, even though the quality makes it difficult to operate the power plant at low loads without adding fuel oil (ERAV & DEA 2023)	Reduce reliance and use of domestic coal, especially on power plants in areas with high VRE potential.
Viet Nam's power system requires very high amount of inertia, which leads to high baseload operation	Formulate strategies to reduce the reliance on required inertia demand, including improving grid connection codes for generators and large demand units.
Operators have limited know-how and experience with operating plants at lower minimum loads and higher ramp rates (ERAV & DEA 2023)	Ensure regular demonstration and testing of flexibility parameters, with increasing ambitions for the tests and daily operation parameters.

By incentivizing and improving the profitability for thermal power plants to provide higher flexibility, the individual plants heat rate may decline, but this comes at a higher efficiency of the system as a whole, since renewables are utilized more fully and the system improves its resilience.

Transmission reinforcement

Reinforcement of the transmission capacity is necessary to balance and operate the system adequately, reduce congestions of lines and especially balance regional distribution of RE generation towards demand regions. The transmission grid is therefore crucial for the security of supply and to enable high shares of RE.

The analyses show that large transmission capacity reinforcement is required in any scenario (Figure 5.8) from 27 GW in 2022 to 81-90 GW by 2050, which represents more than a 3-fold increase of transmission capacity within the next three decades in Viet Nam. Both investments in High Voltage AC and DC lines are found.

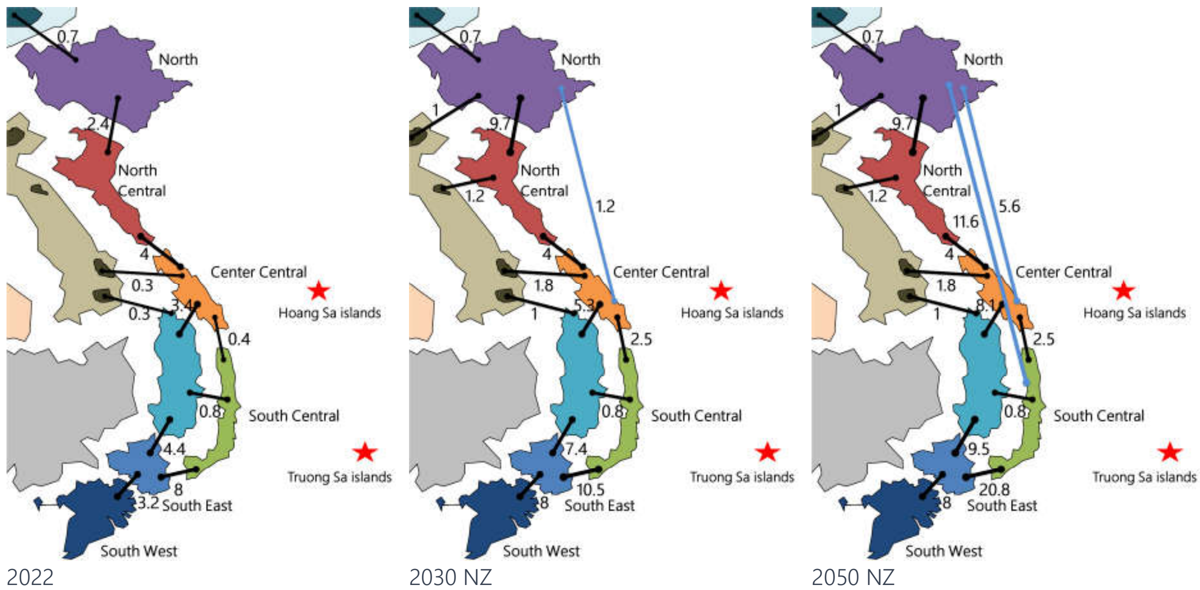


Figure 5.6 Installed transmission lines in GW in 2022, 2030 and 2050 in the Net-Zero scenario (black lines indicate HVAC connections, and blue lines indicate HVDC connections).

Towards 2030, a planned expansion of interregional grid capacity to 48 GW, almost doubling today's capacity (Figure 5.6), is implemented in all scenarios and is found to be in line with the projected need for the net-zero pathway. Thus, it is highly important that the planned transmission upgrades are implemented within this decade and commissioned to ensure the security of supply and integration of distributed RE technologies. This planned reinforcement is mainly to strengthen the connection to the North (N) from North Central (NC) by an additional

7 GW, as well as 5 GW connection towards South East (SE) from the surrounding region and some reinforcement in the central regions. In net-zero scenarios already by 2030, an additional 1 GW of High-Voltage Direct Current (HVDC) line is added connecting North with Center-Central (CC).

The need for increasing interregional transmission capacity is largely driven by the geographical distribution of power production and consumption. The regional production of electricity will be determined by the local potential of RE and electricity consumption is assumed to have similar demand distribution as observed today. As a result, North and South East regions consume more than they generate on an annual basis in 2050 (Figure 5.7), which drives the need for interregional transmission lines. By 2050 for the NZ scenario, the North Region, encompassing Hanoi, has an annual net deficit of 77 TWh. For South East, where Ho Chi Minh City is located, the annual consumption surpasses the production by 154 TWh, considering similar regional demand distributions as today. A different geographical placement of new industries has not been analysed in the EOR-NZ scenarios; however, it is evident that there are possible savings in the power grid to be had by promoting new energy-intensive industry in regions with high RE capacities over placement in regions with less RE potentials.

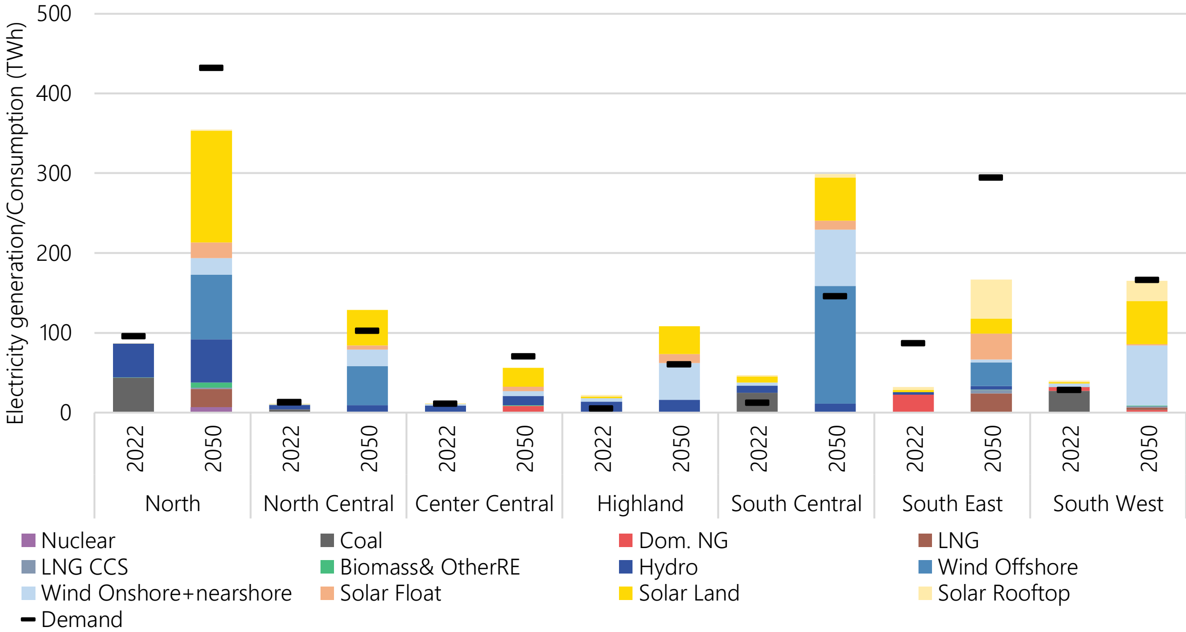


Figure 5.7 Generation and consumption per region for Net-Zero scenario in 2022 and 2050.

Within the period 2030-2040, 12-14 GW of additional transmission capacity is installed in all scenarios, where the majority is HVDC lines. For transmission of electricity over long distances, HVDC provides the benefit of lower losses and reduced investment costs for long distances (more than 400 km) compared to High-Voltage Alternating Current (HVAC) (Institute of Energy 2020). By 2040, a total of 10-13 GW HVDC lines are commissioned in all scenarios to enable power exchange from South Central (SC) and CC to N (Figure 5.8). By 2040, SC is an area with surplus of exported electricity, due to large generation from onshore and especially offshore wind, while CC has mainly flexible gas power generation.

In the period 2040-2050, large investments are required, with additional 17 GW capacity in the NZ, 28 GW in the BSL and 20 GW in the NZ+ scenario. The development is focusing on 3 main connections, with the development of 10 GW from SC to SE in the NZ scenario in order to further enable the transmission of the growing offshore wind generation thus supporting the import need of SE; the HVDC expansion towards the high demand centre in the North, with 5 GW from SC, and further reinforcement of transmission from the Highlands (H) to CC.

In summary, the connection from SC to SE becomes the largest (21 GW in NZ and 22 GW in NZ+ scenario) to support the high import needs of SE. Moreover, connections from the Highlands to SE and from H to CC (each 8-10 GW), harness the excess RE generation from the H region. HVDC lines are expected to play a significant role and the development is crucial to support the high electricity demand in the North. In 2050, HVDC lines of 9-11 GW from SC to N region and 6 GW between CC and N are installed in the NZ and NZ+ scenario respectively.

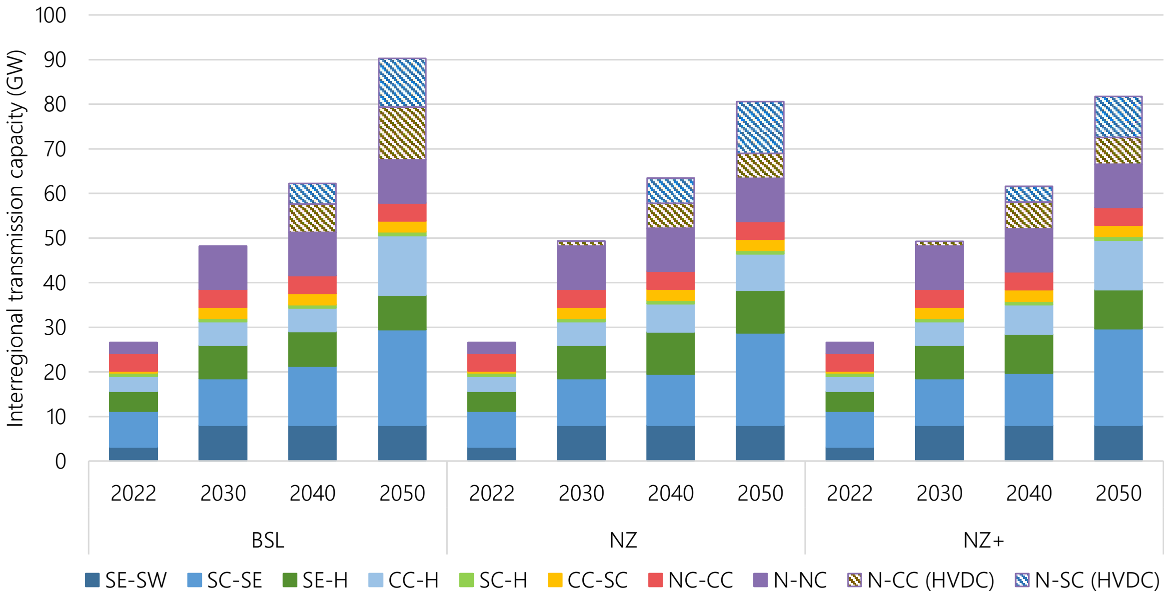


Figure 5.8 Interregional transmission capacity development for key scenarios.

Storage

Storage solutions will increasingly contribute to the balancing of the system and accommodate the huge investments in RE. In the long-term, battery storage is of particular importance to support the electricity generation during night hours without solar generation. Storage investments are crucial from 2035 onwards (Figure 5.9), and even when the net-zero target is not enforced (BSL scenario), a storage capacity of 78 GW/ 451 GWh is cost-efficient by 2050. The storage need is largely increased in the net-zero pathways, with almost a doubling in volumetric storage need to 124 GW/ 793 GWh in the NZ scenario, and a tripling of capacity to 154 GW/ 1,372 GWh in the NZ+ scenario.

Electricity storage technologies include pumped hydro projects, batteries and flywheels. However, only pumped hydro and batteries are invested in across the analysed scenarios. Today, pumped storage facilities are under construction and the first pumped hydro storage is expected to be commissioned in 2030. Until 2045, pumped storage serves the majority of storage need, with the full potential (26 GW/ 200 GWh) being reached. The first battery storage is installed by 2035 in NZ, NZ+ and GG scenarios with small investments (0.6- 1.5 GW) and by 2040 in the BSL and GT scenarios. After 2040 the storage need increases rapidly. As pumped hydro limits are reached and more RE are integrated, large battery investments are needed, amounting to 98 GW in the NZ and even 128 GW in the NZ+ scenario becoming the main storage technology.

Over time, there is the need for an increased C-ratio[14] and storage volume size. Pumped hydro storage has a fixed storage volume per turbine capacity (around 7-9 h). For battery technologies, individual storage volume and inverter capacity are individually optimized, resulting in storage sizes increasing from an average of 2 h in 2035 to 6 h in 2050 in the NZ scenario and 9 h in the NZ+ scenario. This is a result of the need for high solar energy stored during the day and long discharge periods during the night.

[14] The storage volume (GWh) divided by the installed turbine capacity (GW), provides the time duration a full storage completely discharges.

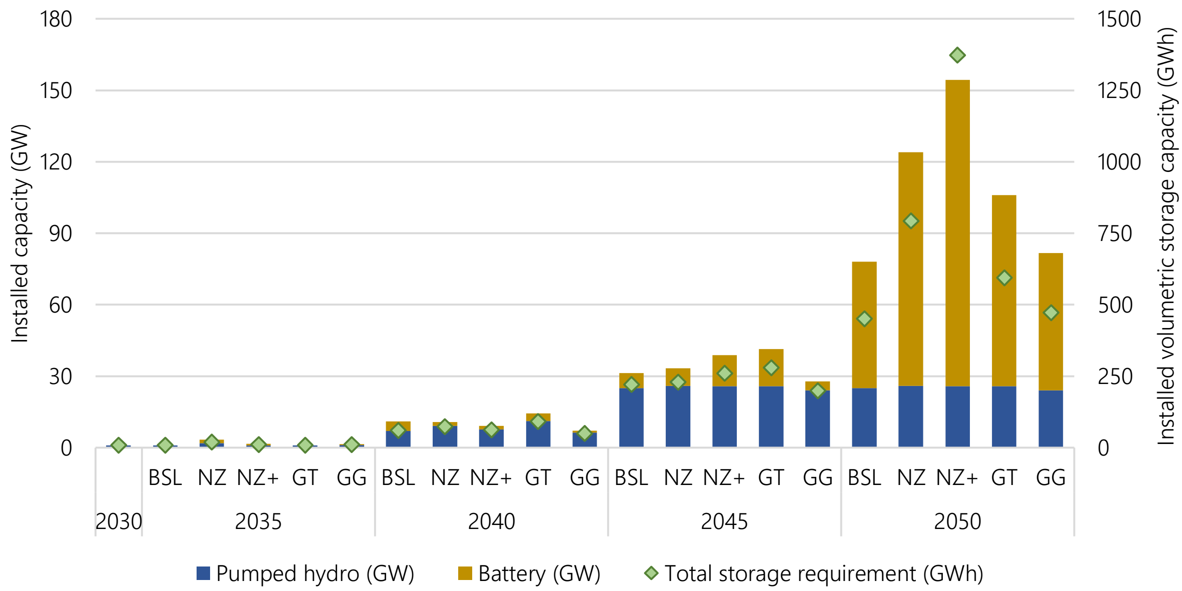


Figure 5.9 Battery and pumped storage capacities (GW) and total volumetric storage capacity (GWh).

The investments in batteries are driven by two main factors: the location of high RE potentials, specifically solar power, and the availability of other balancing options like transmission and flexible demand. The close development of storage and solar generation is illustrated below (Figure 5.10), exemplified for the NZ scenario. As solar power is only available during day hours, the storage can charge excess solar generation during the day and provide electricity during non-solar hours (as seen in Figure 5.3). As a result, the North has a very high need for storage (190 GWh in the NZ), as it is the region with the highest solar capacity.

The limited availability of other balancing options like transmission capacity is also a driver for storage needs, as is the case in the South West region where the high storage (203 GWh in NZ) instalments are due to a combination of high solar and onshore wind capacity, as well as the need to compensate for the low transmission capacity of SW's non-central location.

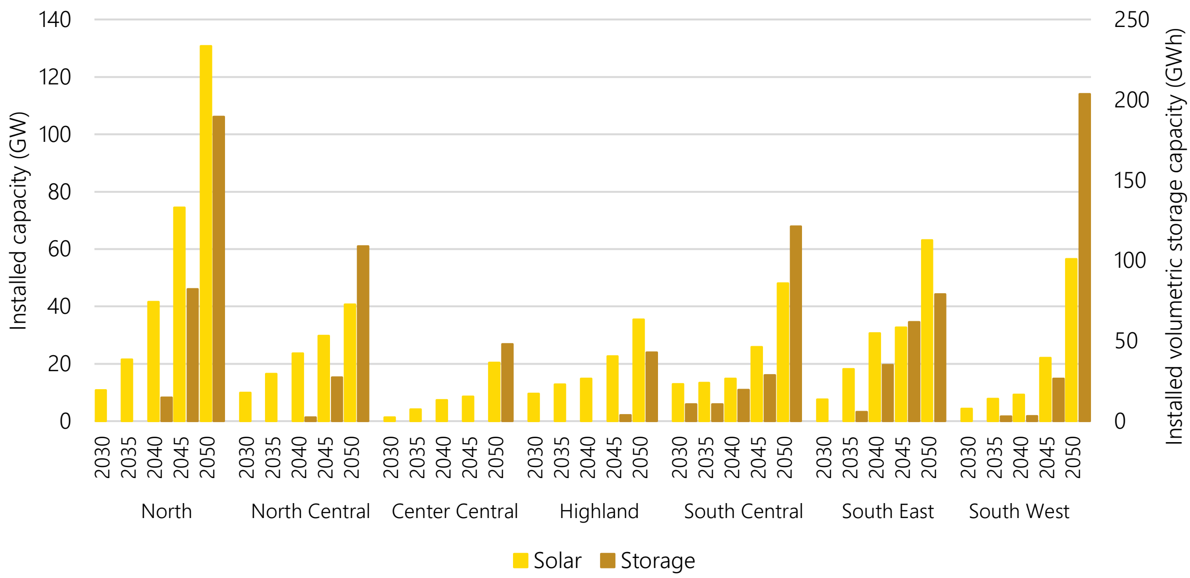


Figure 5.10 Installed capacity of storage (batteries and pumped storage) in GWh and solar power in GW per region in the NZ scenario.

The close relation between storage need and solar power is also evident from the sensitivity analyses on battery costs for the NZ scenario. A lower battery price by 52%[15] in 2050 makes investments in not only battery but also solar power (+80 GW) more attractive at the expense of wind (-63 GW) and nuclear (-1 GW) (Figure 5.11). However, higher battery prices (+150%)[13] lead to no investments in batteries and in turn also lower solar capacities. To meet the demand, mainly additional investments in nuclear power are made.

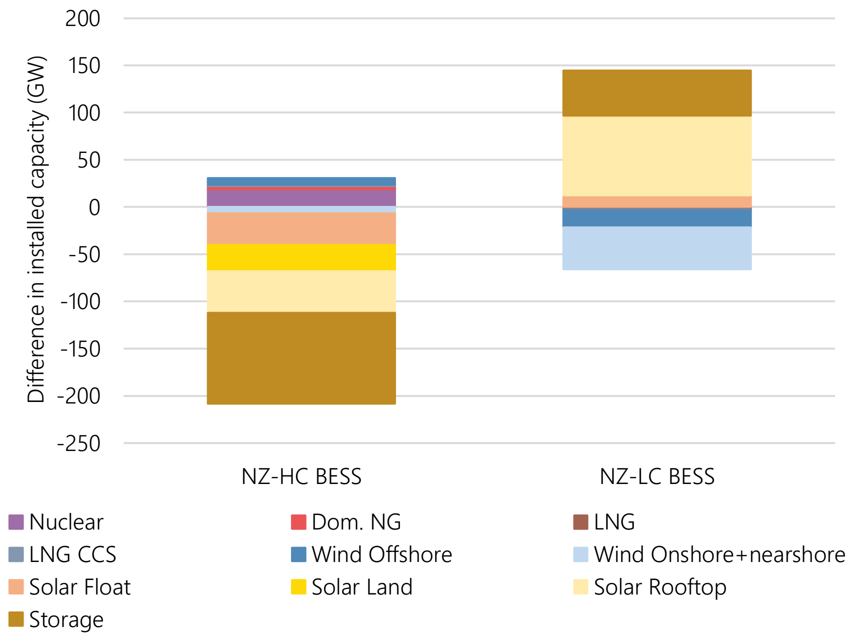


Figure 5.11 Installed capacities in generation and storage technologies under high battery cost (HC BESS) and low battery cost assumption (LC BESS), as compared to NZ scenario in 2050.

Flexible demand and sector coupling through electrolysers

With a growing demand and larger shares of variable RE production, demand side flexibility is an important tool to ensure a reliable system, by adjusting part of the power consumption following the RE-based generation. With increasing electrification of end-use sectors, such as electrification of industrial processes and high penetration of electric vehicles (EV) in Viet Nam, new opportunities for flexible demand arise.

It is assumed that by 2050, 18% of industrial processes based on electricity will shift their demand flexibly, up to a 4-hour shift. Electric vehicles can provide flexibility to the grid by shifting the time of charging, adjusting the charging rate and even by discharging to the grid. For EVs, it is assumed that up to 40% of all EVs will contribute to flexible charging, with separate maximum shares on peak charging. With a fleet of above 100 million EVs (considering mainly cars and motorbikes) by 2050, there is a large potential to be harnessed in shifting power demand through flexible charging and vehicle-to-grid (V2G) from private consumers.

The hourly variation during the day shows how demand flexibility is important, by shifting consumption towards hours during day time with excess RE production (high solar generation), thus reducing the need for additional storage (Figure 5.12).

By setting grid connection requirements for all participants, including both generators and consumers, and providing incentives and developing communication and control standards, more industries can start changing their production based on electricity prices, grid infrastructure and based on customer needs.

The production of hydrogen through electrolysers for end-use sectors (covered in more detail in Chapter 6) can provide additional flexibility in the future.

[15] Based on the uncertainty range given in the Viet Nam Technology Catalogue for Energy Storage, Renewable fuels, Power-to-X 2023 (EREA & DEA 2023b)

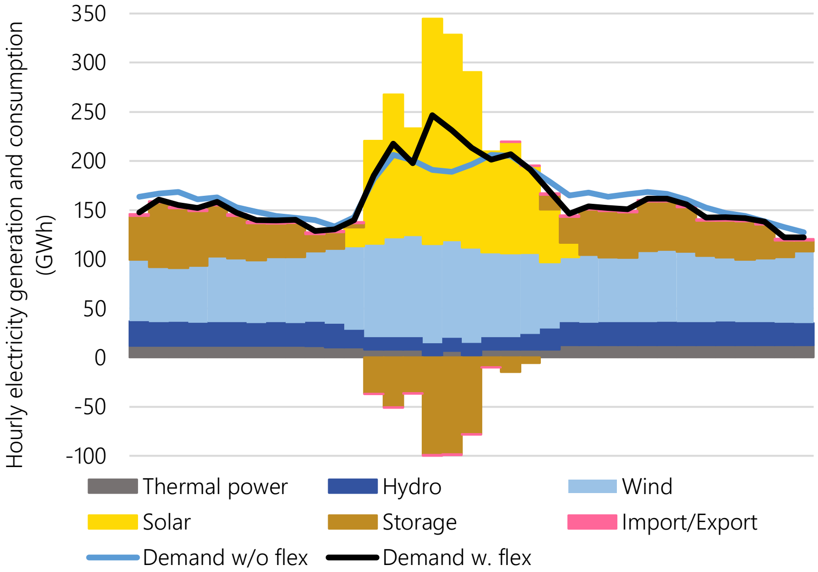


Figure 5.12 Electricity generation and demand before and after flexibility for a summer day in the NZ scenario in 2050.

The flexible operation of electrolysers allows for the documented use of fluctuating renewable energy, even when it is consumed from the national power system. This enables accounting towards any requirements on documentation for the green share of electricity consumed (such requirements were put in place in EU in 2023, for example[16]). It also helps reduce the cost of electricity consumption, as the flexible electrolyser units can avoid producing during hours where there is low production of renewable energy, resulting in lower hydrogen production prices.

Moreover, there is a substantial benefit for the power system and other consumers (i.e. residential, industries), when introducing the flexibility of electrolysers into a power system with significant shares of VRE production. By operating at production intervals between 0% and 100%, flexible operation of the electrolysers enables down-regulation of electricity consumption, which corresponds to classic up-regulation in the power system, as well as rapidly ramping up consumption. Both services are highly valuable in a VRE-based system.

The value of electrolyser flexibility is analysed in a number of studies, including by the Danish TSO, Energinet. One conclusion is as follows: "*the value of flexibility more than counters the costs of unlocking the flexibility, and that the optimal capacity factor in almost every scenario modelled is below 50%*"[17].

The cost of unlocking the flexibility, as described, pertains to changing the tariff system and market payments for reserves and other flexibility services that can be provided by electrolysers.

The resulting electricity price is shown as dark line. The production of hydrogen is primarily expected during periods of high renewable production, which also corresponds to periods of relatively low electricity prices (Figure 5.13). As the electricity price increases, the production from the electrolysers reduces, and vice versa. In this way, electrolysers' production has a similar positive effect for the economy of the electrolysers, the value of renewable energy, and the overall electricity price for the consumers, similarly to the flexible operation of thermal power plants.

[16] See Commission Delegated Regulation (EU) 2023/1184 for more details on requirements for RFNBO's (Renewable Fuels of Non-Biological Origin).

[17] Source: https://energinet.dk/media/bonk4x1i/the-value-of-flexibility-for-electrolyzers-thomas-dalgas-fechtenburg-energinet.pdf

Figure 5.13 Operation of electrolysers during a week in 2050 for Net-Zero scenario in the South Central region.

Reserves

To maintain a reliable and stable power system, it is necessary for the system operator to have an adequate power capacity available at all times. Reserves are planned into the system to balance the grid, and in order to be able to mitigate any unforeseen event and unpredictable changes in production and consumption.

Reserves, both operating and planning reserves (Table 5.2) are accounted for in the sensitivity scenario NZ-Reserve.

Table 5.2 Operating and Planned reserves in the NZ-Reserve scenario.

	Type	Estimation method	2030	2050
Operating Reserves [GWh]	Outage	N-1	55,005	296,872
		N-2		
	Spinning	3% Demand		
	Regulation	1% Demand + 0,5% Wind + 0,5% Solar		
	Flexibility	5% Wind + 5% Solar		
Planned Reserve [GW]	Dry year, low wind	30% Hydro + 15% Wind	7	34
	Temperature variations	2% (Peak load – flexible demand)		

The operating reserves are estimated based on outages and deviations in forecasts for renewable generation and demand. To account for outages, each region follows N-1 criteria (the largest unit in the region) and some regions have additional N-2 criteria (the second largest unit in the system). To account for deviations, reserves are categorised in spinning, regulation and flexibility reserves depending on how fast the reserve is required to respond. Planning reserves are determined based on climate-related environment, which could lower the annual production of hydro and renewables and increase the temperature leading to a larger electricity consumption.

For more details of how the reserve requirements were estimated in the Balmorel model, the reader can refer to the EOR Technical Report (EREA & DEA 2024).When reserves are included in the long-term power system model, certain technologies are preferred in terms of reserve provision, as not all technologies are able to quickly and flexibly change their output power. For outages, storage technologies such as Lithium-ion batteries are well suited, with a very fast response time. Therefore, the capacity mix optimized in the NZ-Reserve scenario differs from other analysed scenarios. Figure 5.14 shows a comparison between the Net-Zero scenario (without reserves) and the NZ-Reserves scenario (with reserve requirements). Existing plans up to 2030 already account for adequate capacity in the base year, so only a small addition in storage capacity in 2025 is present to accommodate the operating reserves. However, from 2030, it is more important to plan and install reserves beyond the current plans. By 2050, more storage (5 GW) is continuously added to supply reserve capacity, as well as 10 GW of LNG plants. For strategic reserves, 42 GW of hydrogen-fired power plants are necessary, as depicted in Figure 5.14.

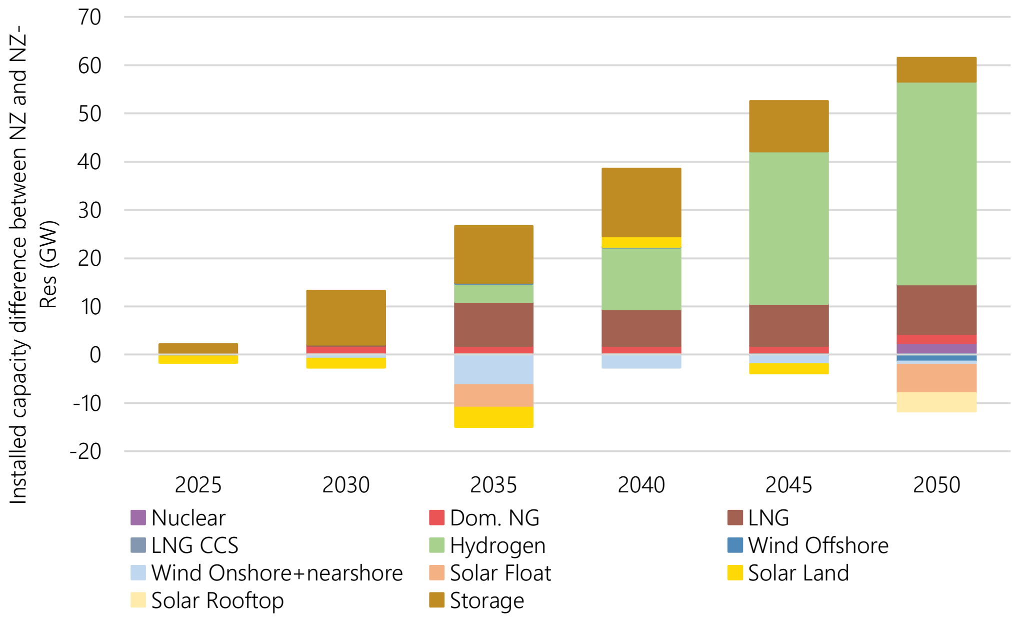


Figure 5.14 Installed capacity difference between NZ-Reserves scenario and core Net-Zero scenario (without reserves).

However, more analysis and assessment of reserves is necessary, as the future will require a larger interaction between plants. The modelling of reserves limits the options for reserves, such that only hydrogen and fossil fuels are available for strategic reserves. However, with a completely different power system and more flexible measures implemented the need for reserves could be lower and RE could also participate as reserves. Promoting the strengthening of inter-regional grid connections, such as the Greater Mekong Subregion countries possibly forming a power pool, can create additional reserve capacity or lower need for reserves.

Reserves are deployed to maintain frequency stability; however, the model set-up herein adopted only captures hourly variability, so the system stability in relation to frequency and voltage is not considered. However, storage and flexible demands can both adjust their electricity output rapidly, making them ideal contributors to maintain a stable frequency. More in depth analysis of frequency, voltage and N-1 contingency analysis is performed and described in the report "Grid modelling of Net-Zero scenario" (Institute of Energy 2024).

5.3 Key messages and recommendations

Improve power system efficiency by enhancing and timely prioritizing flexibility

In order to meet the rapidly growing electricity demand in line with the projected economic development, and to live up to the commitment for net-zero emissions by 2050, a large expansion of generation capacity and transmission grid are required, with a high share of renewable energy contributing to the power mix. To accommodate the transition, flexibility is one of the key factors that enables increasing the efficiency of the system and allowing an effective and smooth integration of renewable energy. Some measures to ensure flexible operation of the power system include upgrading the transmission grid, investing in energy storage systems, and flexible operation of coal-fired power plants. All these measures of flexibility are necessary and feasible to implement in Viet Nam, but priority should be given at different stages to achieve the highest economic efficiency. The analyses show that suitable grid investments in combination with measures to increase the operational flexibility of coal-fired power plants are the most cost-efficient options between now and 2035, after which also batteries will become cost-effective. Flexible operation of coal-fired power plants can be achieved by enacting appropriate mechanisms to increase the effective operation of coal-fired power plants in synergy with production from renewable energy plants, hence reducing the overall cost of the system by saving investment needs in transmission grid and batteries, which are currently very costly. In addition, it is necessary to strengthen training programs for operators for improving power plant flexibility.

Recommendations:

- *Support measures enabling flexible plant operation will help ensure power system stability and efficiency. Consider to introduce support measures for supplying ancillary services to incentivize flexibility.*
- *Set standardized requirements for minimum load and ramp rates for existing power plants and units being planned to provide the legal basis and incentives for increasing flexibility. Perform pilot tests to gain experience and knowledge of the required costs and other barriers for increased power plant flexibility.*
- *Develop the regulatory framework to support large scale deployment of electric storage after 2030.*

Early and consistent expansion of the transmission system in Viet Nam is required

The analyses show that strengthening the inter-regional transmission capacity from 27 GW to 48 GW in 2030 is important and a pre-condition for ensuring security of supply with high shares of RE. In the Net-Zero scenario, investments of 1 GW of HVDC (High Voltage Direct Current) transmission lines from central regions to the North begin already in 2030. In the long term, HVDC connections become a pivotal part of the transmission system enabling the distribution of the high RE generation to the demand centres. By 2050, a tripling of inter-regional transmission capacity is expected, with HVDC lines playing a vital role.

Recommendation: Develop a plan for expansion and upgrade of the transmission grid, including HVDC connections to reach a tripling of the inter-regional transmission capacity by 2050 compared to today.

6. Renewable Fuels: supply and use

6.1 Overview and trends

Viet Nam's electricity sector has evolved dramatically since the turn of the century, with an increase by a factor of nearly 10 in electricity generation from 26.5 TWh in the year 2000 to 260 TWh in 2020. At the same time, the rest of the Vietnamese energy system followed a similar development, with the total primary energy consumption increasing from 214 TWh in 2000, to 1,275 TWh in 2022[18]. Supplying the rapidly growing industry and transport sectors with energy has put a strain on the capacity for production and import of fuels in Viet Nam. Moreover, the thermal power plants also require substantial amounts of fossil fuels, either produced domestically or imported.

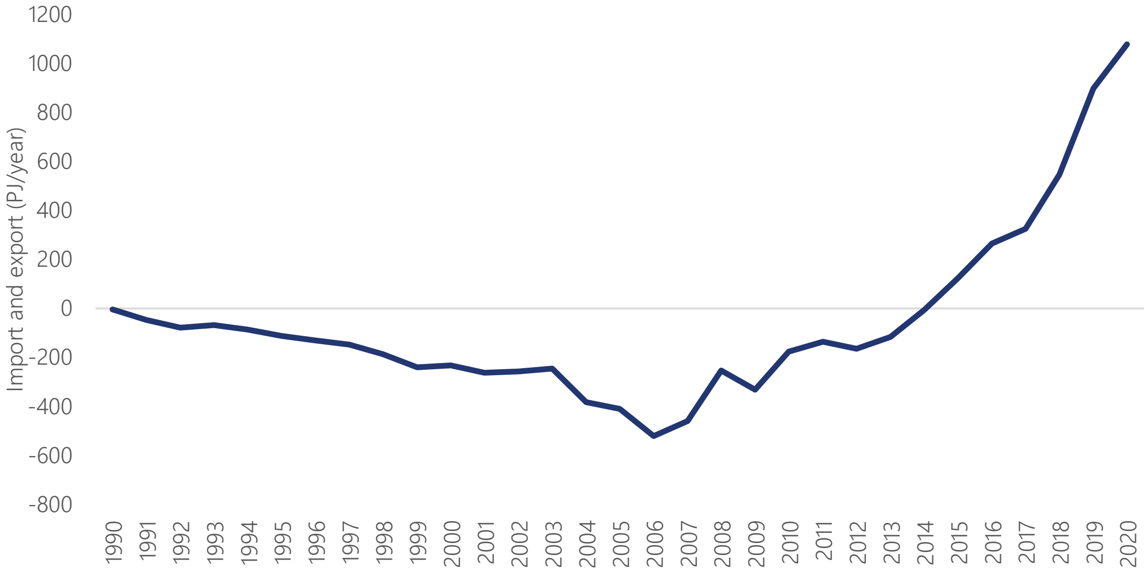


Figure 6.1 Historical import and export balance of energy products to and from Viet Nam. Negative numbers indicate net export (IEA 2024c).

Viet Nam managed to increase production of (primarily fossil) fuels to fulfil, and even exceed the increase in energy consumption up until 2014 (Figure 6.1). In the past decade (2010-2020), domestic production of coal, oil and gas has declined, which, combined with the ever-increasing energy demand, has led to a drastic increase in fuel imports to Viet Nam.

In light of the net-zero goal by 2050, increasing the share of renewable fuels is one of the key measures for mitigation of carbon emissions in the hard-to-abate sectors, i.e. industry (high-temperature heating) and heavy-duty transport segments (road freight, aviation and navigation). Renewable fuels comprise *bio-based liquid and gaseous fuels*, e.g. biogasoline from fermentation and biogas from anaerobic digestion, and *renewable synthetic fuels*, e.g. hydrogen from RE-based electrolysis, and ammonia from renewable hydrogen (IRENA 2024).

In recent years a number of plans have been implemented in Viet Nam, which seek to address the future domestic production of fuels and, not the least, renewable fuels. Reaching the national emission reduction targets while reducing the fuel import dependence can be said to rest on three important pillars, according to the results of this report: 1) Switch from coal and other fossil fuels to renewables; 2) Increase adoption of more energy efficient technologies, and electrification levels; and 3) Increase domestic production of renewable fuels.

This chapter focuses on the third of these pillars, i.e. the production of renewable fuels in Viet Nam. The transition of the power sector is described in Chapters 4 and 5, while the second pillar, regarding energy efficiency and electrification of industry, residential and transport sectors is described in Chapters 7, 8 and 9.

Currently, the National Energy Master Plan (NEMP) and the Hydrogen Strategy offer guidelines on how to develop the production of domestic renewable fuels in Viet Nam. Namely, the following overall goals and efforts are described in the NEMP:

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[18] Source: Viet Nam country data from Ourworldindata.org. Accessed in April 2024.

1) Achieve 80-85% of Viet Nam's power supply by renewable energy by 2050. Currently, the share of renewable-based generation (RE share) stands at 14% for 2022 (EVN 2023).
2) Reach a domestic energy production of 6,490 PJ by 2030, and 12,309-13,021 PJ by 2050. For reference, the total energy supply in 2022 was 4,140 PJ, of which coal accounted for about 44%.

Renewable fuel production targets are described in the NEMP and Hydrogen Strategy and herein provided for context. However, these specific targets are not included as assumptions or constraints in the modelling.

1) Biofuel production to reach about 11.7 PJ by 2030, and 544 PJ by 2050, with biogas reaching 60 million m^3 by 2030, and 100 million m^3 by 2050.
2) Annual production of synthetic fuels to reach 2-3 million tonnes by 2050 (note that this corresponds to 37-130 PJ, depending on the type of e-fuel) as stated in NEMP, and green or blue hydrogen to reach 100-500,000 tonnes (12-60 PJ) by 2030 and 10-20 million tonnes by 2050 (1,200-2,400 PJ), as stated in the Hydrogen Strategy.

In the Hydrogen Strategy, up to 10% of the domestic national energy consumption is targeted to be supplied by domestically produced hydrogen by 2050. Any additional production can be exported. No clear distinction between blue and green hydrogen is offered, except to state that both are viable.

While the NEMP primarily targets biofuels for use in the transport sector, the Hydrogen Strategy is more explicit in targeting hard-to-abate sectors for the consumption of green or blue hydrogen. This is primarily within the industry sector, such as fertilizers, chemicals and steel production, as well as use in some segments of transportation, either as direct hydrogen uses or as e-fuels, in e.g. heavy-duty road transport, shipping and aviation. In the NEMP, some focus is also on promoting a shift towards using green hydrogen and hydrogen-based ammonia in the thermal power plants towards 2050 in line with PDP8, with capacities of up to 25 GW being converted to co-firing with (or in substitution to) natural gas and coal respectively, if price-competitive.

Key assumptions for modelling of renewable fuels

In order to analyse the role of renewable fuels in the future energy system under the net-zero target, the modelling framework has been updated with a number of improved capabilities for analysing the production, transmission, storage and consumption of biofuels and synthetic fuels, including hydrogen. The renewable fuels supply chain includes the production of biogas, synthetic (bio- or e-) gas, renewable (bio- or e-) methanol, e-ammonia, and renewable liquid (bio- or e-) fuels (diesel, gasoline, and jet fuel). The hydrogen supply chain includes the production of hydrogen (blue, grey, and green), storage, conversion processes, and distribution to domestic end uses. Hydrogen can be either produced from electrolysis or through steam reforming of methane, the latter with or without CCS.

Techno-economic assumptions on the technologies included, as part of the value chains for renewable fuels are described in the Technology Catalogue for Energy Storage, Renewable fuels and Power-to-X (EREA & DEA 2023b), while further details on the modelling specifics can be found in the EOR Technical Report (EREA & DEA 2024) and the TIMES-Vietnam User Manual (E4SMA 2024).

Biomass potential

Viet Nam has a large potential for biomass energy, as it is an agricultural country with a large amount of biomass residues from crops, livestock, forestry, and industrial activities. The main biomass resources in Viet Nam are rice husk, bagasse, wood waste, animal waste, and municipal solid waste. A recent study shows that the total theoretical potential for all biomass types amounts to 3,700 PJ in 2050 (MOIT, VEA, VESC 2021). Based on this data, and with assumptions on a steadily increasing collection rate for each type of biomass, the applicable potential was estimated (Table 6.1). The assumed cost of the biomass is in the range of 0.7-3.7 USD/GJ depending on the biomass type, applied throughout the whole modelling period. This assumption, however, is subject to a high degree of uncertainty, as biomass prices can be expected to fluctuate based on international markets and availability.

In NEMP and PDP8, there are specific projects for developing biomass power plants in the short term, as well as long-term visions for using the biomass resources for energy purposes. As to renewable fuels produced from biomass, as well as the direct use of biomass for combustion processes in industry, no targets or other goals are currently set, except for a blending of bioethanol into gasoline (E5).

Table 6.1 Assumed potential of biomass types (PJ). Crop residues comprises bagasse, straw and rice husk.

Type of biomass	2020	2030	2040	2050
Wood	239	326	405	498
Crop residues	194	335	497	771
Manure and bio-waste	26	103	211	366
Agriculture waste and other	4	18	38	84
Total	**463**	**782**	**1151**	**1719**

As Viet Nam's natural forests are under significant pressure from deforestation today, potential use of forestry biomass should be carefully considered. While Viet Nam is attempting to reduce deforestation, as exemplified in the revised amount of land available for energy purposes in Resolution No. 39/2021/QH15, primary forests are still under significant pressure, and general tree cover is receding in many regions. Therefore, careful management of Viet Nam's remaining forest resources is vital, not only for the local population and environment, but also for tackling global climate change, as the forests store millions of tonnes of CO_2[19].

6.2 Key results

Biomass consumption

By 2050, most of the biomass potential is used for energy purposes across scenarios, with a utilization rate ranging from 73% to 100% (Figure 6.2). Straw and risk husk are fully utilized across scenarios, as well as wood biomass, the latter with the exception for the GG scenario in 2050. The organic fraction of waste (bio-waste) is used entirely in all scenarios, as it is assumed that the environmental benefits from collecting and using bio-waste for energy purposes offset the costs for the collection. Agricultural waste and manure are used to a lower extent in NZ and GG scenarios in 2050, due to the cost associated to collection and transportation and generally lower biomass use in these two scenarios.

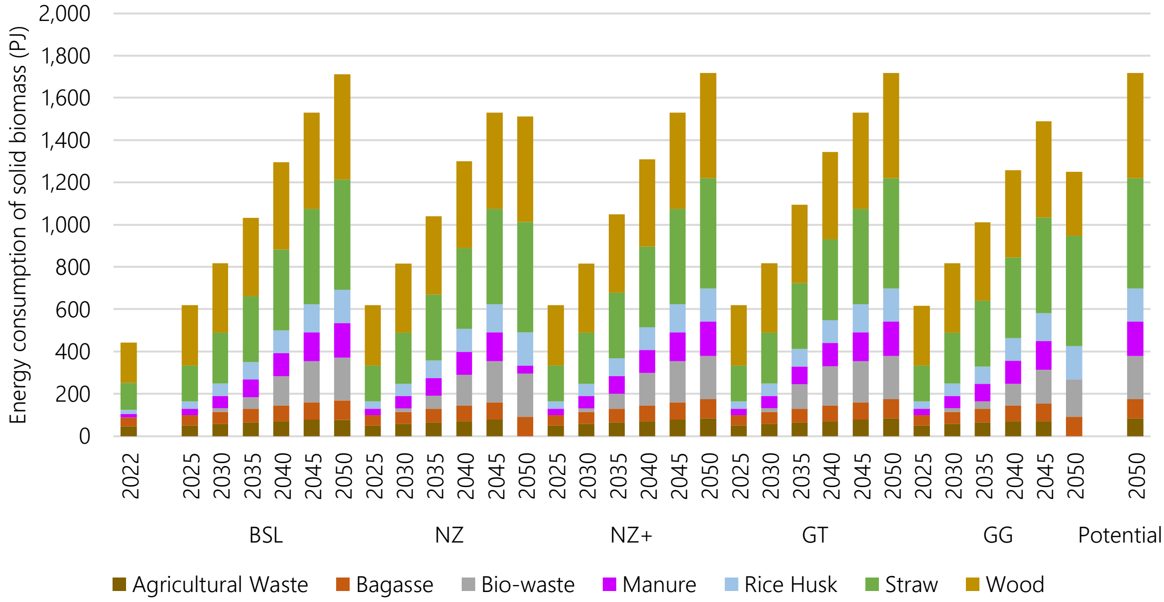


Figure 6.2 Consumption of solid biomass across scenarios in energy terms (PJ).

The main reason for this is connected to the developments in the cement industry. Biomass can be used as a substitute for coal in clinker production. However, in the NZ scenarios, biomass use is not the preferred option, because CCS needs to be installed in the cement plants in order to achieve process emissions goals and biomass-based power plants with CCS (BECCS) are not allowed in the scenario optimization due to sustainability and environmental concerns.

This modelling choice is based on the fact that BECCS bears risks for biodiversity, livelihoods, and intertemporal carbon balances. Specifically, the assumption of producing a certain amount of land-use change-related emissions first (i.e. in relation to biomass collection), and then relying on uncertain emission reductions several decades later

[19] Source: https://www.globalforestwatch.org/ and https://www.weforum.org/forests-for-climate/vietnam-from-quantity-to-quality/

entails a significant risk. It assumes a long-term commitment on land use, and does not consider economic incentives to rededicate land for other purposes (Creutzig 2021). Moreover, investments in BECCS can deter or delay ambitious emission reductions in other sectors and technologies.

In all scenarios, bioenergy is used primarily in the industrial sector to offset the use of fossil fuels (Figure 6.3 and more details in Chapter 8). This is occurring even in the Baseline scenario, which indicates that this solution is cost-effective even without accounting for CO_2 emission reduction targets. Across scenarios, the use of biomass in residential sectors is almost entirely phased out towards 2035, favouring electrification and use of other, less polluting fuels.

In the NZ scenario, the transport sector uses about 235 PJ biofuels in 2050, whereas in the GT and NZ+ scenarios, the transport sector accounts for half or more of the final bioenergy consumption. This is because biofuels are an expensive solution to realise CO_2 reductions, and thus play a larger role when stricter emission reduction targets are applied to a large extent.

Use of biomass in the power sector is not advisable based on the scenario results, considering the limited availability of such resource compared to e.g. VRE. Biomass should be therefore prioritized for use in industry sector segments where few other feasible alternatives exist, such as high-temperature steam processes.

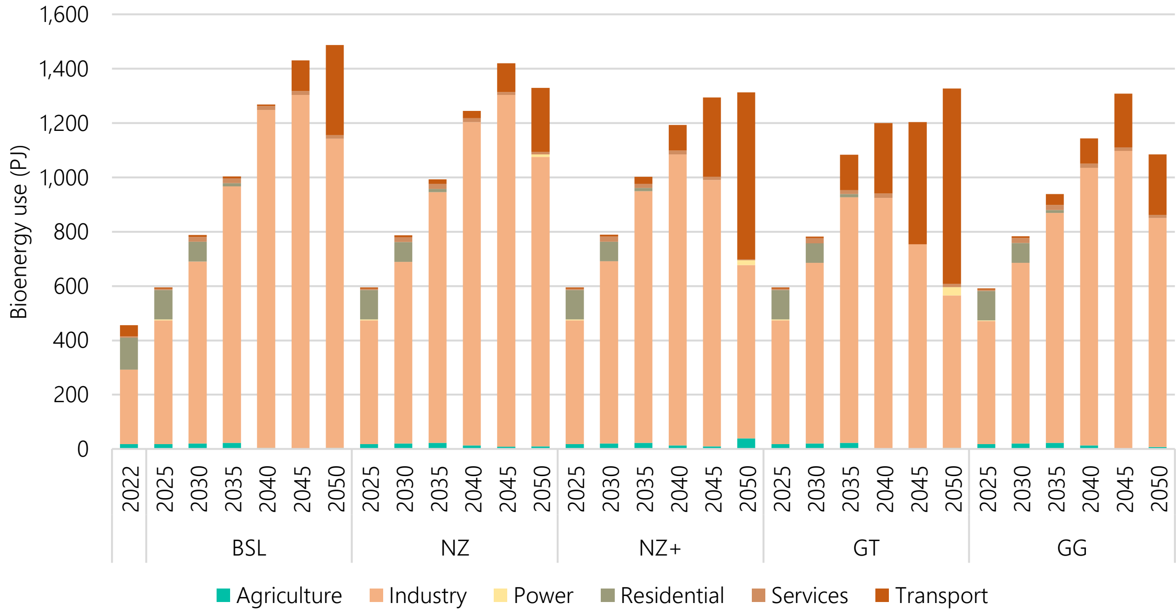


Figure 6.3 Use of bioenergy in different sectors across scenarios. Bioenergy comprises both direct use of solid biomass, as well as biofuels resulting from the conversion of solid biomass.

Renewable fuel production and consumption

Starting from 2030, a substantial increase in production of a number of renewable-based fuels can be observed across scenarios (Figure 3.6). Biogas from anaerobic digestion is quickly ramped up across all scenarios, to its fullest potential for use in the industry and transport sectors (when upgraded to synthetic gas), indicating that this technology represents a robust development path. The total supply of renewable fuels in the NZ scenario reaches a peak of about 923 PJ/year in 2050. In all other net-zero scenarios, renewable fuel production is increased even further in order to comply with the stricter emissions reduction targets (especially for NZ+ and GT scenarios).

When looking at the consumption of renewable fuels, across sectors in 2050 (Figure 6.4), the industry sector is the largest consumer, mainly for hydrogen and RE-synthetic gas, these playing a role in securing emission reductions in industry sectors like fertilizer and steel production (more details provided in Chapter 8). The transport sector consumes most of the renewable fuels for use in heavy-duty, maritime and aviation segments, particularly with RE-methanol and smaller amounts of hydrogen used for navigation (more details provided in Chapter 7).

It is worth noting that none of the renewable fuels are used in the power sector for the main scenarios and variations, but only used in the sectors which are harder to electrify and decarbonize, such as industrial processes and heavy transport. However, if reserves are implemented for the power system then hydrogen could play a role in the power sector by supplying strategic reserves (see Chapter 5.2).

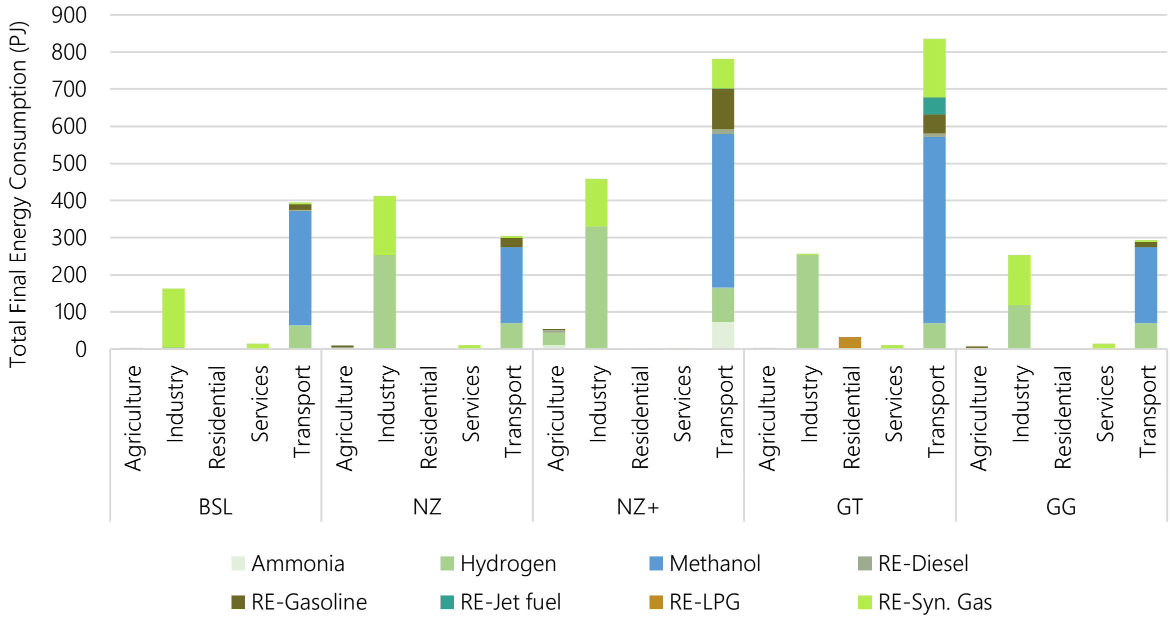


Figure 6.4 End-use of renewable fuels (excluding solid biomass) across different sectors in 2050.

Hydrogen and ammonia production

The need for hydrogen production on a commercial scale arises from 2035 in all scenarios, with 9-13 PJ (80-110,000 t), which is on the lower end of what is planned for in the Hydrogen Strategy in 2030. A continuous increase in hydrogen production is found in the BSL scenario, reaching 76 PJ in 2050 (Figure 6.5). However, whereas hydrogen is produced in much larger amounts increasingly over time across all the Net-Zero variations. In the NZ scenario, over 330 PJ (2.8 Mt) of green hydrogen are produced in 2050. In the NZ+ scenario, hydrogen demand is significantly higher than the NZ scenario, reaching 573 PJ of produced hydrogen in 2050. Additionally, it is also the only scenario where a relevant part of this hydrogen (17%) is further used for green ammonia generation (83 PJ in 2050) for the shipping sector.

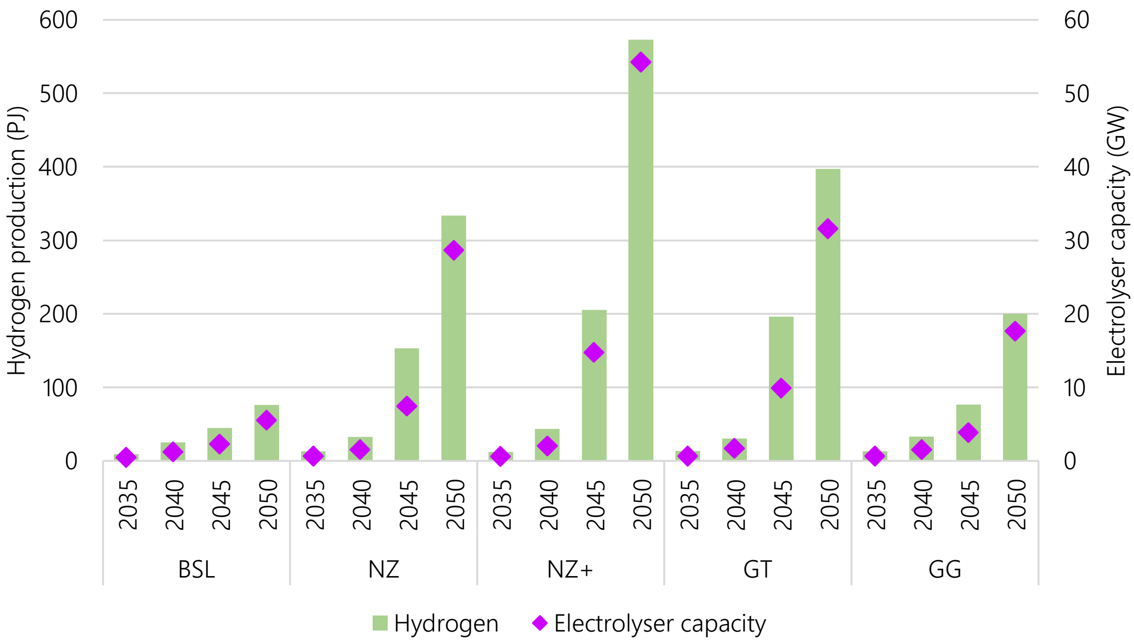


Figure 6.5 Production of green hydrogen and installed electrolyser capacity across scenarios.

Across scenarios, all hydrogen production is from electrolysis, which requires investments in electrolysers reaching around 30 GW in the NZ scenario and 55 GW in the NZ+ scenario in 2050. There are substantial losses associated with converting electricity to hydrogen: based on the energy balance of a 100 MW alkaline electrolysis cell, efficiency stands at 66.5% (EREA & DEA 2023b). To meet the demand for production of green hydrogen, a total of 13.6 TWh (corresponding to 48.8 PJ) of electricity are required in 2040 and 133 TWh in 2050, corresponding to 11% of the entire electricity demand in the Net-Zero scenario. Considering the energy losses and the investment cost for this technology, hydrogen production is primarily deployed where no other feasible alternatives exist.

Hydrogen infrastructure

The hydrogen demand is assumed to be similarly distributed across the seven modelled regions as the current electricity demand, thus the largest demand occurs in the North and South East. The analysis shows that hydrogen production is not necessarily located in the main demand areas. This is due to a significant cost difference between constructing electricity transmission vs. hydrogen transmission. Using data from Denmark, the capital cost of electricity transmission is between 5 and 15 times more expensive compared to hydrogen (Table 6.2).

Table 6.2 Investment cost of three different electrical transmission systems, compared to hydrogen pipeline. Costs are normalised per GW/km. *including HVDC station at 150 km distance (Energinet 2020).

	Indicative cost of new investments (Mill. USD/GW/km)
HVDC (2 GW)	4.03
150 kV underground cable (0.26 GW)	1.37
Overhead transmission system (2x400 kV) (2x1.9 GW)	0.58
Hydrogen pipeline 36 in (10 GW)	0.18

Due to this significant cost saving potential, the power sector optimization chooses to place the electrolyser capacities for the hydrogen production near large renewable energy potentials (solar, wind and hydro) and from there transport the hydrogen to the assumed consumption centres near the major cities of Viet Nam. Therefore, investments in hydrogen pipelines can be observed, following similar trends as the investments in electrolyser capacity (Figure 6.6).

For the BSL scenario, a modest requirement of 5 GW pipelines is required by 2050, whereas in the NZ scenario, a total of 23 GW is required. Due to significant scaling effects, which are not fully encompassed by the investment optimization, it will likely be more feasible for Viet Nam to invest in larger pipelines between different regions, depending on the long-term projected needs. For example, in the Net-Zero scenario, this could mean constructing an initial excess capacity between electrolyser production centres and demand centres in the North and South, which can later be connected through additional investments to the central Viet Nam, thereby connecting the two systems and enabling full use of the capacity. Another relevant factor to take into consideration for regional development of hydrogen pipelines is the location of new energy-intensive industries with a hydrogen demand. While different geographical placement of such industries has not been analysed, possible savings in a hydrogen pipeline network can be harvested by promoting industries with hydrogen needs in regions with high RE capacities and hydrogen production.

Besides the transportation of hydrogen, storage possibilities, both in form of large-scale underground storage and steel tanks, are relevant infrastructure when hydrogen becomes a vital part of the energy system. Here, the regional availability of underground storage can also play a role when planning hydrogen grid infrastructure. In this study, only steel tanks are included in the model optimisation based on cost assumptions from the Technology Catalogue (EREA & DEA 2023b), due to uncertainties regarding the cost and availability of underground storage. More detailed analyses of an optimised investment plan into the hydrogen infrastructure would be required, including detailed analyses on potential storage sites, yet this is beyond the scope of this EOR.

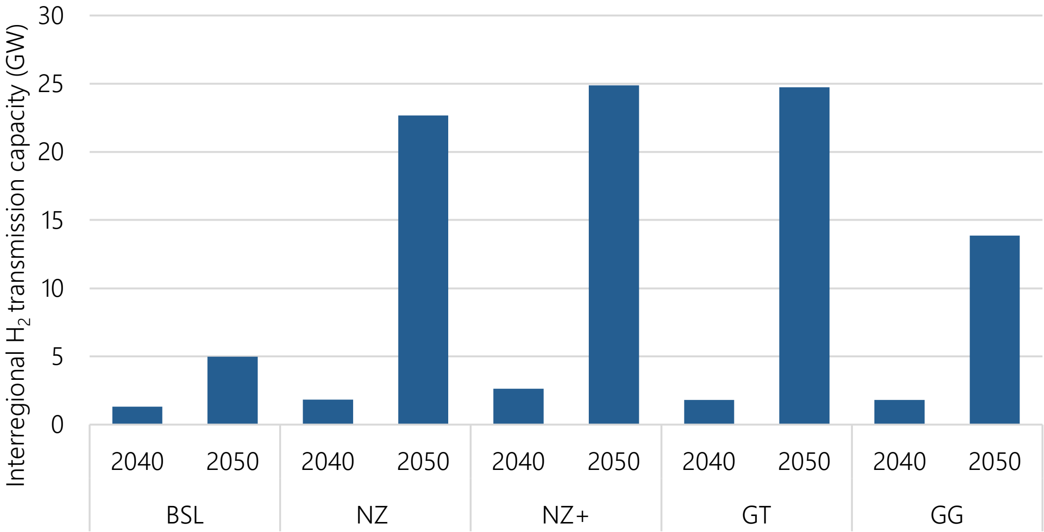


Figure 6.6 Investment in hydrogen pipelines for key scenarios.

6.3 Key recommendations

The development of hydrogen production and infrastructure will be cost-efficient after 2035

A significant amount of green hydrogen will be needed in Viet Nam in the long term to decarbonize transport and industry, but other than this, the use of hydrogen is expected to be limited to around 1-5% of the total fuel consumption (depending on the scenario), due to high domestic production costs, and even higher import costs. Hydrogen demands in the future are assumed similarly distributed to today's high demand regions, thus mainly in North and South regions. However, the analysis shows that it is more cost-effective to place hydrogen production near good RE sources and establishing an internal hydrogen pipeline system can be beneficial and therefore reduce the need for electricity transmission investments in the long-term.

Recommendations:

- *Establishing hydrogen infrastructure, namely production, transmission, distribution and storage, will be cost-effective from 2035.*
- *Analyse the potential location of hydrogen production sites close to RE generation and consumption facilities, and the possibility of hydrogen transportation by pipeline to reduce the need for transmission grid investments in the long-term.*

Prioritize hydrogen use in hard-to-abate sectors over use in the power system

Green hydrogen is expected to be necessary in large scale starting from 2040s, reaching production of 334 PJ of hydrogen in 2050 (Net-Zero scenario), up to above 573 PJ (Net-Zero+ scenario). The analyses show that application of green hydrogen and derivatives is only cost-efficient in hard-to-abate sectors, where direct electrification is not possible, such as heavy industry, shipping and aviation, and not as fuel for power generation. In industry sub-sectors such as iron, steel and cement production, hydrogen can contribute to achieving emission reduction targets, primarily from 2040, when technologies are expected to have matured. Moreover, domestic production of hydrogen through electrolysis can contribute to utilizing local RE-based generation, hence reduce reliance on fuel imports.

Recommendations:

- *Prioritize the use of green hydrogen in heavy industry sectors, i.e. cement, iron and steel production, as well as shipping and aviation through a combination of target setting and market-based measures, such as CO_2 tax or quota scheme and CO_2 credits.*
- *Implement pilot projects before 2035 in hard-to-abate sectors to build knowledge and experience before upscaling.*

Ensure sustainable utilization of biomass resources and biogas production

Sustainable biomass plays a crucial role in the industry to phase out coal where only few other feasible alternatives exist, such as high-temperature heating. Sustainable biomass is also utilized in the transport sector for the production of biomethanol through biomass gasification, synthetic natural gas and biodiesel for the heavy transport modes. Therefore, the use of biomass in the power sector is not cost-effective from a system's perspective, as sustainable biomass is a limited resource and less competitive than RE alternatives and nuclear for power generation.

The analyses consider a sustainable biomass potential of about 1,719 PJ in 2050; however, estimations on potentials and costs remain uncertain, as these are subject to changes in land use and climate change impacts, including water demand and rising sea levels, among other factors. These factors contribute to the increased risk of relying heavily on biomass for energy. Therefore, specific regulations and guidelines for the sustainable production, collection, processing and use of biomass should be developed.

Moreover, across all scenarios, the potential for biogas, with up to 176 PJ produced across scenarios in 2050, should be utilized to reduce emissions from agriculture and secure a reliable fuel supply in rural areas.

Recommendations:

- *Prioritize sustainable biomass use in industry and transport, rather than power sector.*
- *Develop regulations and guidelines on biomass resource production, collection, processing and use, including development of biogas production, where relevant.*

7. Transport sector

7.1 Overview and trends

Passenger transport has been steadily growing in the past ten years, although with a sharp decrease in 2020-2021 due to the effects from the COVID-19 pandemic (Figure 7.1). Preliminary data for 2022 indicates that transport demand has picked up again, on a trajectory to reach pre-pandemic levels.

It is important to note that the historical data herein reported is a result of statistical surveys from enterprises and transport companies, yet does not include comprehensively private uses, thus likely underestimating the total passenger transport demand.

Most domestic passenger transport in Viet Nam today is covered by road, followed by aviation. Railways and maritime transport only play a small role. In large cities, most passenger transport is covered by motorbikes. However, with improving living standards and increasing share of higher income households, a shift towards wider use of cars is projected. This could impose a large burden on the traffic in the cities, which are already experiencing frequent congestion. Improved accessibility, connectivity and reliability of public transport services, like busses and urban railways, could contribute to counterweight this development, possibly shifting a larger share of passenger transport from private to public modes.

Moreover, the large cities of Viet Nam are experiencing alarmingly high rates of air pollution with substantial negative impact on public health. The transport sector is a significant contributor to this development, together with other economic sectors. Higher efficiency standards, particle filters, and electrification, among others, could contribute to mitigate and reduce these impacts.

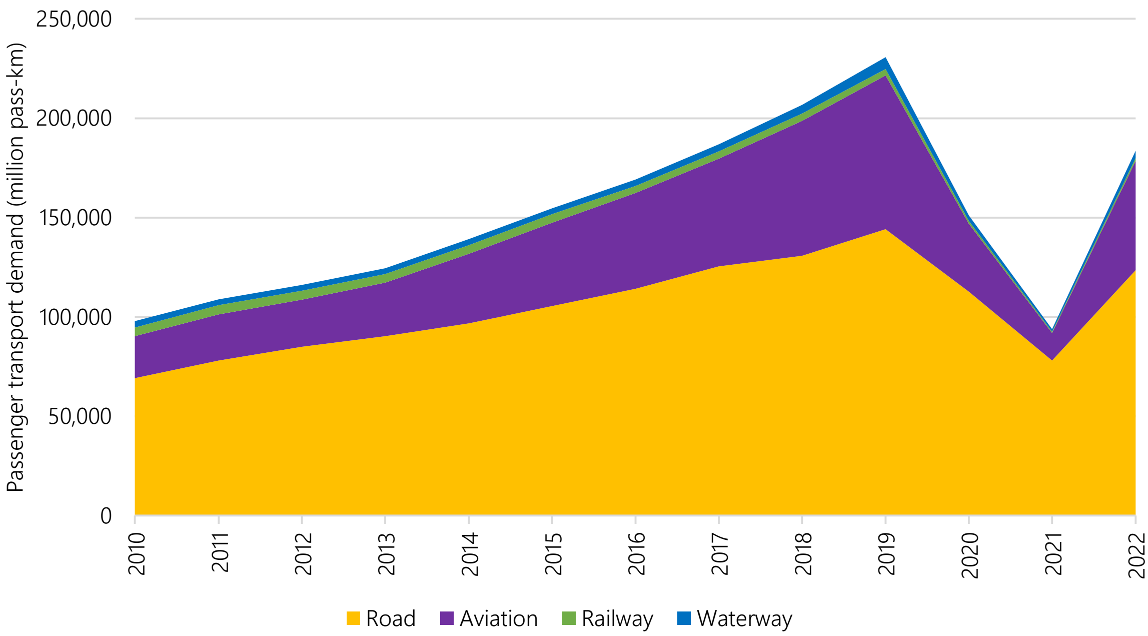


Figure 7.1 Passenger transport demand by mode (GSO Statistical Yearbook, 2021). Data for 2022 is preliminary.

Freight transport presents a similar trend as passenger transport, albeit with lower growth rates (Figure 7.2), growing steadily in the past decade, except for the period 2020-2021 due to the pandemic. Starting from 2022, as preliminary data indicates, freight transport demand has been increasing again. Domestic freight transport is mainly covered by shipping (both inland waterways and maritime transport) and road transport (i.e. trucks and vans).

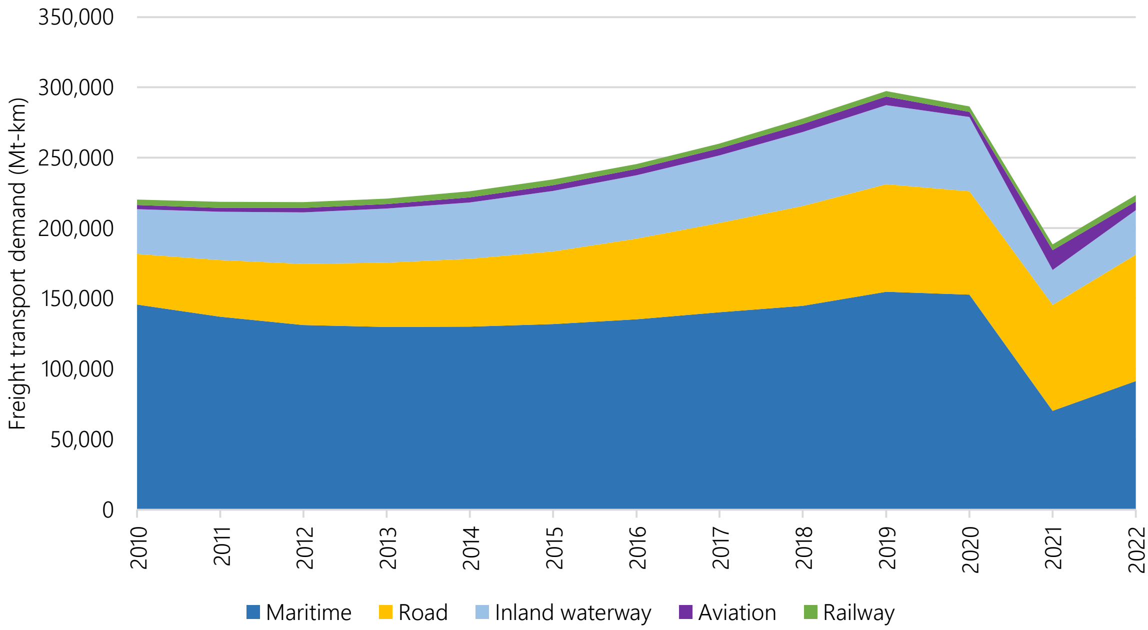


Figure 7.2 Freight demand by mode (GSO Statistical Yearbook, 2021). Data for 2022 is preliminary.

The energy supply to the transport sector in Viet Nam constitutes 23% of total primary energy supply in 2020. Today, the sector is almost exclusively fuelled by petroleum products, with the transport sector consuming around 85% of the total oil use in Viet Nam. As a result, the transport sector accounts for 15% of CO_2 emissions. With the transport demand growth projected to continue and considering the current reliance on oil products, the transport sector could potentially have a growing climate impact and fuel import dependency, unless sufficient and adequate targets and measures are set in place.

The Green Transport Strategy (Dec. 876/QD-TTg, 2022) sets important targets for the development of the transport sector towards the goal of net-zero GHG emissions by 2050. These include increasing the share of electricity and green energy across transport modes, with targets starting from 2025, as well as plans for shifting transport demand towards public modes in the main urban areas.

7.2 Key results

Following the assumed GDP growing trend, transport demand in Viet Nam is projected to increase by a factor of 4 and 10 in 2050 for passenger and freight respectively, compared to 2019 levels, as shown in Figure 7.3 and Figure 7.4. Energy consumption to supply the future transport needs follows the same growing trend (by a factor of 2.3-2.5 in fuel consumption depending on the scenario), with savings to be harnessed both through increased electrification especially of the light segments but also in other modes in the later years, as well as energy efficiency gains considering the uptake of more advanced vehicle technologies.

Moreover, in the net-zero core scenario and all net-zero variations, an assumption on modal shift has been included reflecting the introduction of a North-South high-speed railway system catering to freight transport. The assumption posits that 5% of freight transport in 2030 will be serviced by this system, which equals an increase by a factor of 5 compared to the default projection in the baseline scenario, at the expense of other freight modes, such as shipping, aviation, trucks, and vans. This shift progressively increases to 35% by 2050. As for passenger transport, an assumption regarding a transition to metro and urban railway systems in the five major metropolitan areas of Viet Nam, i.e., Ha Noi, Hai Phong, Da Nang, Ho Chi Minh, and Can Tho has been incorporated, facilitating the shift of demands from cars and motorbikes to urban railway.

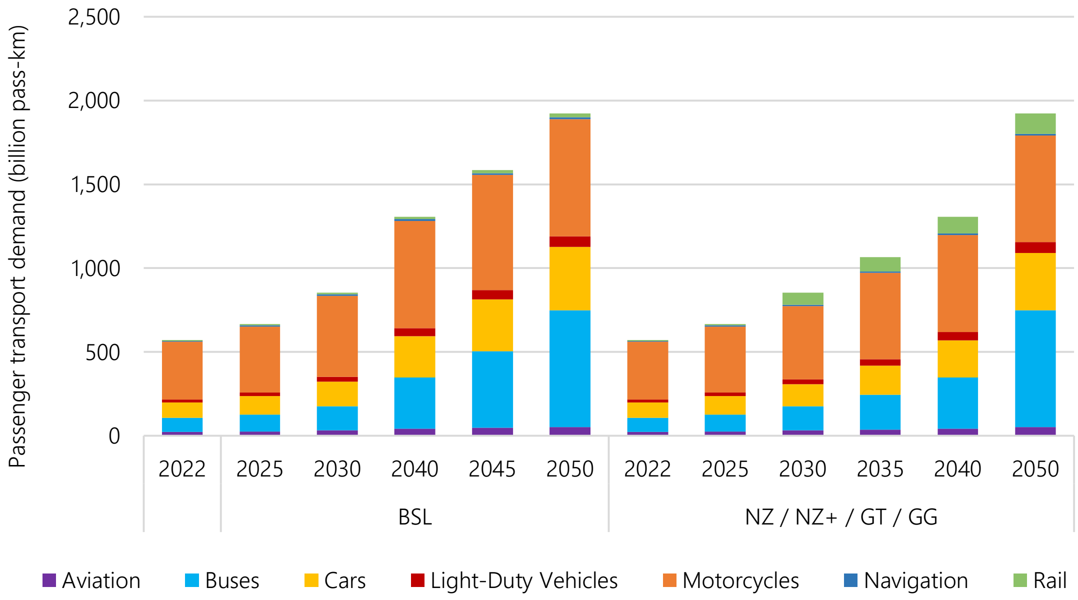


Figure 7.3 Transport passenger demand across transport modes.

Both baseline and net-zero scenarios are aligned to meet the short-term targets for the transport sector set in the Prime Ministers Dec No. 876 QD-TT for the years 2025 and 2030. This entails that all new busses and taxis must either run on electricity or be based on fossil-free fuels from 2025 and 2030, respectively for the two modes. After 2030, the development of the transport sector across the analysed scenarios follows a least-cost optimization with no specific requirement on fuel shares in the different modes, except for an assumption on increased electrification of the railway network in the net-zero case (reaching 96% and 57% electrification rates for freight and passenger trains respectively).

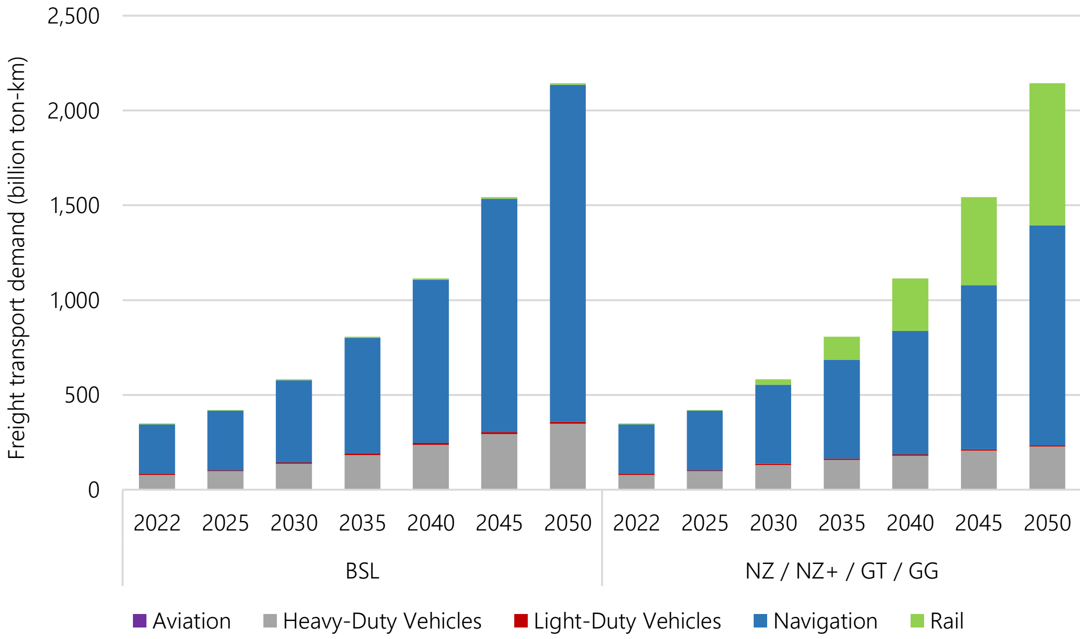


Figure 7.4 Transport freight demand across transport modes.

The assumed increasing trend for transport demand in the future is reflected in an almost doubling of energy consumption, from a current 723 PJ in 2022 to 1,380 PJ in 2050 under a net-zero scenario (Figure 7.5). In the baseline case, energy needs are even higher (1,515 PJ in 2050), mainly due to the unexploited energy savings of a more electrified system, as well as the assumed unchanged modal composition in the future. Moreover, also the more carbon-constrained scenarios (NZ+ and GT) incur in higher energy consumption for transport in 2050 compared to the core net-zero case, due to deployment of less efficient vehicle technologies (compared to the fossil equivalent) for heavy vehicles, i.e. trucks and busses.

Currently, as of 2022, diesel and gasoline are the dominating fuels used in the transport sector with a not negligible role for renewable gasoline, which is partly due to a policy directive regarding minimum blending levels for renewable fuels. The energy mix for transport until end of this decade presents a similar development for all the reported scenarios. Post 2025, electricity emerges, replacing firstly gasoline and secondly diesel, becoming the main fuel used in a net-zero scenario in 2050, and particularly evident in the most carbon-constrained scenarios (Figure 7.5).

In the later years, renewable methanol penetrates the fuel mix across all scenarios, becoming a key fuel for maritime transport. The shift away from fossil-based fuels in navigation is driven both by air pollution costs (especially in the baseline case) and emission limits in the net-zero scenarios. Modal shift in the net-zero scenarios results in a relatively lower total fuel consumption post-2030, as travel demand for both passenger and freight is increasingly moving from private means and maritime modes towards (electrified) railway and metro respectively, with the ensuing energy efficiency gains.

The growing trend on utilization of renewable fuels in the future, driven both by the climate goals and the internalization of air pollution costs in the analysis, results in RE fuel shares of up to 56% in 2050 on the total energy needs, under the most ambitious transport policies as implemented in the GT scenario.

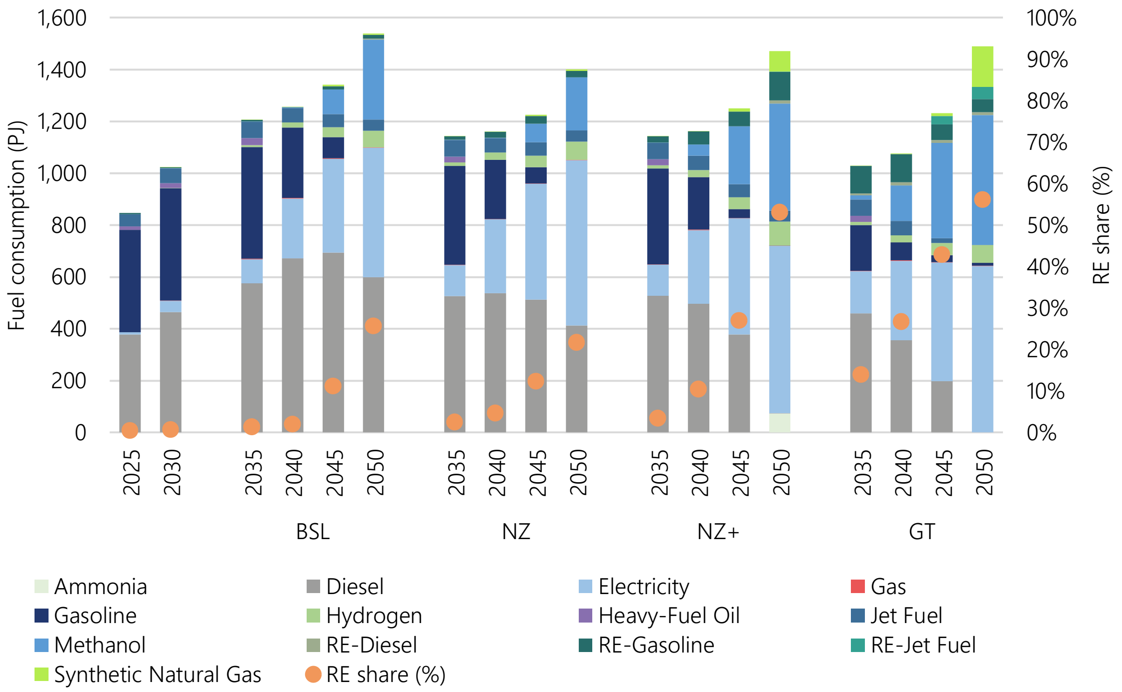


Figure 7.5 Final energy consumption in the transport sector (PJ). RE fuel share includes RE fuels (ammonia, methanol, RE-gasoline, RE-diesel and RE-jet fuel and synthetic natural gas), excluding electricity.

Towards 2050, both the composition of transport modes and the fuel consumption mix face a dramatic shift (Figure 7.6). As of 2022, the road segment, headed by motorcycle and heavy-duty vehicles dominates the energy consumption based on fossil fuels. While maritime and railway segments account for only 8% and 0.3% of the total energy consumption for transport in 2022 respectively, in a net-zero scenario their contribution increases to 18% and 17% in 2050 respectively, following from the growing trends on transport demands, as well as the assumed modal shift to rail for both passenger and freight.

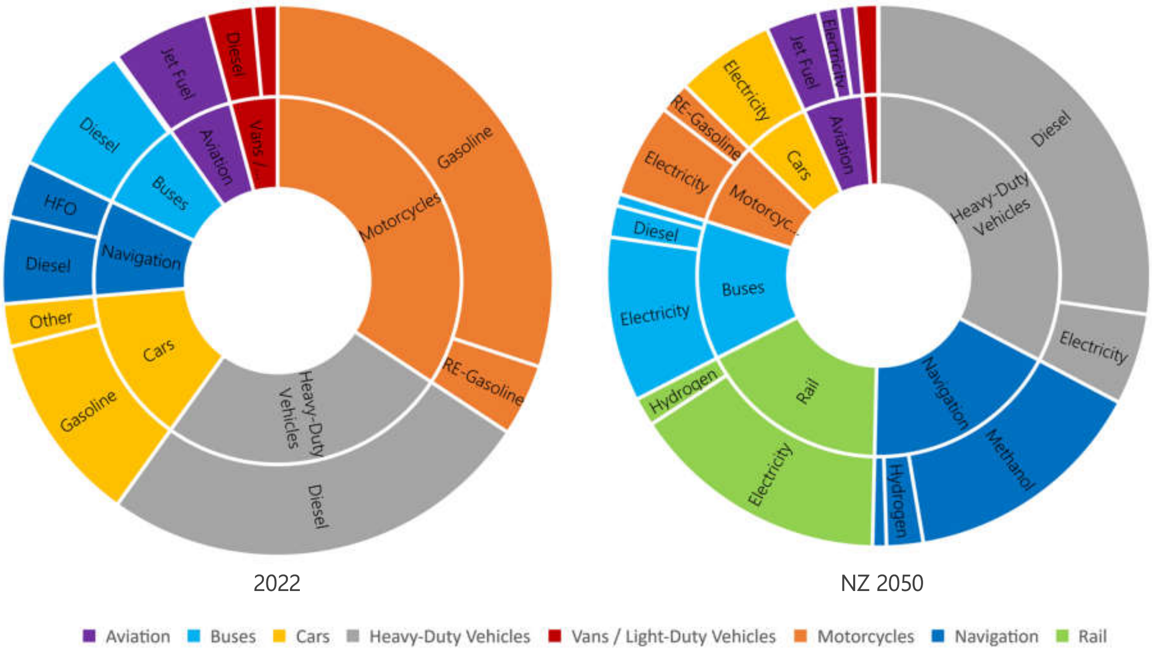


Figure 7.6 Fuel consumption by transport mode in 2022 and 2050 in Net-Zero scenario (PJ %).

The electrification level, across all transport segments, drastically moves from a current 0.4% of the fuel mix in 2022 to covering 44% of the energy needs in transport in 2050 in a net-zero scenario (Figure 7.7). However, even in the Baseline scenario, with no targets on GHG emission reduction, electrification rates increase to 32% in 2050.

Post-2030 hydrogen will play an increasing role under carbon-constrained scenarios in the non-road transport segments, i.e. aviation, navigation and rail. Among renewable liquid fuels, methanol covers the majority of fuel consumption for maritime transport in 2050 in the baseline and net-zero scenarios, with a share of 86%. Starting from 2040, methanol will become a key fuel also for heavy-duty trucks in the NZ+ and GT scenarios, reaching more than half of the total energy consumption in this segment by 2050. Under the ambitious carbon limit for the whole energy system set in the NZ+ scenario, with the only residual emissions in 2050 stemming from industrial processes, ammonia will also be part of the optimal fuel mix to supply maritime transport, covering 31% of the energy needs in 2050.

It is worth mentioning that there is a large range of uncertainty around costs and development projections for the different possible production routes for alternative fuels for transport, including methanol, which e.g. could be produced through the bio-route or as a synthetic e-fuel. Moreover, there is also uncertainty around the costs and technical potentials for sustainably harvesting and utilizing biomass for RE fuels production, as well as the availability of cost-competitive carbon source (CO_2) for production of synthetic e-fuels. In conclusion, heavy transport segments will definitely require RE fuels (either bio- or e-based) in the future, in order to meet the net-zero target in 2050.

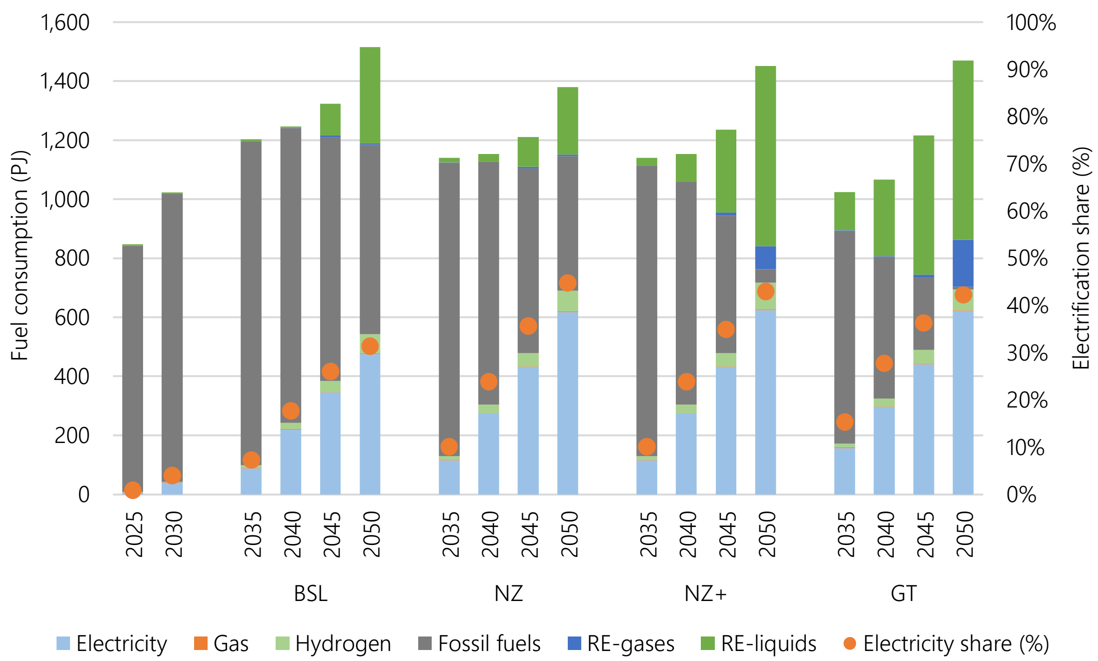


Figure 7.7 Fuel consumption by fuel type across all transport segments and electrification share.

Transport costs weigh around 50% of the total system costs for the energy system in 2050 across the analyzed scenarios, growing from a current 33% in 2022. Both investment costs and O&M costs are slightly lower in the net-zero scenario compared to the baseline case (Figure 7.8) mainly due to the effect of modal shift to rail, for which less investments in new vehicles are needed to supply the same total transport demand. It is important to note that investment costs exclude any infrastructure investments due to expansions and upgrades of the road and railway networks and any other transport infrastructure costs in general. In the same way, charging infrastructure for electric vehicles is not included in the analysis.

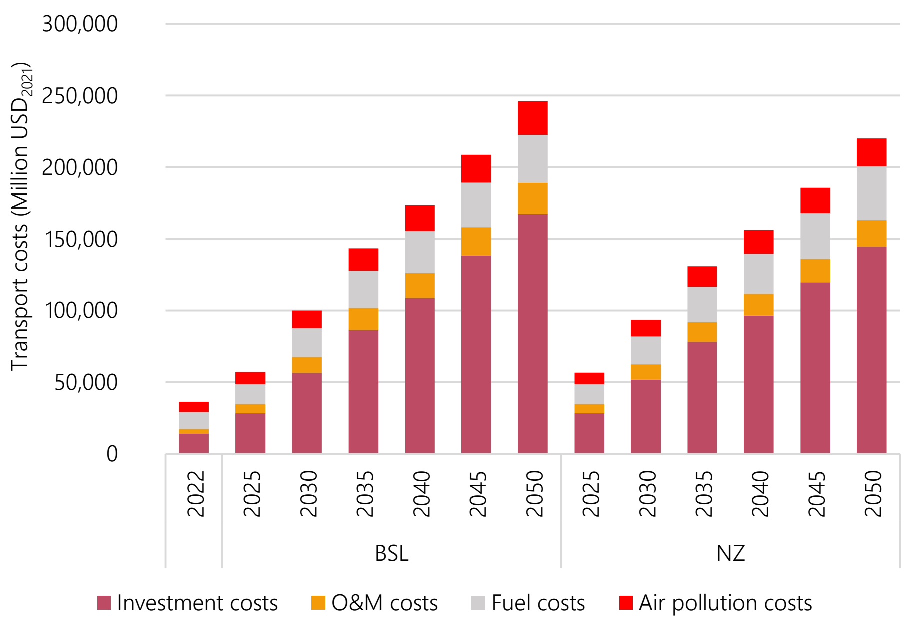


Figure 7.8 Costs for the transport sector, excluding transport infrastructure.

The vehicle stock for both private passenger cars and motorbikes will change drastically in the future, both in terms of size and composition, in line with the expected increase in transport demand, and the electrification trend, both in a baseline and net-zero case. The car stock today is around 2.4 million vehicles, almost entirely running on gasoline. In 2050, only electric vehicles will be on the road with a projected stock of 10.5 million cars in a baseline case, and 9.6 million cars under a net-zero scenario. The lower level of the stock for the net-zero case is explained by the assumed modal shift from private cars to public transport in main cities (i.e. urban railway).

Motorcycles are the main mean of private passenger transport today and will maintain a major role in the future transportation as well. While the entire 48.3 million-vehicle fleet today in 2022 is based on gasoline, the future motorcycles will be mostly electric (94-97%) with a fleet of 89-98 million vehicles in 2050 across the analyzed scenarios. Once again, the modal shift to metro assumed in the net-zero scenario explains the slightly smaller fleet, compared to the baseline case.

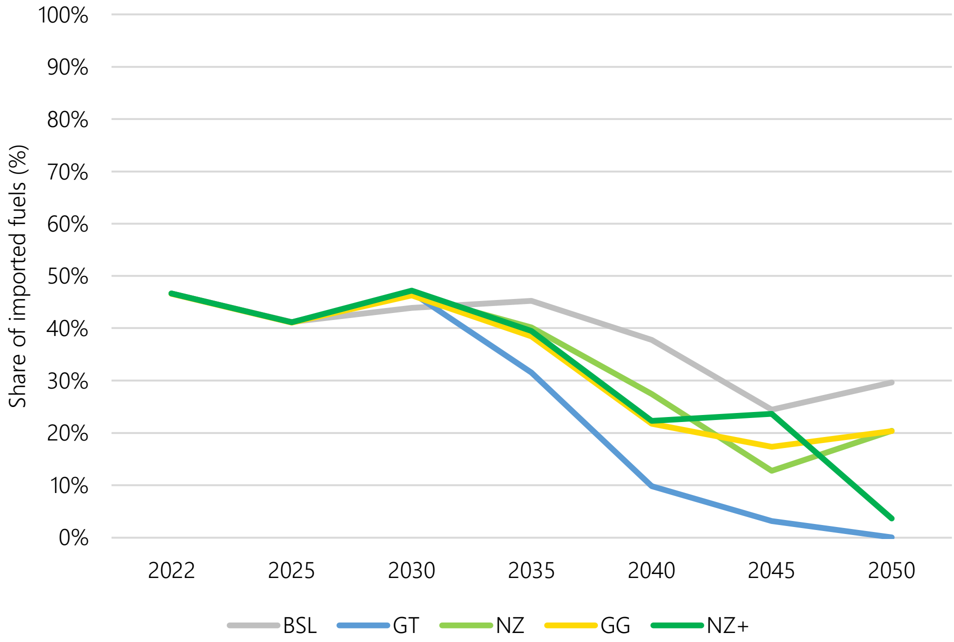


Figure 7.9 Share of imported fuel on total fuel consumed in the transport sector across main scenarios.

As previously observed, energy needs to supply transport demands are only going to increase in the future, holding a significant share of the total final energy consumption in Viet Nam. Moreover, while part of these fuel needs is supplied through domestic production, a relatively large share also needs to be imported. Today, around 50% of the fuels used in the transport sector (excluding international aviation) are imported. In a baseline case, this share will decrease to 30% in 2050, with part of the diesel and jet fuel being imported (Figure 7.9). Among the net-zero scenario, the core NZ case, as well as the GG scenario, present a lower need for imported fuels, partly explained by the lower total fuel consumption due to modal shift, as previously seen. In the most ambitious net-zero scenario (NZ+), all the needed jet fuel is imported in 2050, as well as a small part (8%) of RE gasoline. There are no imports of fuels in the Green Transport scenario in 2050, with all energy needs supplied through domestic fuel production.

7.3 Key messages and recommendations

Electrify the light transport modes rapidly and use of renewable fuels in the heavy transport segments to cost-effectively reduce climate and environmental impacts

Direct electrification of the light transport segments should be prioritized as it is cost-effective, even in the baseline scenario. A shift towards electric vehicles (i.e. electric cars and motorbikes, but also vans and busses) not only represents a measure for climate mitigation, but also holds the opportunity to diminish the health and environmental costs associated to air pollution, especially in urban areas. The whole car and motorbike fleet should be fully electrified by 2050, since it is the cost-optimal option across all scenarios, with a significant shift in the vehicle stock starting from 2030. However, a smoother and earlier introduction of Battery Electric Vehicles (BEVs) is recommended already from today, to consider factors like inertia and behaviour in private households' purchase decisions.

Recommendations:

- *Consider to formulate targets of 50% BEV by 2030 and 90% BEV by 2040.*
- *Consider short-term incentives (i. subsidy) on purchase of BEVs, especially 2-wheelers, as well as suitable tariffs for electricity price at EV-charging stations.*
- *Prioritize the use of hydrogen and e-fuels in the heavy transport segments (i.e. freight trucks, aviation and shipping).*

Plan the needed infrastructure for the electrification of the transport sector

Considering global technology development and projected cost reductions for BEVs, Viet Nam will witness a very rapid increase in consumers' demand for electric 2- and 4-wheelers in this decade. However, Viet Nam's local electricity grid infrastructure and urban planning are currently not prepared for the requirements that such transformation would entail. Demand for electricity to supply transport demands in the electrified modes will drastically increase in the future, with around 380 TWh of electricity needed in 2050 in the Net-Zero scenario, increasing to 408 TWh for the Green Transport scenario. Correspondingly, the electrification level, across all transport segments, drastically moves from a current 0.4% of the fuel mix in 2022 to covering 44% of the energy needs in transport in 2050 in the Net-Zero scenario.

Recommendations:

- *Develop an investment strategy for EV charging infrastructure based on international standards both at national and provincial level.*
- *Integrate EV charging infrastructure, including reinforcement of the distribution grid for charging stations, into national road planning as well as provincial, city and urban plans before 2030.*

Adequate infrastructure is necessary to enable the shift towards public transport and electric railways

Net-zero scenarios assume a key role for modal shift in reducing total energy needs to fulfil the passenger and freight demands in the future in Viet Nam. In particular, shifting from private vehicles to urban railway in the main urban areas for passenger transport, and moving part of demand from road, shipping and airplanes to railway for both passenger and freight transport can reduce the total fuel consumption in the transport sector by at least 9%, when comparing Baseline and Net-Zero scenarios. The modal shift is projected based on expected plans for railway infrastructure upgrades, with, among others, the introduction of a North-South high-speed railway system catering to passenger and freight transport. Such infrastructure investments require not only timely planning and implementation, but also setting the adequate incentives to promote the shift from current modes, differentiated respectively for passenger and freight transport.

Recommendation: Ensure timely investment roadmap for electric railway system is aligned with transport targets, both in scale and timing, accompanied with the necessary incentives to promote larger use of public transport.

Renewable fuels will play a major role for heavy-duty transport segments

Domestically produced green hydrogen becomes cost-competitive starting from 2040. The need for e-fuels including hydrogen and bio-based fuels to supply non-road transport segments that cannot be directly electrified, such as aviation and shipping, will increase to around 65-90 PJ in 2050 across net-zero scenarios. Moreover, methanol and ammonia could play a large role to supply maritime transport and heavy-duty vehicles, with up to 500 PJ needed in the Green Transport and Net-Zero+ scenarios in 2050.

Recommendation: Develop production and prioritize the use of e-fuels including hydrogen and bio-based fuels to supply shipping and aviation.

8. Industry sector

8.1 Overview and trends

It is a continuing challenge to expand the electricity generation and transmission capacity and meet with the rapid pace of development of the electricity demand growth. For this reason, Viet Nam has promoted the efficient use of energy since 2006 through a range of different programs. The main program is the Viet Nam National Program on Energy Efficiency and Conservation for 2019-2030 (VNEEP), which is currently in its third phase. The program created energy savings of 3.4% from 2006 to 2010 compared to a Business-as-usual (BaU) scenario and the 2011-2015 target of 5.7% reduction was reportedly met and even surpassed in certain industries (The Ministry of Industry and Trade, March 2022).

The VNEEP3 is split into two periods, i.e. 2019-2025 and 2026-2030. The 2025 targets include an overall energy demand reduction of 5-7%. In addition, several targets are set related to the energy efficiency (EE) level of specific sub-sectors as well as power losses, policy development targets, targets for compliance with regulation and more. The 2030 targets include an overall energy demand saving of 8-10% during the period 2019-2030 compared to a BaU scenario.

The implementation of VNEEP3 has been somewhat slowed down by several factors, including the loss of momentum in the interim phase between VNEEP2 and VNEEP3, and the COVID-19 pandemic. For the industrial sector, the main policy mechanisms focus on large (designated) energy users. They are required to implement energy audits, to implement energy management systems, and to develop energy efficiency plans[20]. In addition, energy efficiency benchmarking regulation has been developed for all enterprises in 7 selected sectors.

A study under the Danish-Vietnamese Energy Partnership Program in 2022 suggests that the compliance with the regulation on energy audits as well as energy plans is at a low level[21]. A survey of compliance with plastic sector benchmarking from 2022 similarly finds a low level of compliance. The reasons for the low level of compliance are, amongst others, the weak enforcement of the regulation and the lack of technical expertise within the industrial enterprises, as well as among energy efficiency service providers to develop and implement major energy efficiency projects[22]. While the "low-hanging fruits" of electricity savings are widely addressed, there is still a very large potential for improved efficiency of the use of heat (such as steam or hot water).

The government has launched several new initiatives to further strengthen energy efficiency. Decree No. 06/2022/ND-CP of 7 January 2022 stipulates the issuance of carbon emission quota, based on which the relevant entities must make carbon reduction plans. A carbon market is planned for full operation by 2028, with the pilot starting in 2025. This scheme would potentially increase the financial incentive for industries to implement energy efficiency measures. However, without substantial support to develop the needed technical capacity, the effectiveness of the scheme could be limited.

MOIT, with the assistance of the Danish Energy Agency, is working on the development of a voluntary agreement scheme with technical guidelines for EE in industrial sectors as well as direct technical support to develop large-scale and high-potential energy efficiency projects. This should support the implementation of Decree No. 06 to support and stimulate adoption of best available technologies.

When fully implemented, Decree No. 06, combined with technical support, could considerably increase the financial incentive for energy intensive sectors, such as heavy industries, to invest more in EE.

The Law on Economic and Efficient Use of Energy is currently under revision. This is a good opportunity to provide a balance between benchmarking, energy audit requirements, improved compliance on one side, and support to technical assistance and capacity building on energy efficiency projects on the other side.

The same goes for a potential enforcement of Circular 25/2020/TT-BCT, which would provide a solid data foundation and implementation of EE of large consumers. Circular 25/2020/TT-BCT stipulates the reporting and auditing of large energy users (more than 1,000 t.o.e. annually) and would directly provide improvements to EE as well as benefit long-term energy planning studies.

[20] Circular 25/2020/TT-BCT
[21] LEEC Implementation in Vietnam, MOIT and DEA, 2018.
[22] Diagnostic Review and Analysis of Energy Efficiency Development in Vietnam, Energy Transition Partnership, 2022.

Other international cooperation initiatives are ongoing to strengthen the VNEEP3 program implementation, addressing particularly VNEEP3 compliance issues; easing financing of EE investments and strengthening MOIT program implementation capacity.

In addition to the VNEEP3 program, a demand side management program (DSM) has been running for several years with a particular focus on efficient use of electricity, including installation of time-of-use electricity meters, efficient lighting programs, promotion of solar water heaters and solar rooftop systems to save on grid electricity, and demand response programs to reduce peak electricity demand. The DSM program is planned to continue until 2030.

Key assumptions on the development of industrial sector

During the last decades, Viet Nam has experienced economic growth, increasing urbanisation and transport demand, improved energy access, rising living standards as well as industrial development, all of which are major drivers for growing energy consumption.

Industrial energy service demands are growing in all scenarios in the future. The primary demand drivers include GDP growth, population growth and sectoral shares, namely the contribution of each sector to GDP. In 2019, the industrial sector accounted for 36% of the Vietnamese GDP while service and agriculture contributed respectively to 43% and 11%. In all scenarios except GG, the share of industry sector in GDP increases to 40% in 2030 and stays at that level until 2050. The service sector reaches the share of 50% in 2030, which is kept constant until 2050. These assumptions are potentially reflecting changing economic priorities and trends over the coming decades.

The applied average GDP growth rate is 6.5%/year in all scenarios except NZ-GDP+ where a GDP growth rate of 7.5%/year is applied. In the GG scenario, the GDP growth rate is kept at 6.5% but the sectoral growth rates are changed to reflect emphasis on high value-added, but less energy-intensive sectors, such as services.

The physical output from iron & steel industry is expected to grow with 9.5% per year in the 2019-2025 period, 1.9% per year until 2035 and 4.3% until 2050. The ammonia industry is expected to grow with 8.6%, 14.9% and 4.1% per year, up to 2025, in period 2025-2030 and after 2030, respectively. The production of the cement industry is high in volume; however, the growth rate for the demand gradually decreases in the 2019-2050 period. Starting from 97 Mt in 2019, demand is projected to reach 168 Mt in 2050. In general, predictions for energy service demand for industries exhibit a trend of growth throughout the period of 2019-2050. Demand growth rates between 2025 and 2030 are higher than in previous periods for most industries, however, after 2030, growth rates gradually decrease.

Unlike other analysed scenarios, the Green Growth scenario focusses on a system, where the GDP contributions by sector shift away from energy intensive industries to the services sector, while overall maintaining the same national productivity, i.e. annual GDP growth rate is maintained at 6.5%. From 2030 to 2050, a noticeable shift is projected. As a result, the industry share of 40% by 2050 (NZ scenario) is reduced to 30% (GG scenario) and the service share of 50% (NZ scenario) is increased to 60% (GG scenario).

The Baseline scenario follows sub-sectoral energy efficiency targets until 2030, as outlined in VNEEP, while the net-zero pathways (NZ, NZ+, GG) illustrate cost-optimal solutions for the whole system, so these could overshoot or undershoot the EE targets set in the BSL scenario. The EE improvement in BSL is determined by analysing the base-year's energy consumption and demand output, alongside the expected percentage decrease in the energy intensity of each sub-sector by 2030. The minimum energy efficiency improvements by 2030 are set for the following sub-sectors: textile and leather, cement, food and beverage, iron and steel, pulp and paper and material construction. Minimum improvements are not assumed for the remaining industrial sub-sectors. The minimum EE improvements set in VNEEP are likely underestimated, particularly on the thermal side; the estimation of EE potentials and costs could be analysed in more detail in subsequent EOR studies.

8.2 Key results

Figure 8.1 shows the growth of energy service demands relative to 2019 for BSL, NZ-GDP+ and GG scenarios, respectively; energy service demands in other scenarios grow as in BSL. In all scenarios, the energy service demands grow the slowest in the cement subsector and the fastest in manufacturing of motor vehicles. Energy service demands between 2019 and 2050 will grow on average by a factor 4.2, 5.6 and 6.7 in GG, BSL and NZ-

GDP+ scenarios, respectively. Textile and leather subsector represent a good proxy for (average) growth of the industrial sector as a whole across scenarios.

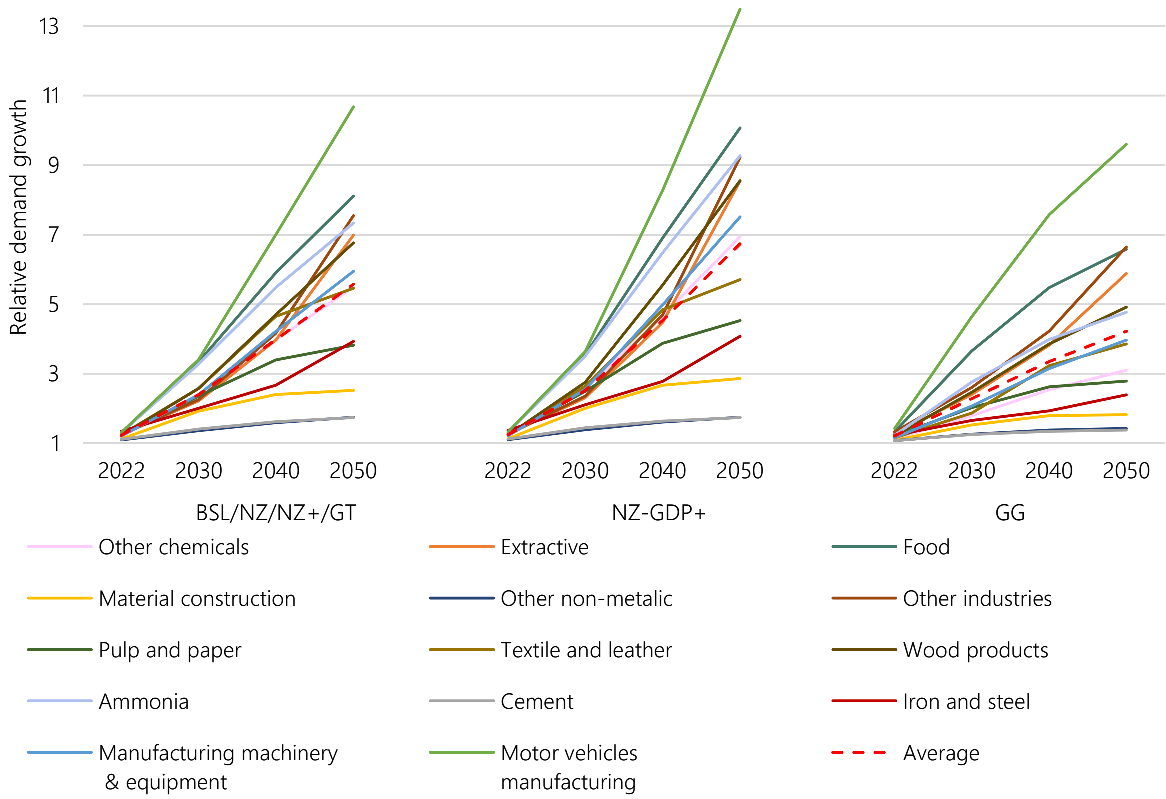


Figure 8.1 Demand growths for industrial sub-sectors across relevant scenarios.

Figure 8.2 presents final energy consumption (FEC) in the industrial sector in the main scenarios. Electricity becomes the main fuel used in all scenarios, with its share growing from 31% in 2019 to 58%-73% in 2050. In BSL scenario, the electricity share on FEC is around 60% in 2050. In 12 out of 14 sub-sectors, electricity dominates FEC in 2050; in cement sector it is biomass and natural gas in ammonia production. In the net-zero scenarios, this share ranges between 58% and 66%, except for NZ+ scenario where the electricity share reaches 73% in 2050. In NZ+ scenario, 6 industrial sub-sectors (out of 14) are fully electrified which makes NZ+ the scenario with highest electricity share in industrial FEC. A second highest share of electricity in industrial FEC in 2050 occurs in the GT scenario; higher consumption of methanol in the transport sector in the GT scenario fits well with more affordable electricity for electrification of industries.

Biomass is the second most used fuel in the future, with its share growing from 13% in 2019 to 14%-27% in 2050 and it is the smallest in the scenarios with highest share of electrification (GT and NZ+ scenarios). The combined share of electricity and biomass in FEC in industries is very stable between the scenarios. In the BSL scenario this share amounts to 85% in 2050, 81%-82% in NZ-based scenarios, except in NZ+ where the combined share of electricity and biomass in 2050 is 87%. Hydrogen does not play any role in the Baseline scenario, while in NZ scenarios hydrogen comes into play from 2040-2045, amounting to 4-9% of FEC in 2050.

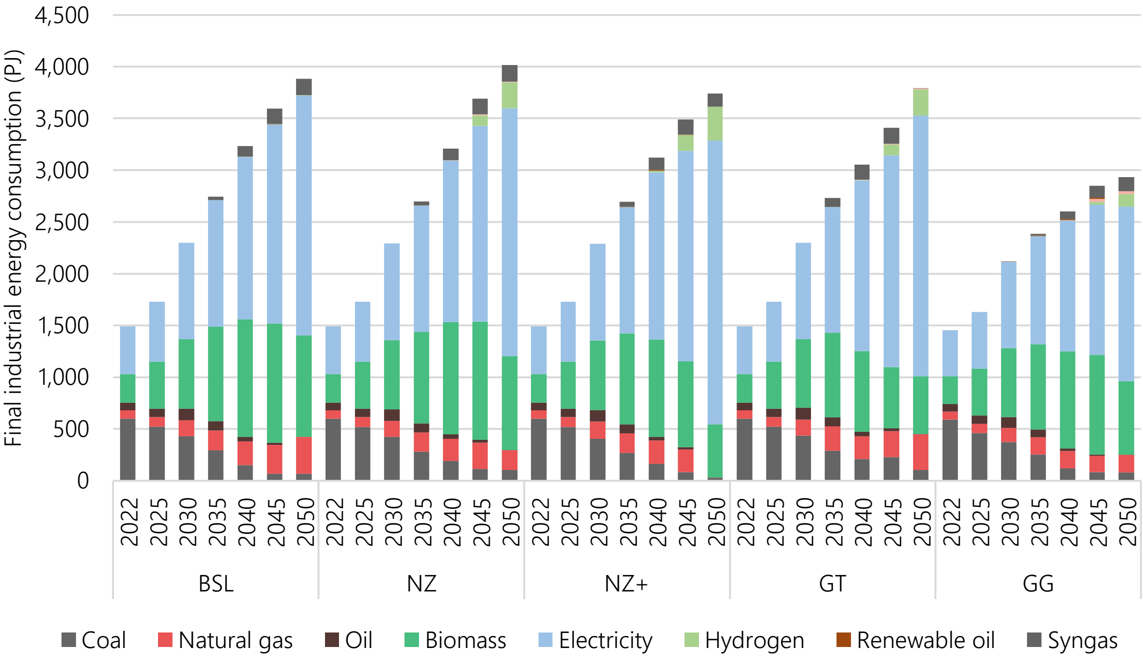


Figure 8.2 Final Energy Consumption in industrial sector (PJ) across scenarios.

The CO_2eq emissions from the industrial subsectors, including energy- and process-related emissions are presented in Figure 8.3. The sum of emissions in BSL scenario decreases from around 118 Mt in the base year to 94 Mt in 2050; in NZ-based scenarios, the emissions decrease to 25-43 Mt in 2050, which implies that the emission targets are necessary for decarbonization of industries. Iron and steel (IS) and cement (CM) are currently the largest emitters and will stay the largest emitters in the future. Their combined share remains in the same region: from 78% in 2019 to 69%-88% in 2050. The NZ+ scenario presents the highest combined share of CO_2 emissions from IS and CM at 88% in 2050. This is because, unlike other scenarios, where all industrial subsectors still emit in 2050, 7 out of 14 subsectors in 2050 are fully decarbonized in the NZ+ scenario and the entire industrial sector decreased emissions by 79%.

Process-related emissions in the BSL scenario grow throughout the analyzed period and reach 70 Mt in 2050. Cement sub-sector is by far the largest process-related emitter in BSL, even though its share drops from 90% in 2019 to 77% in 2050. In NZ-based scenarios, process-related emissions in 2050 are kept below 20 Mt through an emission target, which implies a drastic drop in process-related emissions from the cement sub-sectors. In NZ and GG scenarios, iron and steel will emit more than cement in 2050. Ammonia production reduces process emissions to 0 in 2050 in the NZ+ scenario.

Existing industrial processes are reaching the end of their lifetimes by 2045 and need to be replaced while new need to be installed as a response to demand growth. Figure 8.4 shows how the industrial energy demand is supplied based on energy efficiency levels. "Existing" processes exist in the base year, while "Ordinary", "Improved" and "Advanced" refer to growing energy efficiency levels of new processes.

By 2040, all "Existing" processes will reach end of lifetime. In the Baseline scenario, "Ordinary" processes dominate, while the most efficient options ("Advanced") are part of the solution only in NZ-based scenarios and still to a limited extent (maximum is 7% in 2050 in NZ+ scenario).

In NZ-based scenarios in 2050, the majority (around 95%) of demand is covered by "Ordinary" and "Improved" processes, with "Ordinary" covering 71%-81% of the demand, and 13%-23% supplied by "Improved" processes. "Advanced" processes are applied only in the cement sector (CM).

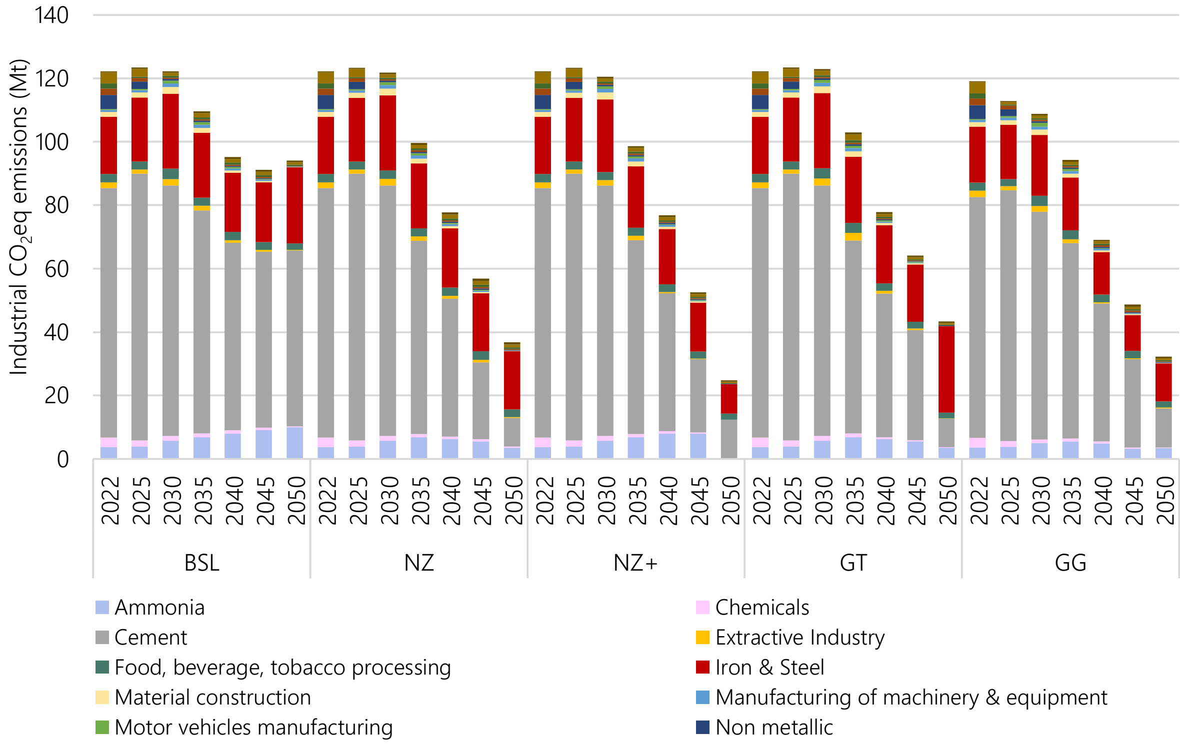


Figure 8.3 CO_2eq emissions by industrial subsectors.

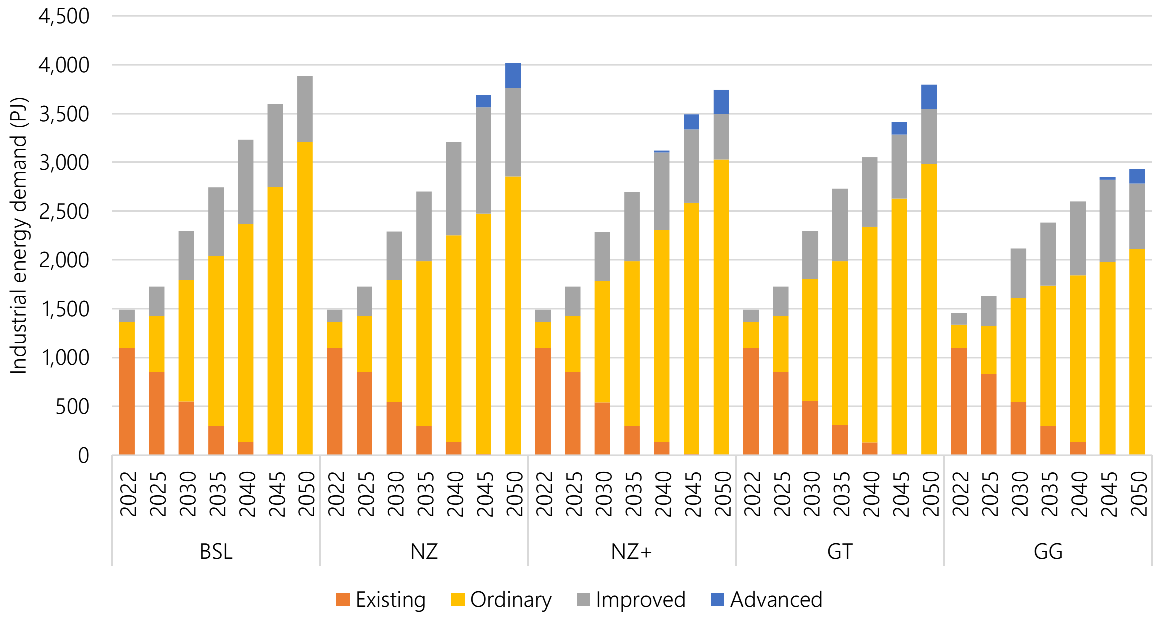


Figure 8.4 Energy demand in the industrial sector from devices at different energy efficiency levels (PJ).

Costs due to air pollution from the industrial sector are presented in Figure 8.5. Several trends can be observed. First, air pollution costs grow in all scenarios. The highest growth between 2019 and 2050 is observed in the Baseline scenario, with an increase of 5.4 times. In the NZ-based scenarios, the growth is between 2.5 times (NZ+ scenario) and 5.3 times (NZ scenario). Second, in all scenarios except GT, the air pollution costs do not peak before 2050. Only in NZ+ scenario, air pollution emissions peak in 2045. Here NO_x emissions remain the main source of air pollution costs in all scenarios, as they are responsible for around 80% of the costs in 2050 across scenarios. The main source of NO_x is coal in the first period and biomass closer to 2050.

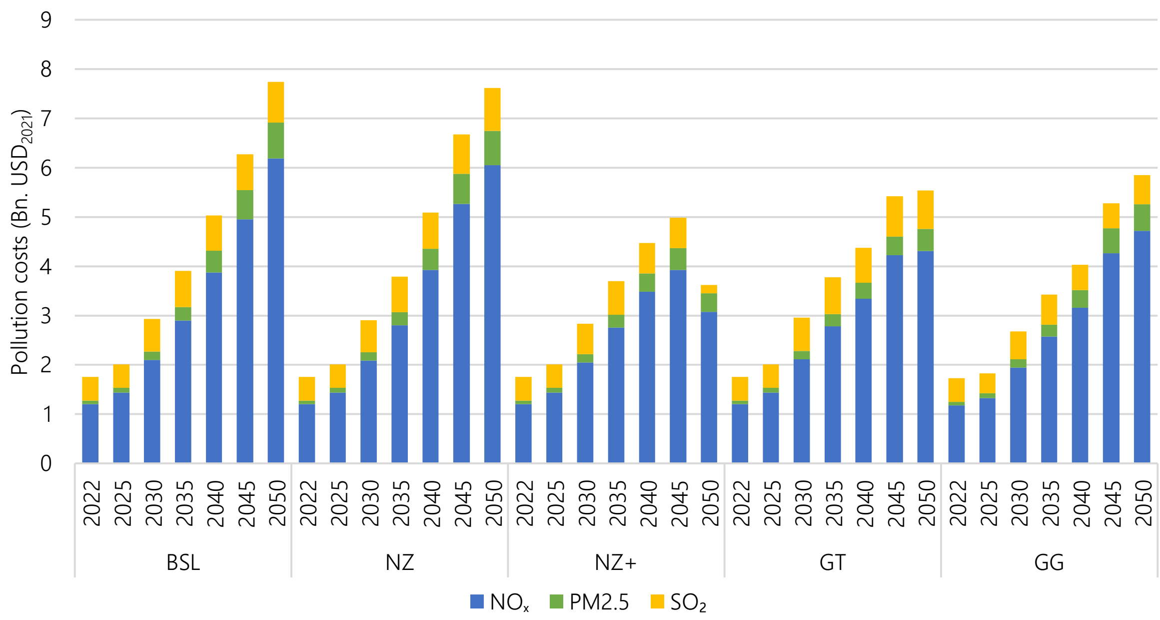


Figure 8.5 Pollution costs from the industrial sector (billion USD_{2021}).

Out of 14 industrial sectors, cement (CM), iron and steel (IS) and food and beverage (FB) have the highest costs (Figure 8.6). The relative share of CM is decreasing and share of IS increases in BSL scenario, making them equally expensive in 2050, at around 28% of the total industrial costs. In all other scenarios, the share of IS on the total industrial cost stands at 20%-25% and for CM at 35%-40% throughout the analysed period. In all scenarios, including BSL, the share of FB is 10%-15%. The industrial shares on total industrial demand and the assumptions regarding sub-sectoral growths mainly drive these results. Fuel and air pollution costs are not included in Figure 8.6.

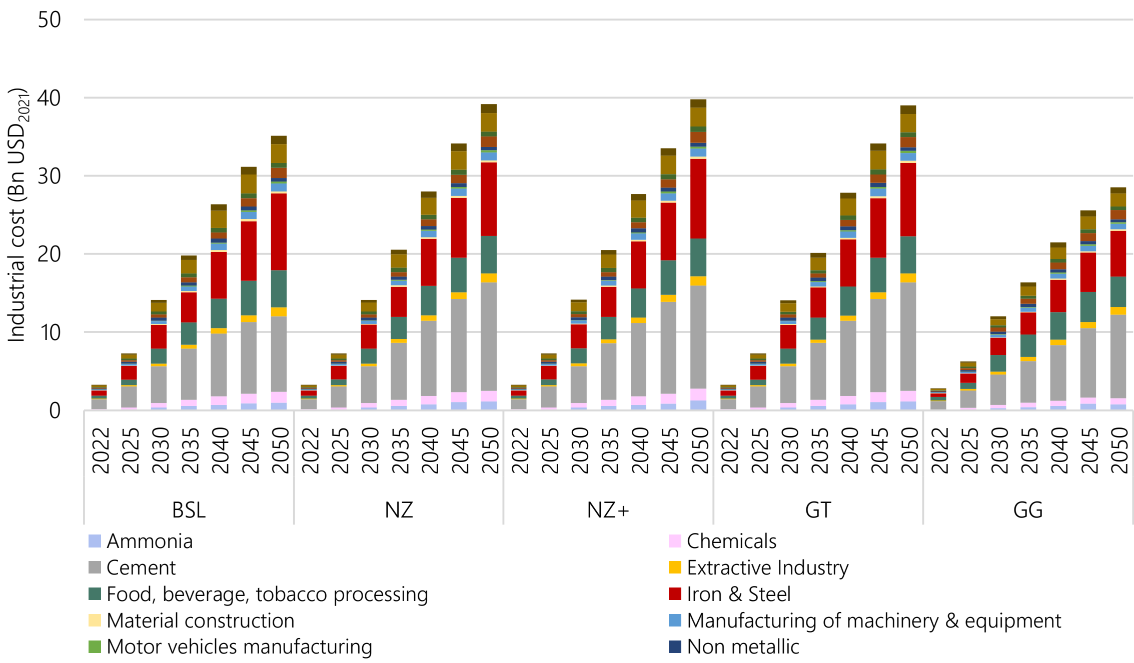


Figure 8.6 Cost of industrial subsectors (billion USD_{2021}).

The use of CCS technologies is needed in NZ scenarios to reach the net-zero emission targets (Figure 8.7). Several messages can be drawn from these results. First, CCS is needed to decarbonize the industrial sector in NZ scenarios. Second, CCS technologies appear only in NZ scenarios, which means that they are driven by climate targets, i.e. not pure cost-competitiveness. Thirdly, they appear from 2040-2045, almost exclusively in the cement sector, with capture of 30-45 Mt CO_2eq in 2050.

When realizing large-scale CCS applications in industry in Viet Nam, the geographical location of such industries can be of relevance. The EOR-NZ does not include analyses on different placement of industrial sub-sectors or regional carbon storage facilities; however, potential benefits of developing CCS clusters, such as cost reductions through shared infrastructure, should be investigated and are relevant to consider, especially in the initial development phase.

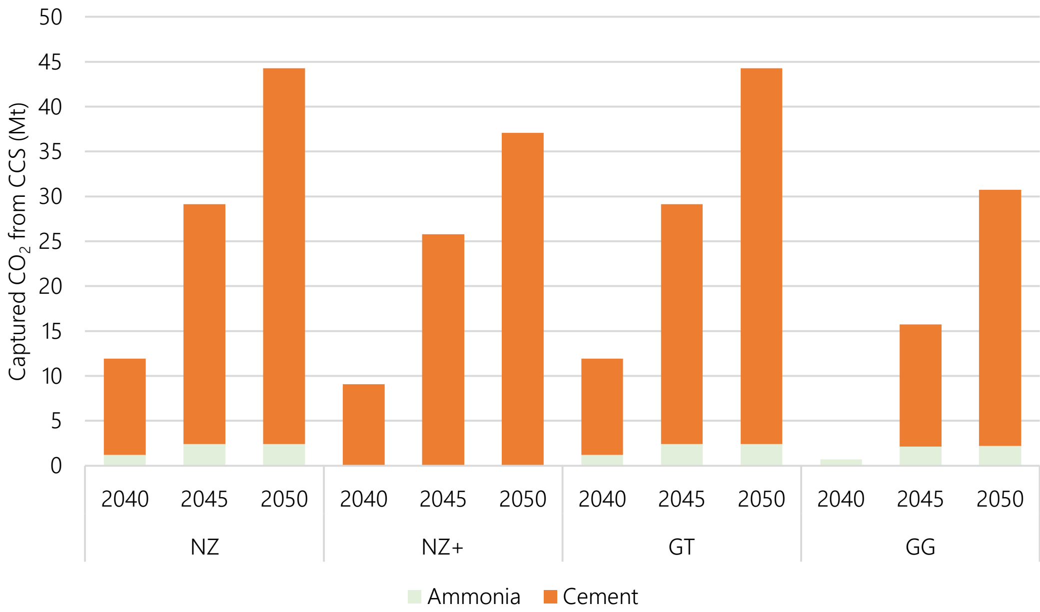


Figure 8.7 Use of CCS in relevant industrial subsectors across scenarios (Mt).

8.3 Key messages and recommendations

Ensure electrification of all industrial processes where possible

In 2050, electricity could make up 58-73% of final energy consumption in industries, depending on the scenario. Using electricity is one of the cheapest solutions to improve efficiency and cut emissions, especially when it replaces traditional fuel sources. As the industry is rapidly growing, transitioning this sector should be prompt and targeted, concentrating on the sub-sectors with large energy consumption and potential for emission reduction. This can be achieved through use of electricity and biomass to replace coal.

Recommendations:

- *Analyse and develop policy mechanisms to support switching of all industrial processes to electricity, as soon as possible.*
- *Consider making use of electricity compulsory for specific processes, when switching to building new facilities or switching to new equipment. This could include the development of a roadmap for implementing the switch to electricity in industry from voluntary-based to compulsory.*
- *Ensure a phase-out of coal use for energy purposes in new industrial production investments no later than 2030, towards no new coal use at all in industries from 2040, unless CCS is implemented.*

Focus on transitioning the high-emission industrial sub-sectors

Heavy industrial sub-sectors such as iron, steel and cement represent a large share of the total energy consumption of the industrial sector in Viet Nam today. However, their share on the total industrial energy consumption can shift from the current 42% to 23-25% in 2050. Furthermore, these sectors also hold the largest share of GHG emissions, excluding process related emissions. The latter amount to 69 Mt in the Baseline scenario in 2050, whereas they are reduced to 20 Mt in the Net-Zero scenario.

Recommendation:_Target the hard-to-abate industry sectors with measures to ensure energy efficiency, fuel switch to electricity and biomass, as well as promote alternative production routes and more sustainable construction materials.

- *Implement pilots for low-carbon cement or even zero-carbon cement production. From 2030, study and introduce support mechanisms for green steel production using electricity and green hydrogen rather than coal.*
- *Promote energy efficiency interventions in the cement sector, and consider to provide subsidies for switching to energy efficiency appliances.*
- *Develop and roll-out dedicated education programs targeting transition in the industries with highest GHG emissions.*
- *Support Vietnamese industries in meeting requirements of international carbon management mechanisms, i.e. the Carbon Border Adjustment Mechanism (CBAM), in a way that supports Viet Nam's long-term green transition.*

Prepare for the need of Carbon Capture and Storage (CCS) in selected industry segments

The Net-Zero scenario features investments in CCS to absorb almost 50 Mt of CO_2 in 2050. Therefore, to meet the net-zero target, CCS represents a technology solution in Viet Nam, albeit for use predominantly in the industry starting from 2040 (with an estimated 88% of the CO_2 is captured in 2050), and not for application in power plants, where coal power with CCS is a very costly solution.

Recommendations:

- *Preparing local geological storage of CO_2 should be starting soon, from 2030.*
- *CCS should be prioritized for industrial purposes, and possibly investigate the feasibility for waste incineration.*
- *All new cement and ammonia production industries from 2030 should be prepared for carbon capture facilities for the processing emissions.*

9. Other demand sectors: Residential, service and agriculture

9.1 Overview and trends

Key assumptions for development of residential, service and agricultural sectors

Population growth rate, GDP growth rate and GDP per capita growth rate are energy service demand drivers for agricultural, service and residential sectors, respectively. Energy demands in residential and service sectors are thermal uses, air conditioning, cooking, lighting, electrical appliances and other uses, while street lighting is covered within services. Residential sector is divided into urban and rural.

Energy service demands in RSA (residential, service and agriculture) sectors are growing in all scenarios in the future. The applied average GDP growth rate is 6.5%/year in all scenarios except NZ-GDP+ where a GDP growth rate of 7.5%/year is applied. In the GG scenario, the GDP growth rate is kept at 6.5% but the sectoral growth rates are changed to reflect emphasis on high value-added, but less energy-intensive sectors, such as service sector and higher value manufacturing processes within the industry segment (see Chapter 8). In contrast to all other scenarios, in GG scenario, the industry share of 40% by 2050 (NZ scenario) is reduced to 30% (GG scenario), while the service share of 50% (NZ scenario) is increased to 60% (GG scenario).

These assumptions are potentially reflecting changing economic priorities and trends over the coming decades, as outlined in the National Master Plan for 2021-2030 with vision to 2050, where average GDP annual growths of 6.5% to 7.5% in the period 2031-2050 are targeted, alongside with 70-75% urbanization level by 2050.

The Green Growth variation focusses on a system, where the GDP contributions by sector make an even faster shift away from energy intensive industries to the service sector, while overall maintaining the same national productivity (GDP).

The available demand technologies in residential and service sectors are categorized into three energy efficiency levels: ordinary, improved, and advanced, where advanced signifies the highest efficiency. In the BSL scenario, the penetration level in meeting various end-use demands by category is constrained, with annual shares progressively increasing, reaching 100% for ordinary and improved, and 75% and 50% for advanced in residential and service, respectively; there are no constraints in NZ scenarios.

9.2 Key results

Figure 9.1 shows the final energy consumption (FEC) in RSA sectors. All scenarios follow a similar pattern, except from NZ+.

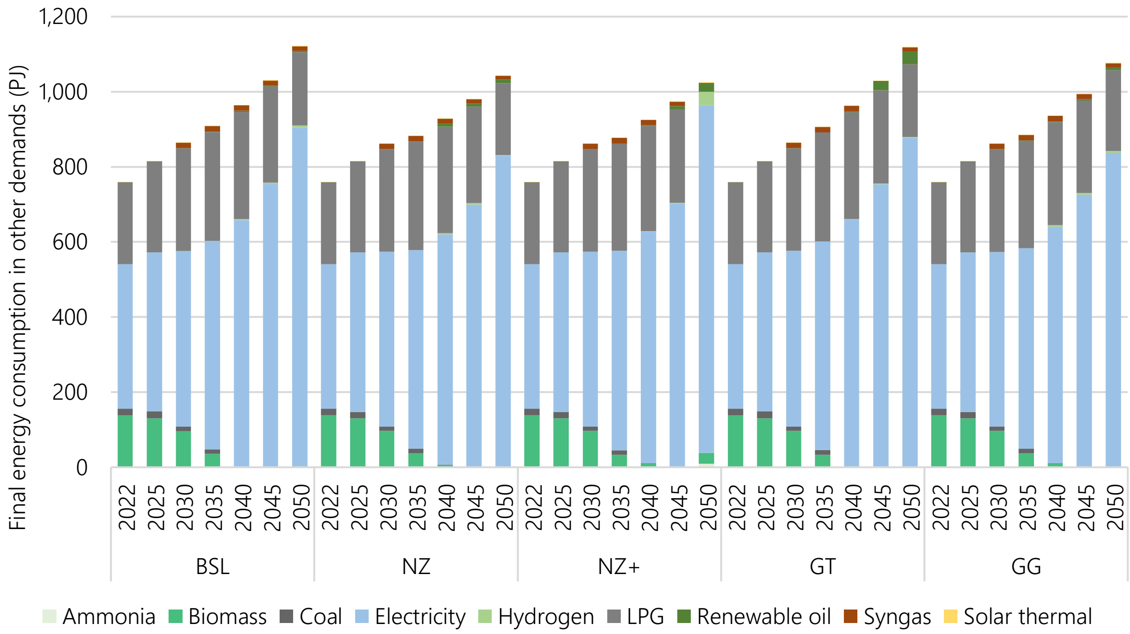


Figure 9.1 Final energy consumption in RSA sectors in the main scenarios (PJ).

Electricity will become the dominant energy type used in RSA sectors. It grows from 50% in 2019 to 77%-83% in all scenarios except NZ+, where it grows to 90%. LPG is the second most used fuel in 2019; its share drops from 28% in 2019 to 15-21% in 2050 in all scenarios, except NZ+. Biomass is phased out between 2040 and 2045. The demands are almost the same in all scenarios except for NZ-GDP+ and GG scenarios, so the differences in the final energy consumption come from the different levels of electrification and energy efficiency improvements. NZ scenarios have overall lower FEC than BSL scenarios post 2030, as BSL is subject to restrictions on the market share of "Improved" and "Advanced" technologies.

As can be seen from Figure 9.1, the final energy demand in the RSA-sectors generally follow the same trends, with only the NZ+ variation forcing the last LPG out just before 2050.

Figure 9.2 shows the penetration of technologies with different energy efficiency levels in RSA sectors (RR-Residential Rural, RU-Residential Urban, S-Services, AGR-Agriculture). Existing processes are reaching end of their lifetimes, and thus their share drops to around 24% in 2030 and 3% in 2050. All three efficiency levels in RSA sectors presented in Figure 9.2 play a role: "Existing" until 2035, "Ordinary" throughout the period, and "Advanced" after 2025. There are only minor differences between the scenarios. Energy efficiency is not included in the agricultural sector, which adds to the small differences between scenarios. "Advanced" level grows from 2025 and supplies largest share of the demand in all NZ-based scenarios in 2050 except GT, but including BSL-EE. Share of "Ordinary" processes reaches its peak in 2025 and drops until 2050. Demand for energy services in the residential sector, specifically electrical appliances, lighting and air-conditioning are supplied by the most efficient ("Advanced") devices even in BSL scenario. Larger demand is supplied by "Advanced" devices in rural than in urban regions. On the other hand, air-conditioning in the service sector is supplied from the "Improved" devices in BSL and "Advanced" in other scenarios. On the contrary, rural cooking and lighting in the service sector is supplied by "Ordinary" devices, i.e. the least efficient new ones, in all scenarios.

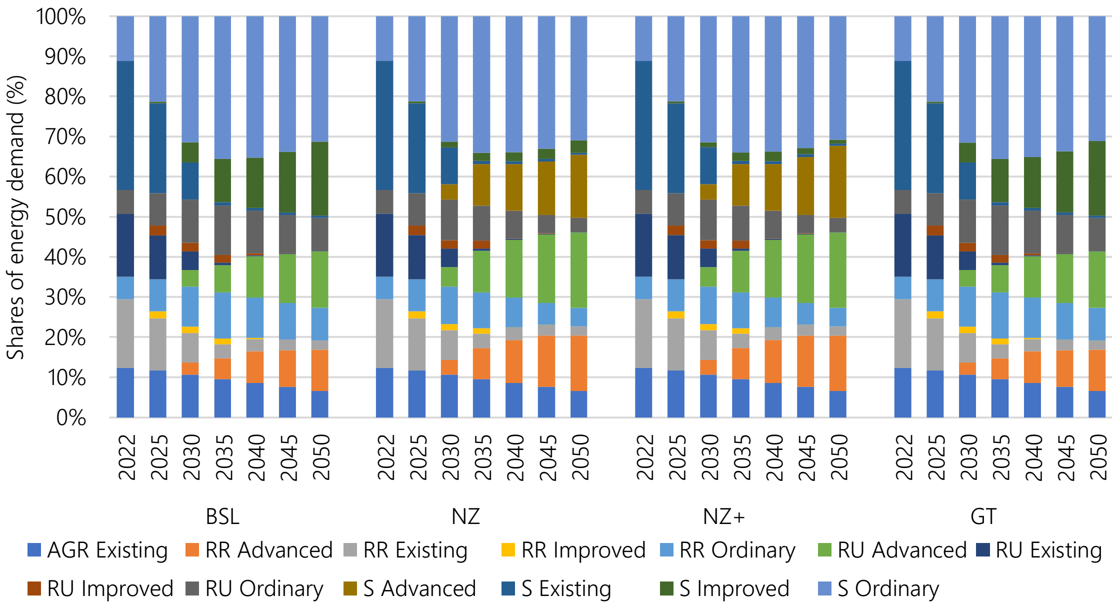


Figure 9.2 Shares of energy demand in other demand sectors delivered by processes with different energy efficiency levels (%).

Figure 9.3 shows CO_2eq emissions from RSA sectors. All scenarios follow similar pattern of development, except from NZ+. In all scenarios except from NZ+, the emissions drop from 16 Mt in 2019 to 11.5-15.3 Mt in 2050, while remaining emissions in 2050 in NZ+ are close to 0. The emissions peak in 2035 in all scenarios is just above 20 Mt.

Services are almost decarbonized in all scenarios, despite the growth of demand. In the residential and services sector, the only remaining emissions in 2050 come from LPG boilers used for cooking and heating.

Figure 9.3 Emissions from other demand sectors in the main scenarios (Mt).

The development of fuel demand in the agricultural sector is shown in Figure 9.4. The energy demand grows by 18% between 2022 and 2050, with very similar developments across scenarios. The electricity share remains constant until 2040 and grows afterwards. The growth of electricity share is stronger in BSL and NZ+, than in other scenarios. In BSL, there is not a lot of competition for electricity from other sectors, therefore cheap electricity is substituting diesel on a cost basis. In NZ+, emission-free electricity is the cheapest way to avoid emissions in the agricultural sector. In other scenarios, the system-wide electricity demand is higher and thus, there is stronger competition between sectors for electricity in order to achieve the decarbonization goals; this results in lower electricity shares in 2050. Diesel plays an important role in 2050 in all scenarios, except for NZ+, where the energy system is pushed to its boundaries and needs to avoid all emissions. The limitation of the present modelling approach is that agriculture is modelled as one aggregated demand process with a single efficiency. Therefore, all scenarios regardless of the FEC serve the same end-use energy demand, while electrification does not lead to reduced FEC.

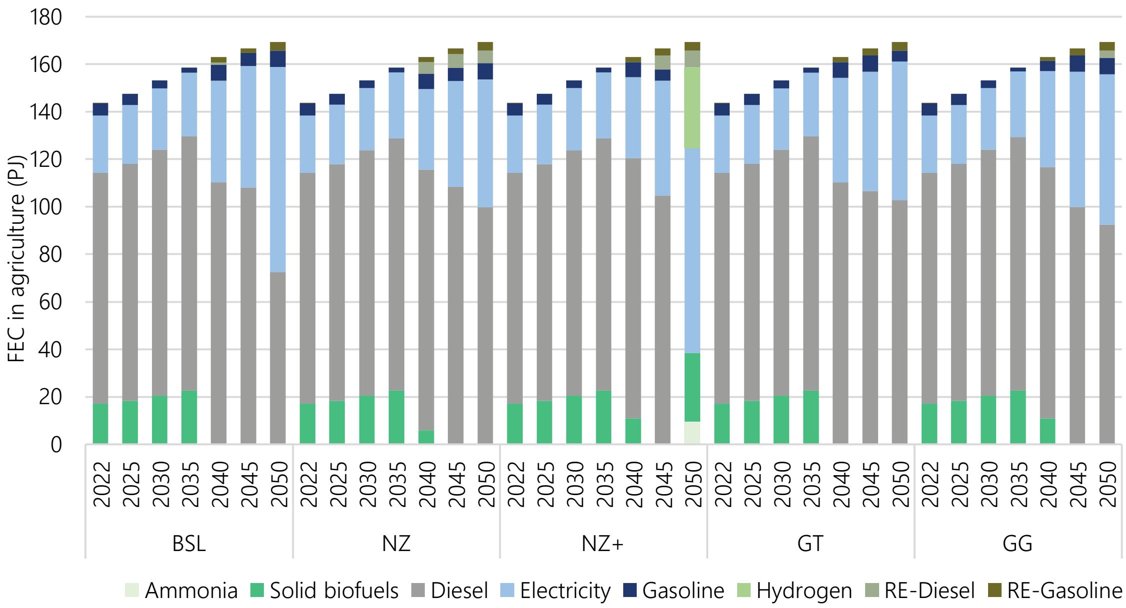


Figure 9.4 FEC in agricultural sector in the main scenarios (PJ).

10. Air pollution

10.1 Overview and trends

Air pollution is a major health concern in Viet Nam. The rapid industrial growth contributing to the country's economic development, coupled with increased urbanization and motor vehicle use, has led to a significant rise in air pollution, particularly in major cities such as Hanoi and Ho Chi Minh City.

According to the World Air Quality Report 2023, Hanoi ranks the 8th most polluted capital city globally and no recorded city in Viet Nam achieved the WHO annual $PM_{2.5}$ guideline level in 2023 (IQAir 2023).

According to the IEA report "Energy and Air pollution" (IEA 2016), the energy sector is one of the predominant sources of air pollution with nearly all sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions and about 85% emissions of particulate matter (PM) originating from the production and use of energy, mainly from the combustion of fossil fuels such as coal, oil, natural gas as well as biomass and waste. Thus, a co-benefit of implementing CO_2 emissions reduction measures, such as decreasing coal power generation and increasing (renewable-based) electrification in the end-use sectors, can directly improve air quality.

Air pollution emissions have a direct economic effect in terms of higher healthcare costs and indirect economic consequences in terms of impact on quality of life and environment. Improving air quality has come into focus in Viet Nam, where for example the PDP8 includes air pollution costs in the analyses. Similarly, all scenarios of the EOR account for air pollution costs and, by this, integrating health and environmental impacts of air pollution into energy modelling and planning.

10.2 Key results

In the EOR modelling framework, the air pollution emissions for NO_x, SO_2, and $PM_{2.5}$ are accounted for every sector (incl. power, transport, industry, supply, residential, service and agriculture) and technology. The associated health costs are factored in for all scenarios, with unit costs per emission varying by sector depending on the level of human exposure. As a result, the costs per unit for air pollution emissions from residential and service sectors are significantly higher than the equivalent emission costs from other sectors (up to 2-5 times higher than industrial emissions), except for domestic aviation.

Further, the unit cost of air pollution increases over time, as the societal cost of air pollution is assumed to increase following to the economic development of Viet Nam (using GDP PPP as metric). The per-unit costs grow 8 times between 2020 and 2050 for all sectors. For more information on air pollution costs, refer to the EOR Technical report (EREA & DEA 2024) and the methodology on accounting of air pollution emissions, as applied in EOR21 (EREA & DEA 2022).

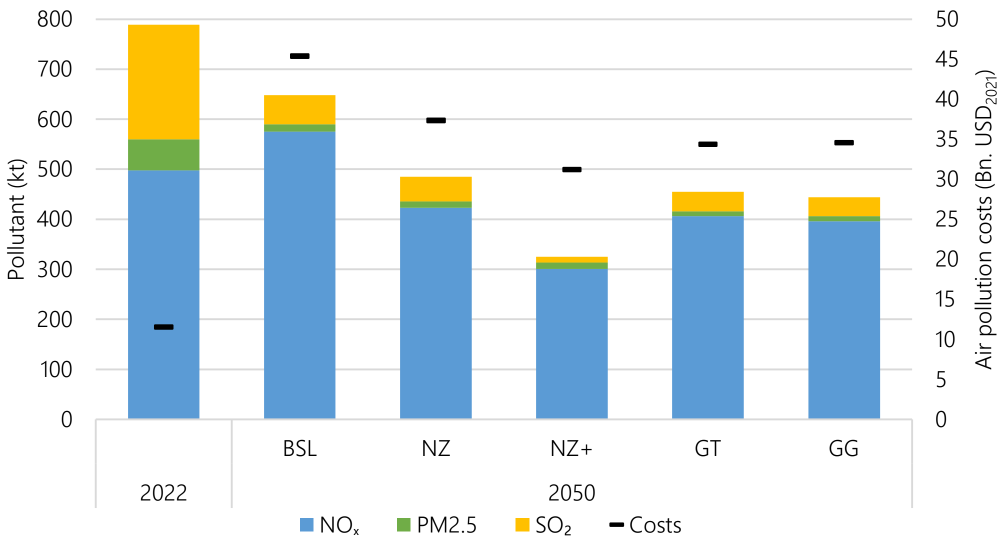


Figure 10.1 Air pollutant level and total air pollution costs in 2022 and 2050 for key scenarios.

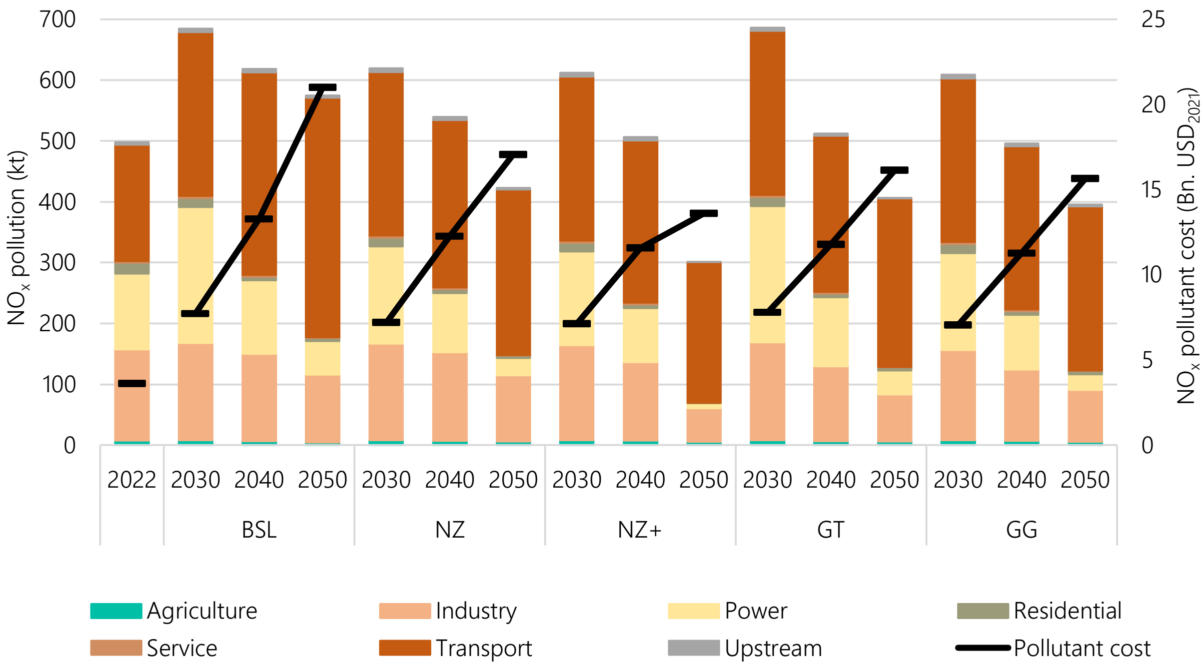
Across all scenarios, the total air pollution level will decrease by 2050 compared to today's values; however, the reduction achieved varies for pollutant and sector largely depending on the scenario. Due to the increasing unit costs of air pollution, the overall societal cost increases over time despite absolute reduction in emissions (Figure 10.1). The value of air pollution costs in the Baseline scenario in 2050 is around 31% higher compared to the NZ+ scenario, which reaches the lowest air pollution level of all scenarios.

By far, the largest implication on the societal costs of air quality stems from NO_x emissions, which contribute to 57% of the total air pollution cost by 2022, followed by $PM_{2.5}$ (31%) and SO_2 (12%). By 2050, the share of NO_x emission costs is increasing, reaching up to 87-90% across scenarios.

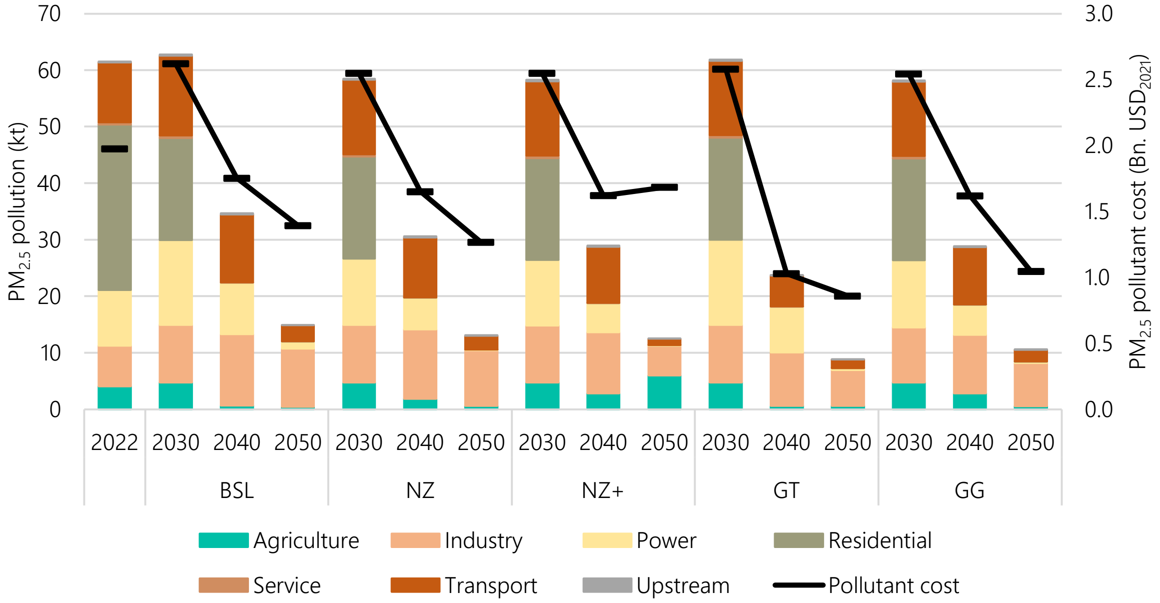
At present, the power sector, closely followed by the transport sector and industry, contribute the most to NO_x emissions (Figure 10.2a). With increasing shares of RE in the power mix, the air pollution emissions from the power sector decrease drastically. However, the NO_x emissions from the transport sector remain at a high level in the future, and even increase in the BSL scenario, with NO_x emissions from the whole energy system reaching 498 kt in 2050 for the BSL scenario and only getting as low as 301 kt in the most ambitious scenario (NZ+) by 2050.

The $PM_{2.5}$ emissions origin from several sectors, with residential being the largest emitting sector in 2022. However, $PM_{2.5}$ emissions from the residential sector are fully abated by 2040, primarily due to the phasing-out of biomass, while emissions from other sectors (primarily industry) increase over time. Overall, $PM_{2.5}$ emissions reduce greatly, from 62 kt in 2022 to 13 kt in the NZ scenario by 2050, with transport and industry sectors being the main polluting sectors in 2050. The industry sector is currently the main contributor to SO_2 emissions, with these reduced by 75% in the BSL scenario by 2050, from the current 147 kt to 36 kt in 2050.

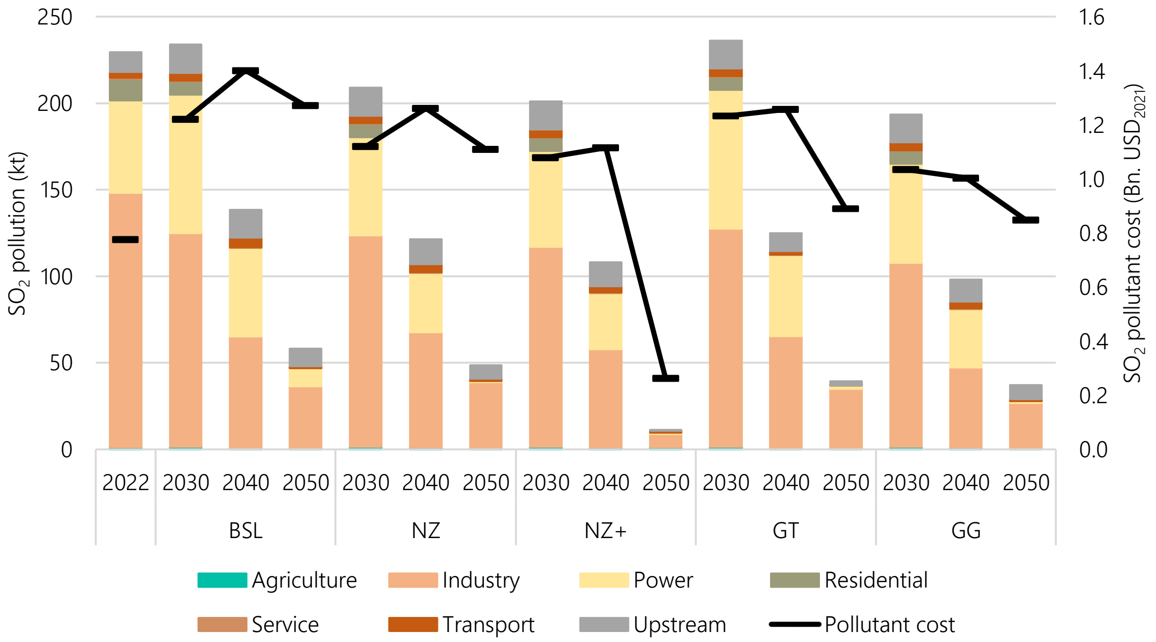
Air pollution is generally reduced through electrification and switching from fossil fuels to other fuels, and with higher emission reduction pathways (NZ+), the highest air pollution reductions are achieved (Figure 10.1). The fuels and technologies responsible for large amounts of GHG emissions, such as the combustion of fossil fuels in power plants and industries, are also main emitters of NO_x, SO_2 and $PM_{2.5}$.



a) NO_x pollution



b) $PM_{2.5}$ pollution



c) SO_2 pollution

Figure 10.2 Air pollution emissions (NO_x, $PM_{2.5}$ and SO_2) and related costs per pollutant in key scenarios.

The relationship between GHG emission reduction and air pollution for the main polluting sectors, i.e. industry, power and transport, is visible from Figure 10.3 for the GT scenario. Across the sectors, the CO_2 emissions decrease between 2022 and 2050, and most of the air pollutant emissions are also decreasing. However, reduction of air pollutants appears to be more challenging for the industrial sector, for which $PM_{2.5}$ stay almost constant in the period 2022-2050, while NO_x emissions are halved, from 150 kt in 2022 to 77 kt in 2050, and SO_2 emissions reach 34 kt in 2050. Reduction of fossil fuel consumption, mainly coal, reduces air pollution significantly, which is evident in the power sector, where $PM_{2.5}$ and SO_2 emissions are fully abated by 2050, while NO_x emissions reach 39 kt in the same year. In the transport sector, while CO_2 emissions decrease over time and reach 0 kt CO_2eq in the GT scenario, the NO_x emissions increase from 192 kt in 2022 to 277 kt in 2050. A large share of the remaining air pollution (NO_x) in the transport sector is emitted from methanol in maritime use and RE jet fuel in aviation, both of which occur in less densely populated areas.

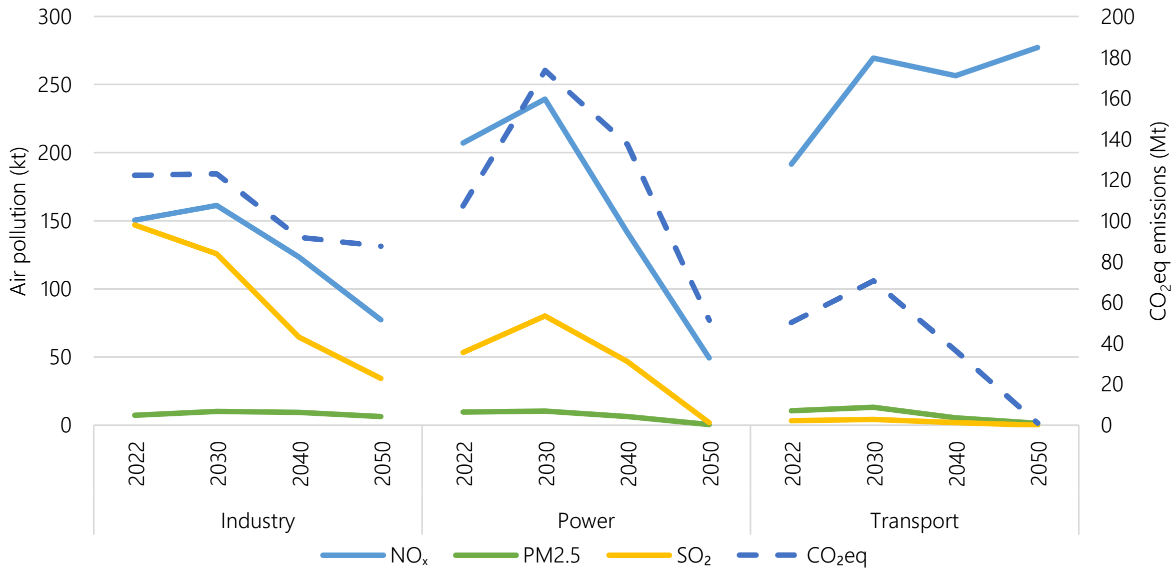


Figure 10.3 Air pollution and CO_2eq emissions of the three most polluting sectors (Industry, Power and Transport) in Green Transport scenario.

Effect of transport sector shift on air pollution

The light transport sector is electrified by 2050 and heavy-duty and maritime transport is decarbonized by transitioning to RE-fuels in the Net-Zero scenarios (Chapter 7). Considering NO_x emissions from the transport sector in 2050 (Figure 10.4), the BSL scenario has the highest emission level, with NZ and GT reaching similar NO_x pollution levels at 272 kt and 277 kt, respectively, despite CO_2 emissions are almost fully abated for the transport sector. The majority of the NO_x pollution emissions originates from methanol use for both NZ and GT scenarios.

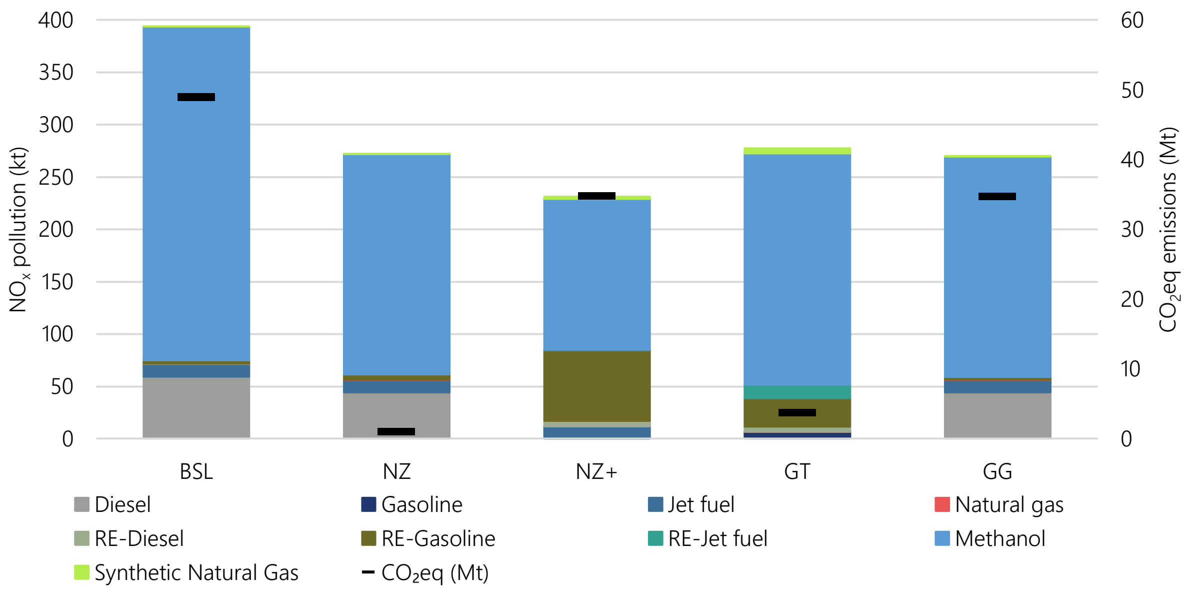


Figure 10.4 NO_x pollution emissions per fuel type and CO_2 emissions in the transport sector in 2050 for key scenarios.

The reason for the same level of air pollution, while projecting different CO_2 emissions levels, arise from the fact that diesel and jet fuel are used in the aviation and heavy-duty transport segments in the NZ scenario in 2050. On the other hand, in the GT scenario these fuels are replaced with a mix of RE gasoline, RE diesel and RE jet fuel, which emit similar amounts of NO_x as diesel and jet fuel. This trend illustrates that decarbonisation, and in particular electrification, is an important part of the solution to reduce air pollution, while renewable fuels could also be contributing to air pollution.

10.3 Key messages and recommendations

Accounting for air pollution in energy production and use to propose measures for improving public health and accelerating the green transition

Polluted air containing $PM_{2.5}$, SO_2 and NO_x emissions in excess of prescribed levels has been proven to have large negative impacts on human health, in turn with consequences on both economy and environment. Studies show that the largest air polluting sector is transport, followed by power and industry, i.e. sectors in which fossil fuels continue to be utilized even until 2050. Accounting for air pollution is needed to identify sources and levels of pollution thereby promoting mitigation solutions. The large electrification reduces the air pollution level and its negative consequences by more than 50% in 2050 compared to today. However, the decarbonization of the heavy transport sector does not necessarily decrease air pollution as some RE-fuels, e.g. biodiesel and biomethanol still contribute to air pollution.

Recommendation: Expanding the air quality monitoring network, as well as conducting further research and development of a detailed emissions inventory to account for air pollution levels and its impacts for each sector; further, proposing mitigation measures along with an implementation roadmap.

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