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Foreword

In 2013, Vietnam and Denmark entered into a long-term cooperation agreement for the purpose of strengthening Vietnam's transition to a low-carbon economy. The Danish Energy Agency (DEA) cooperates with the Ministry of Industry and Trade in Vietnam through the joint Energy Partnership Program between Vietnam and Denmark (DEPP). The program is currently in its second phase (DEPP II, 2017-2020) and covers long-term scenario modeling of the energy sector, the integration of renewable energy in the power grid and energy efficiency in the industrial sector.

This Vietnam Energy Outlook Report 2019 (EOR19) is a central milestone in the DEPP long-term scenario modeling activities and supports the development of Vietnam's energy system in a more sustainable way through implementation of cost-optimized policy and planning. The EOR19 is developed by the Electricity and Renewable Energy Authority under the Vietnamese Ministry of Industry and Trade in close collaboration with the Danish Energy Agency and supported by the Danish Embassy in Hanoi; consultants of the task were the Institute of Energy and EA Energy Analyses. The report has been developed in an open process by involving energy sector stakeholders in various workshops and working groups and by arranging Balmorel model training workshops for Vietnamese stakeholders in the energy sector.

The first edition of the Vietnam Energy Outlook Report was published in 2017. At that time, it marked the initial step of providing long-term scenario-based visions for the Vietnamese energy system and it created an important foundation for energy system analysis based on state-of-the-art energy system models.

Today, the EOR19 takes this to a new level, with an updated and enriched modelling and strengthened scenario analysis. The EOR19 is based on more solid input data, including high quality projections of prices for technologies and fuels as well as energy demand, a more comprehensive set of energy models, linked together to ensure a detailed and operational setup across all sectors. A key improvement in the EOR19 is that it includes dynamic modelling of the Vietnamese power system divided into six regions.

Going forward, it is expected that the Energy Outlook Report will continue to be published once every two years, thereby ensuring that the newest data and model improvements are used to back up decisions and discussions on long-term energy planning in Vietnam.

The EOR19 is supported by a list of other reports and analyses, which serve as the background and contain data and modelling methodologies behind the EOR19. This includes the EOR Technical Report, the Balmorel Data Report, the TIMES Data Report, the Fuel Price Projections Report, the Vietnam Technology Catalogue, and the Detailed Grid Modelling of the Vietnamese Power System Report. These are all publicly available.

Executive Summary

For decades Vietnam has been one of the fastest growing economies in Asia with a GDP growth rate above 6% per annum. The energy sector plays a significant role in the continued development of Vietnam, and access to affordable and reliable energy will be critical for sustained economic growth. Achieving the necessary global reduction of greenhouse gas emissions, as established under the Paris Agreement, depends heavily on the development path of emerging economies like Vietnam.

Vietnam has a huge opportunity to embark on a sustainable development pathway, considering the large opportunities for more efficient use of energy and the domestic resource potential for both solar and wind power. Declining cost of these technologies as well as of battery storage gives Vietnam an advantageous option for a green energy transition. However, such a pathway also entails certain challenges in expanding and integrating renewable energy (RE) in the energy system and realizing the energy efficiency (EE) potential in the most affordable way across sectors.

These challenges must be addressed by policy action. Based on well-documented and detailed modeling of the energy system, the EOR19 provides a scenario-based foundation for policy action by shedding light on the development of the energy system towards 2050. The report presents five scenarios (Figure 1) exploring different least-cost development pathways of the Vietnamese energy system. The scenarios are not intended as the "recommended" energy system pathways, but rather serve as indicative "what-if" scenarios from which insights have been drawn on the relevant themes in the Vietnamese context. Thereby, the EOR19 intends to guide policy makers and inspire deliberation on green transition, while delivering concrete input to the forthcoming National Power Development Plan 8 (PDP8) and the Energy Master Plan.

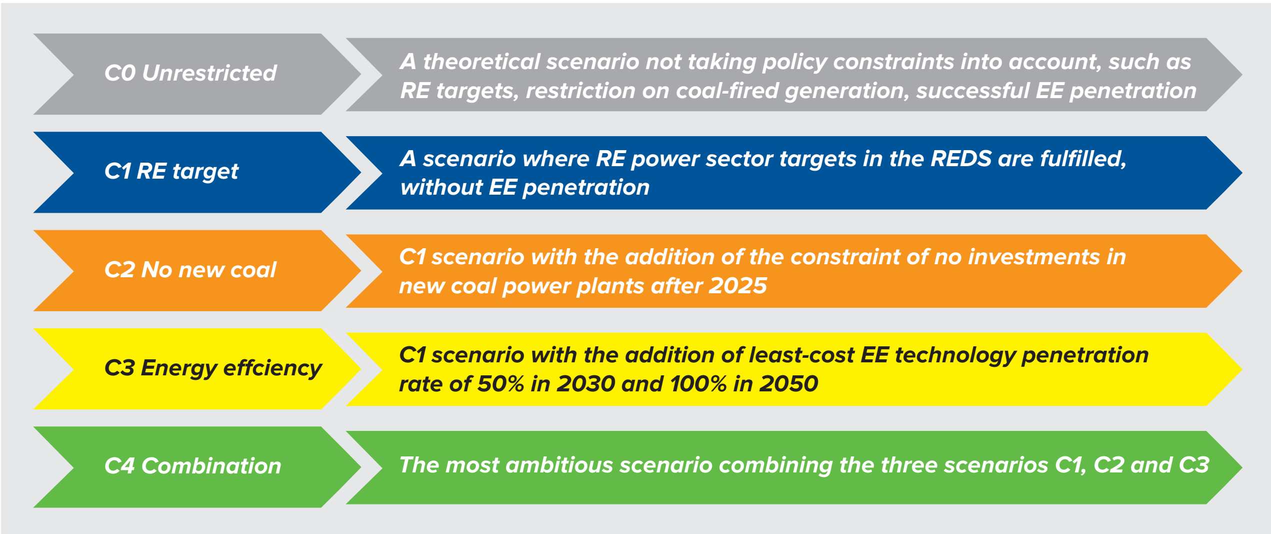

Figure 1: The five scenarios analysed and compared in the EOR19

The EOR19 shows that enhanced EE and development of RE at the highest level can deliver large and cost-effective CO_2 reductions, and reduce air pollution and dependency on fuel imports. Such a transition would require:

- An early **stop for investments in new coal power plants** that would reverse the current trend of increasing coal consumption.
- **Energy efficiency to be a priority.** The results show that it is much more cost-efficient to invest in EE than invest in more power plant capacity and that EE can contribute with important reduction of CO_2 and fuel import.
- **Stable and transparent framework conditions** for wind and solar power expansion, including stable plans and targets, a transparent and coordinated approval system for projects (one-stop shop), and international standard power purchase agreement (PPA). Results show that a 40% RE in the power mix in 2030 in combination with EE is feasible, will not increase costs, and is needed to limit fuel imports.

- **Investments in the transmission grid and electricity storage capacity**, which enable integration of maximum RE capacity.

The EOR19 is structured around five themes: **Energy Resources, Energy Efficiency, Renewable Energy, Power System Balancing** and **Climate Impact and Pollution**. In the following, key findings and recommendations for each theme are summarized.

Energy resources

Key findings

Coal and Liquefied Natural Gas: The trend of increasing use of coal continues, but if coal expansion is constrained, this trend can be reversed already in 2030. Liquefied natural gas (LNG) can replace coal in the power sector at a higher cost but causing less environmental pollution.

Renewable resources: RE resources, like wind, solar, hydro and biomass, can supply up to 24% of the primary energy by 2050 and achieve a RE share up to 59% in the power generation. Modelling results show that the use of biomass in industrial combined heat and power (CHP) and power plants could bring higher economic benefits than the current use for residential cooking. This indicates that biomass could become an important commodity for reducing fuel import and CO_2 emissions.

In 2030, all scenarios show **a massive increase in import of coal and oil**. Fuel import dependency can be reduced from 59% to 51% in 2030 and from 72% to 61% in 2050, if RE and EE in combination successfully replace most coal-fired power plants. The import cost can be reduced by EE measures, while limitation on coal does not alone reduce import cost as it is replaced by expensive LNG. Increased road transport makes the historic trend of increasing oil consumption continue, making it a major imported fossil fuel also in the long term. Based on transport activity data from the Ministry of Transport, the EOR19 shows that a successful transformation of the transport fleet to new and efficient vehicles, both passenger and freight, can lead to a 25% reduction of oil imports in 2050.

Recommendations

Efficient use of domestic resources, i.e. biomass, wind and solar and other RE in combination with EE measures are key elements to reduce import dependency of fuel for power generation.

Early actions to reduce the future coal demand are needed. This may include taxation on the use of coal or limits on new coal-based power generation: Coal power plants built today will operate thirty years from now. Therefore, to avoid lock-in effects, action in the short term is needed to reduce coal (import) dependence in the long term. As a further benefit, a reduction in coal consumption can reduce air pollution and CO_2 emissions.

Enhancing energy efficient vehicles by economic incentives and minimum efficiency standards: Oil will be a major import fuel, and a focus on enhancing energy efficient vehicles will reduce oil import dependence.

Mobilizing domestic biomass potential for energy production: Policy measures such as favorable feed-in-tariffs and investment subsidy schemes are examples of measures that can promote efficient biomass use and change in fuel use from coal to biomass.

Energy efficiency

Key findings

EE savings outweigh EE costs: Increasing cost for technology investments in EE at 7 and 16 billion USD in 2030 and 2050 respectively, will be more than outweighed by savings in fuels and supply sector investments, resulting in total savings of up to 3 and 30 billion USD in 2030 and 2050 respectively.

Considering the targets set out in the Vietnam National Program on Energy Efficiency and Conservation for the period 2019-2030 (VNEEP3), even more ambitious EE penetration remains cost-effective, as the EOR19 least-cost EE scenarios go beyond the high 2030-targets in VNEEP3.

Savings on electricity generation and energy consumption: The combined effects of electricity demand savings and industrial CHP could reduce investment in new power plants due to 10% and 29% lower power demand in 2030 and 2050, respectively, according to modelling results. Implementation of EE technologies can reduce final energy consumption by 12% in 2030 and by 20% in 2050, primarily reducing oil consumption in transport and energy consumption in the industry and residential sectors.

CO_2 emission savings: Implementation of EE technologies can reduce annual CO_2 emissions by 83 Mt in 2030 and by 237 Mt in 2050 in the power, industry, and transport sectors.

The most important areas for EE include **the industry sector** (process heat for cement, iron and steel, pulp and paper, and textile), **the transport sector** (cars, motorcycles, trucks, and buses), and **the residential sector** (cooking, air conditioning, and lighting).

Recommendations

Ambitious energy efficiency measures should be highly prioritized in PDP8: EE is one of the key elements in reducing costs for power plant investments. The coming PDP8 should take EE into account and focus on harvesting both the economic and environmental potential of EE. Making the utility companies co-responsible for energy savings has been successful in some countries and could therefore inspire Vietnam on bringing financial benefits for the utilities and their customers, as well as economic benefits for the society in general.

Continue and enhance the current energy efficiency policy (VNEEP3): More ambitious EE penetration than outlined in VNEEP3 remains cost-effective. In order to fulfill this target, it is important to e.g. enhance minimum efficiency performance standards, fuel economy standards in transport, energy audits and energy management systems (ISO 50,001 and similar schemes) in all major energy-intensive facilities, and develop voluntary agreements schemes with fiscal and financial incentives.

Focus on barriers to facilitate large investments in energy efficient technology in the demand sector: Implementation of EE can have many informational, regulatory, financing and market barriers not covered by the EOR19, which focus on least-cost technology deployment. Some of these barriers can be addressed by *trading energy savings*.

New investments in industrial CHP plants: It is recommended to implement incentives to support investments in industrial CHP plants, in which the use of local resources, e.g. biomass, should be prioritized.

Renewable energy

Key findings

Wind and solar power will be more cost-effective than coal in 2030 for the first 20 GW installations in the best locations. The cost-effective capacity threshold will increase to more than 100 GW in 2050, due to anticipated cost reduction in wind and solar technologies. The least-cost power mix requires a capacity build-up equal to 1 GW/year for wind and 1-2 GW/year for solar PV in the period 2020-2030. While the best wind and solar projects are competitive, they require increased upfront investments compared to conventional power production.

Hydro and bioenergy: While unused hydro power potential is small, bioenergy has a potential to play an increasing role in industrial CHP and power production. However, the two main RE building blocks of the energy system remain solar and wind.

Offshore wind development: The assessment of 6 potential locations for offshore wind indicates that this technology is very attractive as early as in 2030.

Land-use: International experiences show that onshore wind power can easily be combined with agriculture. The largest solar capacity deployed in the EOR19 is in the South Region (76 GW in 2050), where PV will only take up 1.6% of the area of the region.

Recommendations

RE must be in focus in the coming PDP8 to ensure the necessary basis for the RE expansion for the next 10 years. Ensuring investments in the power grid is crucial to enable more RE integration and avoid costly curtailment of wind and solar. Furthermore, special attention must be given to wind power which in a least-cost perspective would develop to generate more power than solar in the next 10 years. Finally, an ambitious RE target in the power mix in 2030 based on detailed scenario analysis should be included.

For a successful wind and solar development in Vietnam, it is crucial to have stable, simple, transparent, and competitive enhancing framework conditions for RE projects, characterized by:

- **Simplicity:** A **one-stop shop** where RE developers have a single point of contact;
- **Stability: Stable and long-term plans and targets** for RE expansion reduce the risk for the investors and support building up of local supply chains;
- **Transparency: Transparent process** for developing RE projects and **close dialogue** with market players along with an **International standard PPA** builds trust and reduces the risk, thus attracting more investors;
- **Competition:** For large scale wind and solar PV projects, it is important to **expose the developers to competition** to drive down prices, as the international experiences with RE auctions have shown (IRENA, 2017).

A framework for the development of offshore wind should be established already in the short term as offshore wind power is a knowledge-intensive technology and requires high upfront investments.

The awareness of local authorities, citizens, and stakeholders should be enhanced to ensure acceptance and facilitate local citizens to benefit from RE projects: The Planning Law[1] already stipulates the increased involvement of local authorities in the planning processes. Thus, to realize the large expansion of RE projects, not only national energy planning but also provincial involvement must be activated.

Power system balancing

Key findings

Balancing the power system is technically and economically feasible, even with high shares of solar PV and wind power. Even at 33% wind and solar share in 2050, the system can be balanced with 74 GW battery storage, mainly in the South region, and 53 GW investments in transmission capacity.

Large amount of batteries in the long term: Electricity storage is key to balancing of wind and especially solar, with around 0.5 MW for each MW of wind and solar in 2050. As short-cycle (few hours) storage favors batteries as a least-cost storage solution, there will be a gradual shift in the balancing role from the current hydropower to battery storage technology in the long term. If battery prices do not decrease as expected, wind and pumped hydro will have a larger role in the future, yet PV and batteries will still be the main RE building blocks.

Full transmission grid assessment shows that in 2030, necessary grid investments amount to 30% of total power system investments.

Recommendations

A stepwise approach to integration of wind and solar power is recommended: In the short term, focus should be on expansion for transmission capacity to ensure RE integration and to avoid costly curtailment of wind and solar. In the long term, electricity storage is key to balancing of wind and especially solar.

Removal of market barriers to ensure timely introduction of electricity storage should be investigated and addressed, thus laying out the favorable market conditions.

[1] Law No. 21/2017/QH14 issued by the National Assembly dated November 24, 2017

Other means for **balancing the system and reducing the need for storage** not analysed in the EOR19 should be addressed; this includes power trade with neighboring countries and other flexibility measures. Increased trade can bring multiple benefits, here among improved competition, security of supply, sharing of reserves, reduced need for storage and improved balancing in relation to hydro (wet/dry years), wind and solar. Flexibility measures in thermal power plants, pumped hydro, demand response and further development of forecasting systems can facilitate the integration of wind and solar power.

Climate and pollution

Key findings

CO_2 emissions from the energy sector are increasing quickly. The combined effect of EE, RE and LNG can reduce CO_2 emission by almost 20% in 2030 and 40% in 2050, primarily in the power sector. The industry and transport sector also give significant contributions, if EE is successfully implemented.

Coal is the main source of CO_2 emissions and contributes across scenarios with 65% to 75% of total CO_2 emissions from the energy system. Departing from new coal investments and increasing the consumption of LNG can save 53 million tons of CO_2 in 2030, while the total system costs increases by approximately 1 billion USD. Additionally, if EE is enhanced, Vietnam will realize both cost and emissions savings.

Compared to the Nationally Determined Contribution (NDC) Business-as-usual scenario, emissions from the energy sector will be reduced by 19% in 2030 in the *C1 RE target scenario* (the national unconditional NDC target is 8%). When further including EE and a stop for new coal investments (*C4 Combination scenario*), CO_2 emission reductions exceed 30% in 2030 (the national conditional NDC target is 25%).

Emissions from coal in the power sector impose a large health cost on society. In 2030 all scenarios result in a health cost of pollution in the range of 7-9 billion USD. Assuming no increase in the level of flue gas cleaning, the cost of air pollution from the power sector reaches 23 billion USD/year, corresponding to 2% of GDP (*C1 RE target scenario*) in 2050. This value is reduced to 7 billion USD in the *C4 Combination scenario,* where EE, RE and LNG can give large health cost savings in the long term.

Recommendations

Introduce incentives to reduce CO_2 emissions and other air pollutants including taxes, emission trading schemes or other forms of market systems: The introduction of incentives to reduce CO_2 emissions and other air pollutants would support RE investments and promote a phase-out of carbon intensive fossil generation plants.

Harmonization of all government RE targets and emission targets for future planning will ensure that the plans support the green transition. This includes a continuous monitoring and comparison of RE targets, energy system efficiency and emission targets. Specifically, this would mean that the coming PDP8 and Energy Master Plan should be aligned with government targets on GHG emissions, e.g. in the NDC or in line with the Paris Agreement.

Tighten air pollution control measures in power generation and industry and include health costs of pollution in energy system modelling and planning, including PDP8. Health costs already today impose a large cost on society, and pollution from power plants is rising. Health externalities are often not considered in economical evaluations of energy planning. Inclusion of such measures would highlight the real cost of energy, especially relevant for coal power.

Adjust the 2030 CO_2 target to be more aligned with restrictions on coal, realization of cost-efficient EE measures and expansion of RE technologies. A more ambitious NDC target is possible and could bring Vietnam direct advantages on reduced fuel import dependence, less air pollution, and lower energy system costs.

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Abbreviations and Acronyms

BAU	Business-As-Usual
CFL	Compact Fluorescent Lamp
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
DEA	Danish Energy Agency
DEPP	Energy Partnership Program between Vietnam and Denmark
EA	EA Energy Analyses
EE	Energy Efficiency
EIA	Environmental Impact Assessment
EOR19	Vietnam Energy Outlook Report 2019
EREA	Electricity and Renewable Energy Authority
ESCO	Energy Service Companies
EVN	Vietnam Electricity
FiT	Feed-in-Tariff
GDP	Gross Domestic Product
GHG	Green House Gas
GOV	Government of Vietnam
GSO	General Statistics Office of Vietnam
IE	Institute of Energy
INDC	Intended Nationally Determined Contributions
LCOE	Levelized Cost of Electricity
LNG	Liquefied Natural Gas
MEPS	Minimum Energy Performance Standard
MOIT	Ministry of Industry and Trade
MONRE	Ministry of Natural Resources and Environment
MOT	Ministry of Transport
MSW	Municipal Solid Waste
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organizations
PDP	Vietnam Power Development Plan
PM2.5	Atmospheric Particulate Matter with a diameter of less than 2.5 micrometers
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
REDS	Renewable Energy Development Strategy
R&D	Research and Development
RPS	Renewable Portfolio Standards
TFEC	Total Final Energy Consumption
TPES	Total Primary Energy Supply
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
VEPF	Vietnam Environment Protection Fund
VGGS	Vietnam Green Growth Strategy
VNEEP3	Vietnam National Program on Energy Efficiency and Conservation for the period 2019-2030
VRE	Variable Renewable Energy
WB	World Bank
WHO	World Health Organization

1 Introduction

1. Introduction

1.1 Background

For decades Vietnam has been one of the fastest growing economies in the region and in the world. Since 1990 the average annual growth in GDP has been more than 6%, with economic growth expected to continue in the future. Economic development has been the key to improvements in the quality of life, and has resulted in a dramatic drop in poverty rate. While economic growth is high priority for the Vietnamese government, governmental strategies emphasize that the fast development needs to uphold sustainability at the same time.

With its rapid economic growth, Vietnam is becoming an important actor in the global agenda – both from an economic and an environmental perspective. The rapid economic growth results in quick growth of energy demand and greenhouse gas emissions. Achieving the reduction of greenhouse gas emissions as agreed under the Paris Agreement (UNFCCC, 2016) depends heavily on the development path of Vietnam and other emerging economies. At the same time, the global energy market has witnessed a remarkable decline in the cost of renewable energy technologies, as well as of battery storage. This gives Vietnam the opportunity to embark on a sustainable development pathway, considering the large opportunities for more efficient use of energy and the domestic resource potential for both solar PV and onshore and offshore wind.

The development of the energy sector plays a key role in supporting the country's economic development. Economic growth requires secure and affordable supply of energy to all of the society and economic sectors. At the same time, to ensure a sustainable growth, the energy sector must be able to attract the capital required to expand the infrastructure and secure the efficient distribution and consumption of energy sources in the long term.

To embrace these opportunities for the development of its energy system, Vietnam is facing new challenges: how to ensure an **efficient use of domestic energy resources;** how to **overcome the barriers for energy efficiency;** how to **utilize the economic potential for renewable energy** while **securing a stable power supply,** and how to successfully contribute to **mitigating climate change and air pollution.**

These challenges must be addressed by policy actions backed by solid energy system planning grounded on holistic analyses of long-term energy scenarios. This EOR19 provides exactly that: Mid- to long-term perspectives of energy system operation and investment to be used as a guide for policy makers and energy planners when balancing both economic and environmental issues, along with ensuring security of supply. In this perspective, the report represents an important input to the forthcoming PDP8 and the Energy Master Plan.

1.2 Current energy and climate policy targets

The Government of Vietnam has several key policies for sustainable energy development with four main pillars: EE, RE, energy market and climate change. The current main policies for shaping the future energy development in Vietnam comprise:

- *Law on Energy Efficiency and Conservation (LEEC)*[2]*:* promoting energy efficiency and conservation activities through regulations, standards and incentives.
- *Electricity Law and Amendment of Electricity Law*[3]: prescribing the electricity development planning and investment; electricity saving; electricity markets and others.
- *Vietnam Green Growth Strategy (VGGS)*[4]: introducing GHG reduction targets aiming to reducing fossil fuel and promoting renewable energy.
- *Law on Environment Protection*[5]*:* promoting clean and renewable energy; environmental protection fee; environmental protection fund; strategic environmental assessment.
- *Renewable Energy Development Strategy (REDS)*[6]: setting RE targets in energy and power sectors; supporting schemes for RE development (Feed-in tariff (FiT); Renewable Portfolio Standard (RPS), Net-metering etc.).
- *National Program on Energy Efficiency and Conservation for the period 2019-2030 (VNEEP3)*[7]*:* setting targets for reducing the final energy consumption compared to a business-as-usual baseline.

[2] Law No. 50/2010/QH12
[3] Law No. 28/2004/QH11 and Law No. 24/2012/QH13
[4] Prime Minister Decision 1393/2012/QD-TTg
[5] Law No. 55/2014/QH13
[6] Prime Minister Decision No. 2068/2015/QD-TTg
[7] Prime Minister Decision No. 280/2019/QD-TTg

- *Intended Nationally Determined Contributions (INDCs):* submitted to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC).
- *The revised National Power Development Plan in the period 2016-2020 with the orientation to 2030 (revised PDP7)*[8]*:* reducing the amount of coal power plants compared to PDP7, enhancing security and implementing innovations for new power plants.

The current main policy targets for RE, EE and greenhouse gas emissions are listed in Table 1.

Table 1: Specific targets mentioned in current energy and climate policy Vietnam

Target	2020	2025	2030	2050
Renewable energy				
RE share in primary energy supply (REDS)	31%		32%	44%
RE share in total electricity generation (REDS)	38%* 4% excl. hydro		32%* 15% excl. hydro	43%* 33% excl. hydro
Energy efficiency as compared to business-as-usual				
Final energy demand saving (VNEEP3)		5-7%	8-10%	
GHG emission reduction as compared to business-as-usual				
Green growth strategy (VGGS)	10-20%		20-30%	
Intended Nationally Determined Contributions (INDCs)			8% (unconditional) 25% (conditional)	
REDS (energy sector)	5%		25%	45%

** Including small and large hydro power, wind power, solar power, biomass, biogas and geothermal energy*

[8] Prime Minister Decision No. 428/2016/QD-TTg

1.3 Purpose of the report

The purpose of this report is to guide decision makers and energy planners to achieve a sustainable green transition of the energy system. The EOR19 presents and discusses the newest insights on the possible long-term development pathways of the Vietnamese energy system, illustrated by a set of explorative and normative scenarios. The objective is to foster a wider consensus and understanding of all parties on the opportunities and challenges of the energy sector and to support and inspire the debate about green transition. As already mentioned, the report and the work behind it is intended to serve as a scientific and knowledge-based input to the forthcoming PDP8 as well as the development of an Energy Master Plan.

1.4 Analysis preconditions

The report is based on long-term energy system analyses, derived from least-cost optimization of investments in and operation of energy technologies, covering the whole energy system (both supply and demand) with a time horizon until 2050. These basic conditions apply:

- Model calculations are performed for the years 2020, 2030, 2040 and 2050.
- The Vietnamese power system is divided into six regions dynamically linked by transmission lines.
- As a starting point, an update of the planned power capacity in the revised PDP7 is included in the models.
- With a focus on the long-term analysis of the system, more detailed short-term energy system development (before 2030) is not in focus, and ancillary services and peak load demand are not analysed in the models.
- Being a multiple scenario study, conclusions are drawn by comparing scenarios, not by pointing out a recommended scenario.
- The scenarios have technology in focus and are built by defining *targets*, i.e. the scenarios present the optimal socio-economic least-cost pathways, under certain conditions, with no direct accounting of taxes and subsidies. The simultaneous least-cost optimization is performed across sectors, except for the transport sector, which is not model-optimized and based on scenarios suggested by the Ministry of Transport (GIZ, 2018a).
- Externality costs, i.e. air pollution, are not a part of the optimization, with health costs discussed separately.
- A 10% discount rate is applied across all technologies in the least-cost optimization, which in the longer term may be interpreted as a conservative assumption unfavorable of capital-intensive technologies such as wind and solar.
- Data for long-term studies will always be uncertain. However, for the EOR19, considerable effort has been made to develop and use sound input data, especially on power generation and fuel prices. To consolidate the key results, a sensitivity analysis for the power sector has been carried out (EREA & DEA, 2019a).

For more details on the modelling framework and the key input assumptions and data, the reader is referred to the Annex and the EOR19 background reports[9].

[9] These include the Technical Report (EREA & DEA, 2019a), the Balmorel Data Report (EREA & DEA, 2019b), the TIMES Data Report (EREA & DEA, 2019c), the Fuel Price Projection Report (EREA & DEA, 2019e), the Technology Catalogue (EREA & DEA, 2019f) and the PSS/E Report: Detailed grid modelling of the Vietnamese power system (EREA & DEA, 2019d).

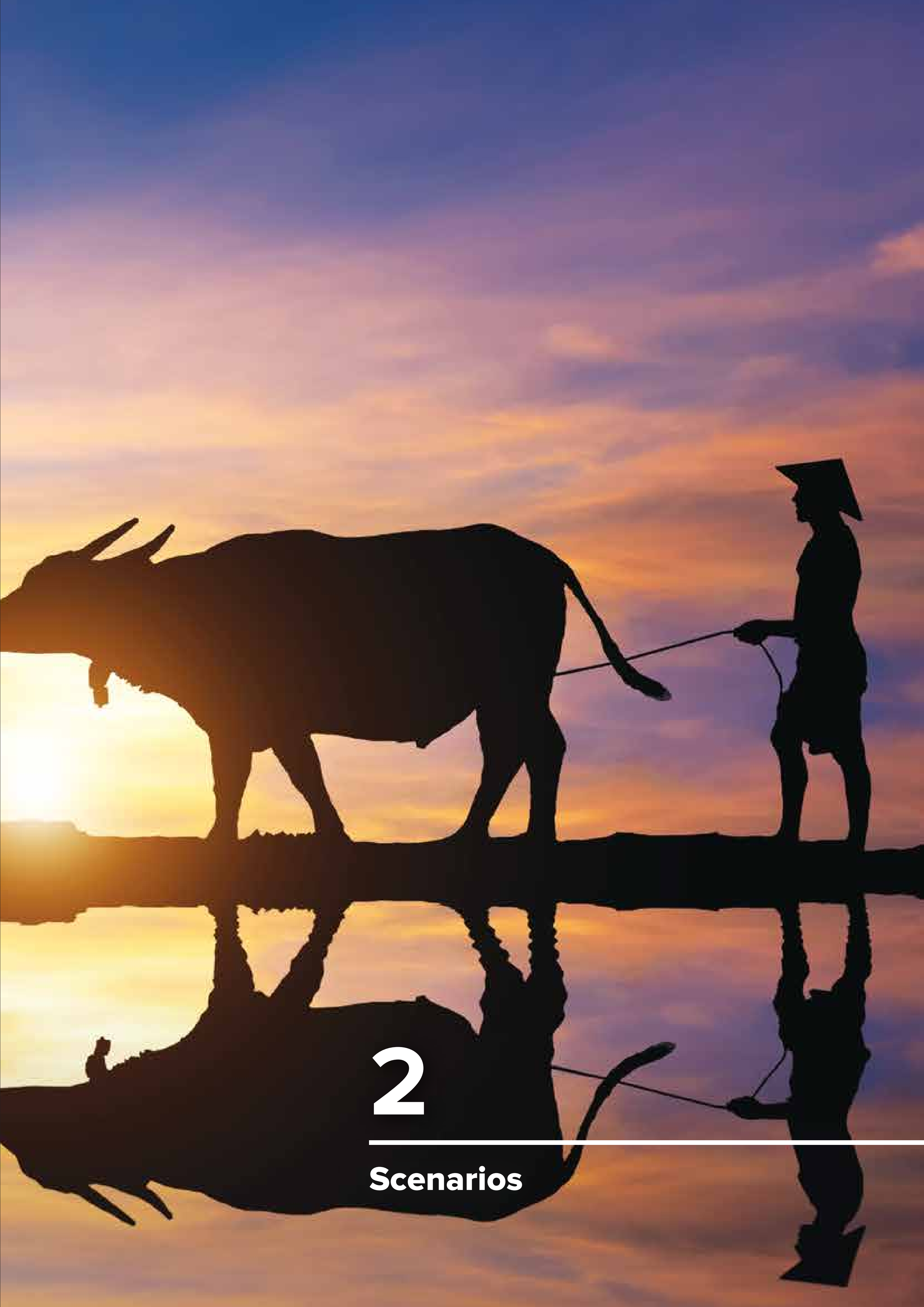
The report is structured around five main themes, which reflect the key challenges for the future green transition of the energy system in Vietnam (Table 2). For each theme, a focus chapter covers:

- **Status and Trends,** describing the current context of Vietnam;
- **Energy Outlook,** discussing the energy system development towards 2050;
- **Policy Outlook and Recommendations,** reflecting on how the challenges can be addressed.

Following this introduction chapter, the remainder of this report is organized as follows: Chapter 2 describes the scenarios analysed in the EOR19; Chapter 3 reports the modelling results and compares the scenarios across key indicators; Chapters 4-8 represent the main body of the report, where an in-depth analysis of the five themes of the EOR19 is undertaken, detailing the current status and trends, the future outlook resulting from the modelling results and the policy recommendations for each theme. The Annex illustrates the modelling framework and key assumptions, for each of the models used in this report.

Table 2: Themes of the EOR19 and related challenges

Theme	Challenge
Energy Resources	• Efficient use of the domestic energy resources while respecting both economy and environment • Energy independence and self sufficiency
Energy Efficiency	• Overcoming the barriers to investment in EE technology
Renewable Energy	• Utilizing the technical and economic potential for renewable energy • Optimal integration of solar PV, onshore and offshore wind
Power System Balancing	• Stable energy supply while integrating fluctuating solar and wind power • Investments and enforcement of power transmission grid network
Climate Impact and Pollution	• Mitigation of GHG emissions to deliver on the NDC obligations and the Paris Agreement • Effect on human health from air pollution from fossil fuels



2

Scenarios

2. Scenarios

Energy system modelling constitutes the basis for the conclusions and recommendations detailed in this report. Five core scenarios are designed to explore different futures for the Vietnamese energy system (Figure 2). As such, the scenarios are not intended as the "recommended" energy system pathways, but rather meant as indicative "what-if" scenarios from which insights have been drawn on the relevant themes for the Vietnamese context.

All five scenarios have been computed in the interlinked set-up comprising three energy models:

- **The TIMES model,** covering the whole energy system, both supply and demand and fuel extraction
- **The Balmorel model,** covering a detailed representation of the power sector
- **The PSS/E model,** representing the detailed power grid

More details on the methodology and model set-up can be found in the Annex of this report. A set of alternative green power scenarios exploring different power system RE-shares are not included in this report but are described in the Technical Report (EREA & DEA, 2019a).

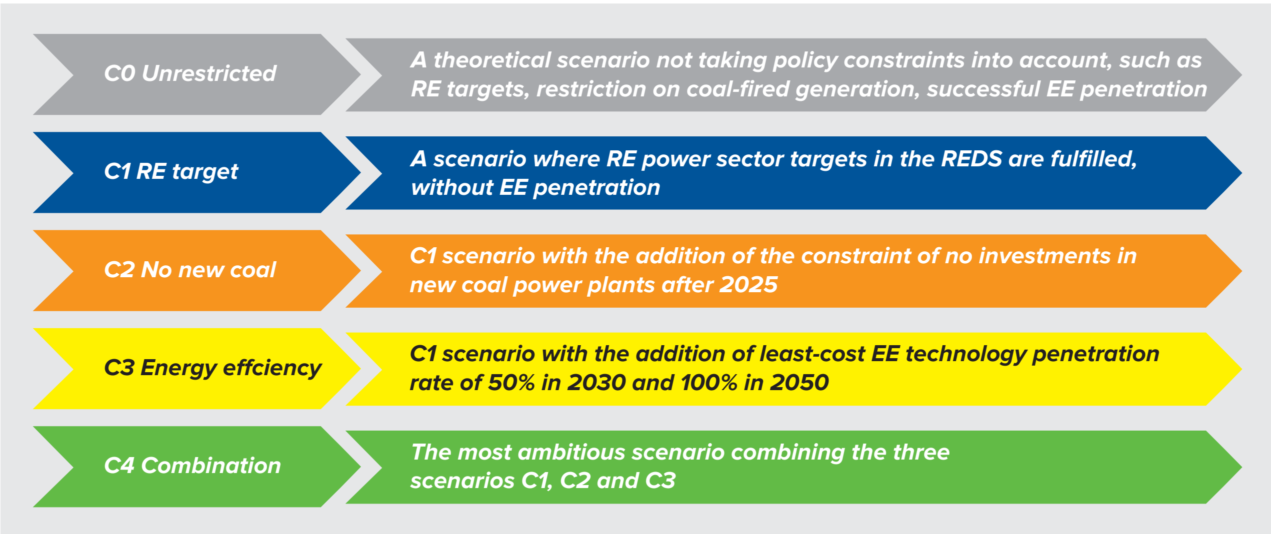


Figure 2: The five scenarios

The five scenarios (Figure 2) illustrate different development pathways for the Vietnamese energy system:

- ***C0 Unrestricted:*** This theoretical scenario simulates a future with no achievement of RE targets or restrictions on coal-fired generation and without penetration of energy efficient demand technologies.
- ***C1 RE target:*** This scenario includes the RE target for the power sector, as set out in the current Renewable Energy Development Strategy (REDS) (see Figure 3) and without penetration of energy efficient demand technologies.
- ***C2 No new coal:*** Additional to the *C1 RE target scenario,* this scenario implements a restriction limiting investments in new coal power plants starting from 2025, albeit domestic coal capacities are allowed to be maintained.

- ***C3 Energy efficiency:*** Additional to the *C1 RE target scenario,* this scenario allows for investments in energy efficient (EE) technologies, with a 50% penetration rate of energy efficient demand technologies being a part of the least-cost solution in 2030 and 100% in 2050[10].
- ***C4 Combination:*** This scenario combines the three previous scenarios, i.e. the REDS target, the coal restriction from 2025 and the high uptake of energy efficient technologies.

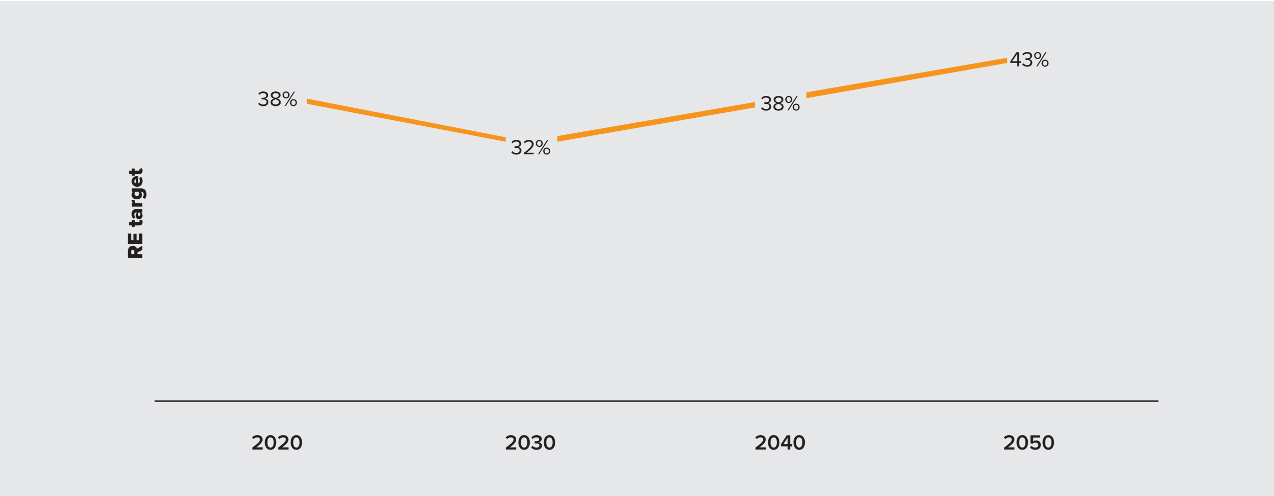


Figure 3: REDS RE target (all RE sources incl. both small and large hydro) on annual power generation, as implemented in all scenarios except for the *C0 Unrestricted scenario.* There is no REDS target for 2040, thus the scenario target used in 2040 is a linear interpolation between 2030 and 2050 targets.

[10] For the transport sector, the mentioned penetration rates are not implemented; instead, the measures included in the *C3 Energy Efficiency scenario* are based on input from Ministry of Transport (more information in the Annex).

3

Key modelling results

3. Key modelling results

This chapter provides a summary of modelling results of the EOR19 across the five key themes. It reports the scenario results for primary and final energy consumption, power capacity (GW) and generation (GWh), energy system costs, as well as it compares the scenarios using a number of key indicators.

3.1 Primary and final energy

The total primary energy supply (TPES[11]) increases about five times in the period 2017-2050 in the *C1 RE target scenario,* following the assumed growth across all sectors of the economy in Vietnam, thereby increasing from 3,200 PJ in 2017 to around 7,600 PJ in 2030, and 14,200 PJ in 2050. TPES is reduced in the *C2 No new coal scenario* mainly, as gas turbines are more efficient compared to coal power plants. EE technologies implemented in the *C3 Energy efficiency scenario* help reduce the primary energy supply by 770 PJ in 2030 (10%) and by 3000 PJ in 2050 (21%) with respect to the *C1 RE target scenario* (Figure 4). The *C4 Combination scenario* features the lowest primary energy supply.

While the REDS RE targets for the *power sector* are reflected in the EOR19 scenarios, the REDS also has targets for RE in *TPES* of 32% and 44% in 2030 and 2050, respectively. All of the EOR19 scenarios are far from fulfilling the *TPES* RE targets which would require a much more extensive RE penetration covering also other sectors than the power sector. Furthermore, it can be noted that because increased energy efficiency in *C3 Energy efficiency scenario* and *C4 Combination scenario* reduce fossil fuels as well as RE in 2050, it can be said that EE technologies alone only to a limited extent contribute to increasing the RE share on the longer term.

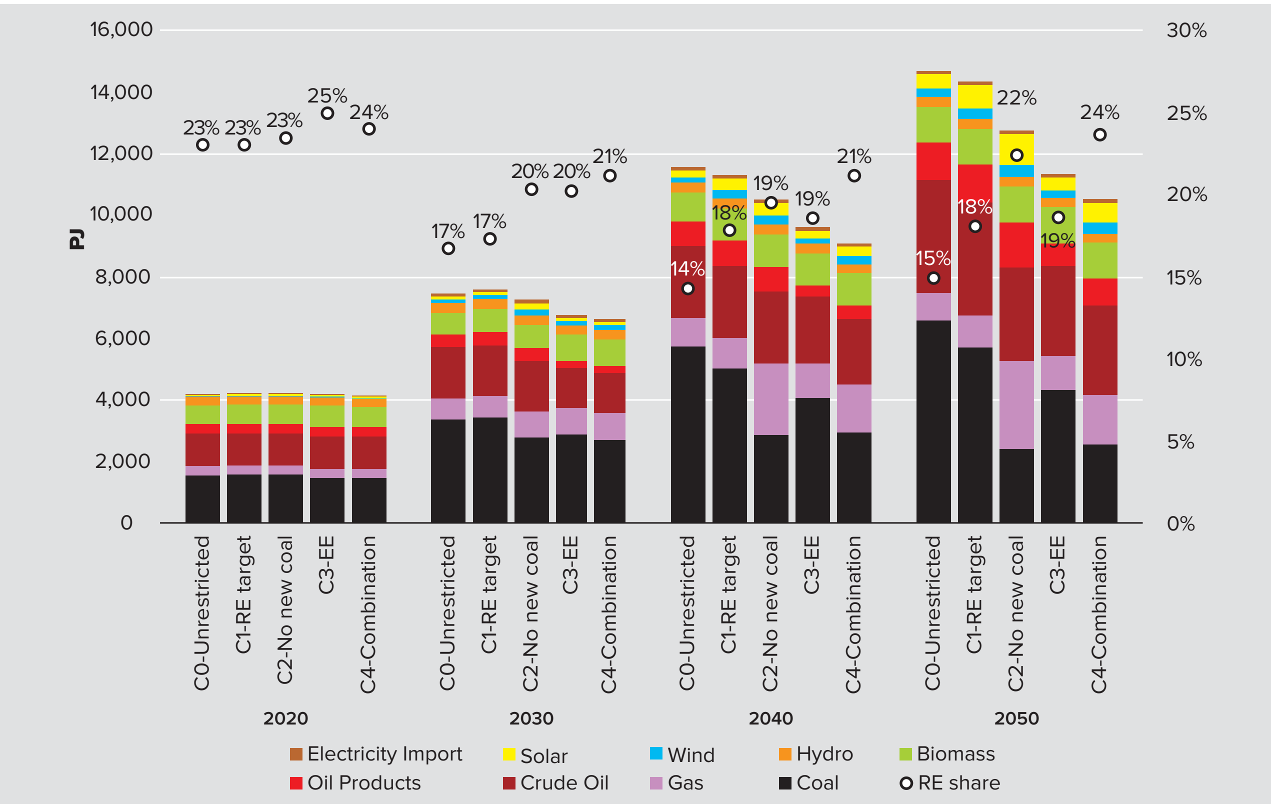


Figure 4: Total primary energy supply (TPES) and RE share in TPES across analysed scenarios in the period 2020-2050

[11] Total primary energy supply describes the total input of primary energy to the energy system. TPES is the sum of production and imports subtracting exports and storage changes. Where primary energy is used to describe fuels, it is the energy available as thermal energy in the fuel. When solar and wind energy is converted to electricity, the electricity made from wind and solar counts as the primary energy for these sources.

Following the trend observed for the TPES, the total final energy consumption (TFEC[12]) will increase about four times in the period 2017-2050, from 2,700 PJ in 2017 to about 5,100 PJ in 2030 and 10,000 PJ in 2050 in the *C1 RE target scenario* (Figure 5). In this scenario, TFEC will increase by 6.6% p.a. in 2020-2030 and 4.4% p.a. in 2020-2050. In 2020-2030, commercial and industrial sectors have the highest growth rates of 7.4% p.a. and 7.0% p.a. respectively. For the whole period 2020-2050, the transport sector features the highest growth rate of 5.1% p.a. In the *C1 RE target scenario,* the industrial sector accounts for about half of TFEC, increasing to 54% of TFEC by 2030 and then reducing to 48% of TFEC by 2050. In 2030, the transport sector accounts for 20% of TFEC, while the residential for 18%, the commercial for 6% and agriculture for 2% of TFEC.

The *C3 Energy efficiency scenario* and the *C4 Combination scenario* have lower TFEC (app. 12% in 2030 and app. 20% in 2050) compared to the other scenarios, due to higher EE technology penetration across sectors. This corresponds to a reduction in the TFEC of up to 630 PJ by 2030 and 1,970 PJ by 2050, primarily due to a decrease in oil consumption in the transport sector and power demand in the industry and residential sectors.

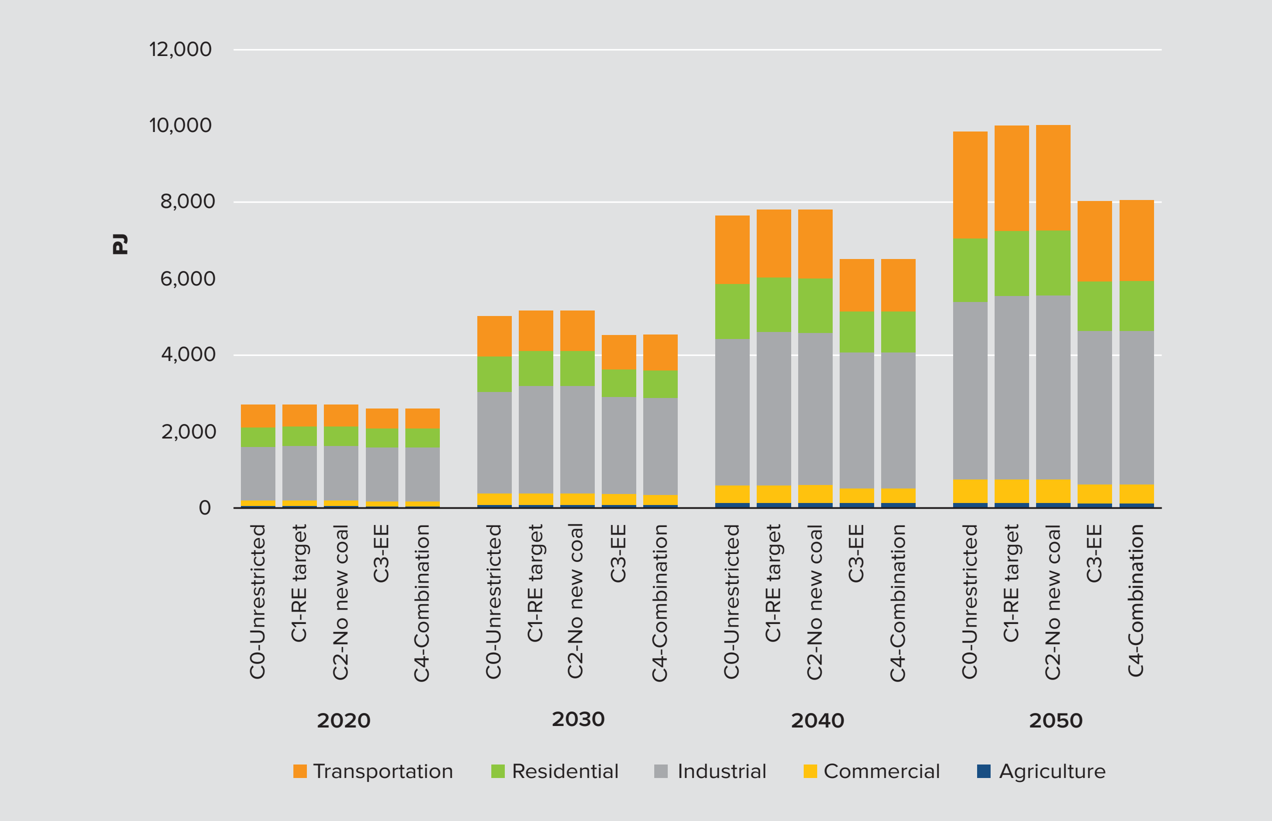


Figure 5: Evolution of total final energy consumption (TFEC) by sector in the analysed scenarios in the period 2020-2050

[12] Total final energy consumption represents the energy delivered to end users, i.e. private and public enterprises as well as households. Final energy is used in the manufacture of goods and services, space cooling, lighting and other appliance consumption as well as transport. Additionally, oil consumption for non-energy purposes, i.e. lubrication, cleaning and bitumen for paving roads is included. Energy consumption in connection with extraction of energy, refining and conversion is not included in the final energy consumption.

3.2 Power system

Large increases in the power demand result in a rapid expansion of the power generation capacity (Figure 6). Across all scenarios, large increases in solar power can be observed (e.g. 117 GW of solar capacity in the C1 RE target scenario by 2050). This trend is prominent even in the *C0 Unrestricted scenario,* where no RE goals are implemented, with 72 GW of solar PV capacity being installed by 2050. Moreover, the EOR19 shows that along with the PV expansion, large expansion of batteries will occur to provide storage for the RE power production (e.g. 74 GW of battery capacity in the *C1 RE target scenario* by 2050).

Furthermore, the scenarios feature a rapid increase in capacity investments for both onshore and offshore wind: by 2050, in the *C1 RE target scenario,* 19 GW of onshore wind is installed, and all 6 GW of the modelled available offshore potential is used. When no restrictions on coal generation are imposed, a large amount of coal is imported. In general, the least-cost modeling approach chooses coal over LNG, as it represents a cheaper fuel option. However, when the expansion of coal-fired generation is restricted (i.e. *C2 No new coal* and *C4 Combination scenarios*), LNG represents a viable option to supplement the RE development instead of coal.

As visible from Figure 7, restrictions on coal investments will increase the share of wind and solar generation, as well as replace the generation from imported coal by imported LNG. In 2050, the RE share (including wind, solar, bioenergy, small and large hydro) increases from 43% in the *C1 RE target scenario* to 50% in the *C2 No new coal scenario.* Power demand reduction due to EE measures results in a reduction of the most expensive power generation. In the *C3 Energy efficiency scenario,* less power is generated from coal and solar PV (compared to *C1 RE target scenario*) and in the *C4 Combination scenario* the power demand reduction affects LNG and PV generation (here compared to the *C2 No new coal scenario* for measuring the EE effect). In general, the generation from high quality RE potentials (high wind speeds and high solar irradiation) is realized, thus constituting a larger share of the total generation. In the *C4 Combination scenario,* the RE share reaches 59% in 2050.

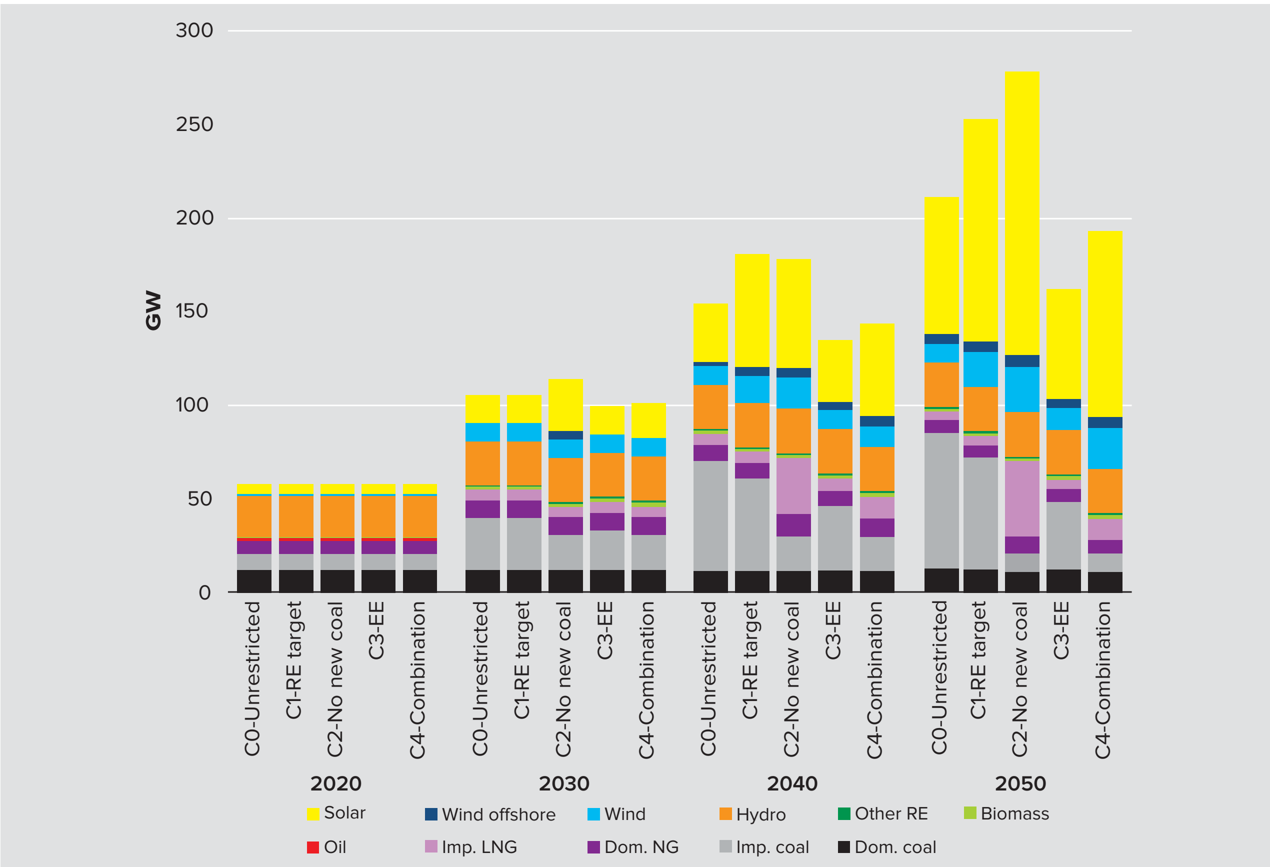


Figure 6: Generation capacity in the power sector for the five analysed scenarios

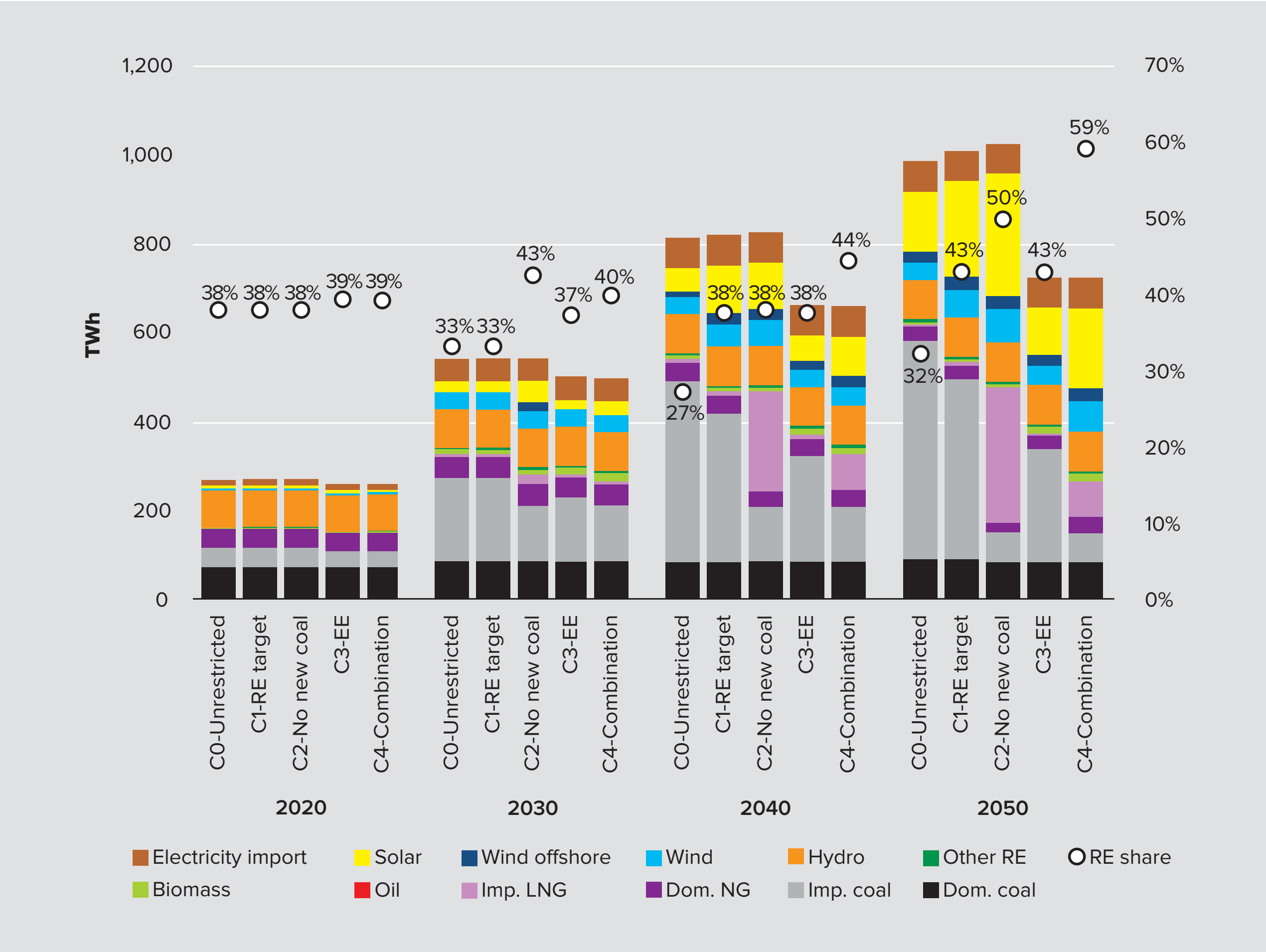


Figure 7: Annual electricity generation form central power production, import from neighbouring countries and power demand (including transmission and distribution losses) in the five analysed scenarios

3.3 Energy system costs

The energy system costs cover annualized investment costs for power generation and transmission capacity and annualized investment costs for energy end-use devices in the end-use sectors; operation and maintenance costs for all sectors; and fuel costs for all sectors. Figure 8 shows that the total annual energy system costs are more than double from 2020 to 2030 as well as from 2030 to 2050 in the *C1 RE target scenario*. It also shows that a high penetration of EE in the *C3 Energy efficiency* and *C4 Combination scenarios* reduces the energy system cost by app. 3% and 9-10% for 2030 and 2050, respectively. This is explained by the fact that the energy savings and power plant investment reduction exceed the investment in EE. Please note that investments in current and committed energy components are not included and externality costs for e.g. health effects are not accounted for.

There is a relatively small difference among the scenarios in the amount of capital needed. In the *C2 No new coal scenario,* higher investments are needed to replace coal with RE and LNG. For the EE scenarios (*C3 Energy efficiency* and *C4 Combination scenarios),* the increased investments in the demand sectors are to a wide extent outweighed by reduced power sector investments.

Even though investment costs for existing and committed power plants are not included, the power system cost (USD/MWh) indicates that increased share of RE and LNG in the *C2 No new coal* and *C4 Combination scenarios* would result in higher costs for the power system in 2030 and onwards. This is also associated with higher power prices. Assessment of market-based power prices is not a part of the EOR19.

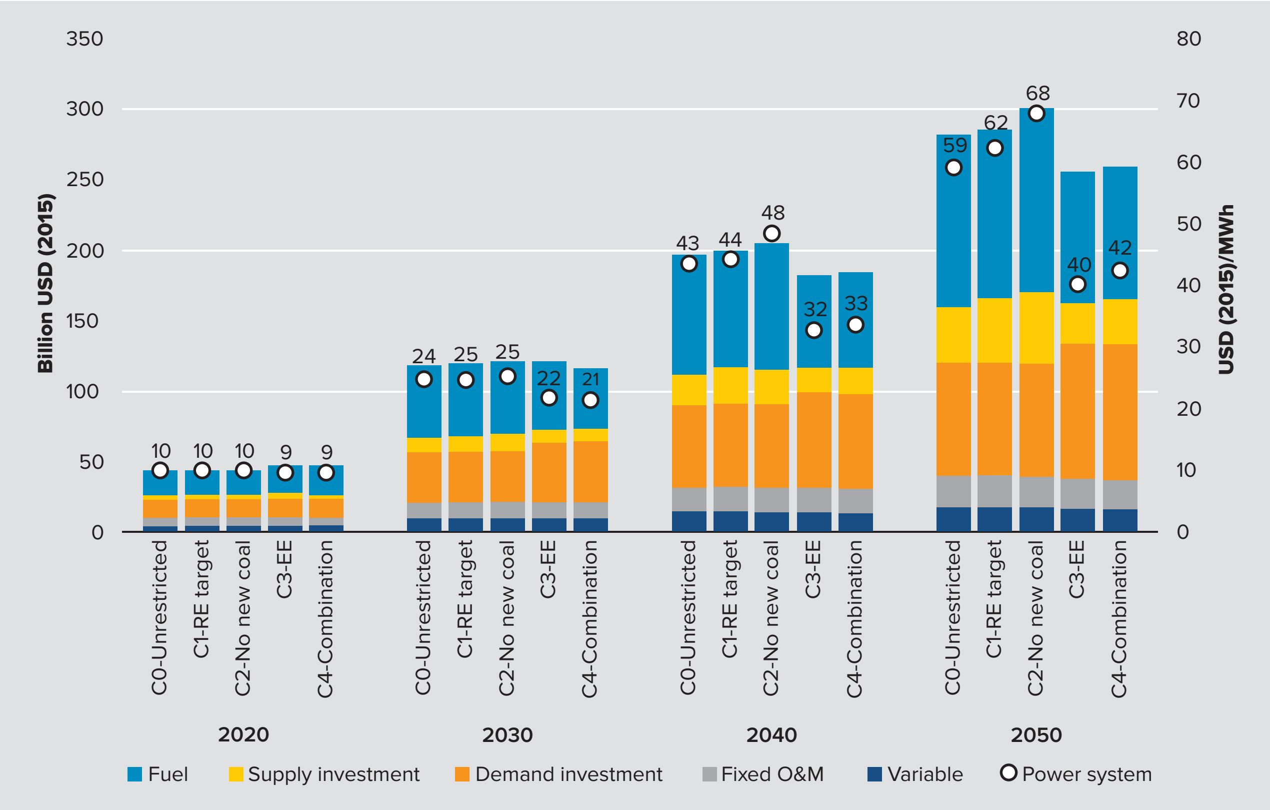


Figure 8: Energy system costs and power system cost per MWh (investment costs for existing and committed plants are not included)

3.4 Key indicators

The key indicators for the analysed scenarios are presented for the years 2030 and 2050 in Table 3. The indicators are shown both for the entire energy system and zoomed-in for the power sector.

The system costs include annualised investment costs, fuel costs, and operation and maintenance costs for the particular year (Bn. 2015-USD). The RE share for all sectors corresponds to the share of renewables (incl. and excl. small and large hydro for the respective column) in the total primary energy supply (upper part of the table) and power generation (lower part of the table). Wind and solar (W&S) share represents the share of onshore wind, offshore wind and solar PV in the primary energy (upper part of the table) and power generation (lower part of the table). The fuel import dependency is calculated as the share of net imported fuels (PJ) in the total primary energy supply (TPES) (upper part of the table) and of imported fuels (PJ) in the power sector primary energy supply (lower part of the table).

The comparison across scenario results highlights the following observations:

- The lowest system cost per year is achieved in the scenarios where EE measures are implemented to a higher extent (C3 and C4). Moreover, while restricting investments in new coal power plants will increase the system costs, adding an EE focus greatly reduces this cost increase (*C4 Combination scenario*).
- The lowest CO_2 emissions appear in the *C4 Combination scenario,* where both an EE focus and no new coal investments are assumed.
- In 2030, the *C2 No new coal scenario* has the highest RE share. However, the *C4 Combination scenario* realizes the highest RE penetration in the long term.
- The lowest import of fuels both in energy (PJ) and cost terms is found in the *C4 Combination scenario.*

All scenarios fulfil the REDS target for RE (*incl. small and large hydro*) in the power sector (except for the *C0 Unrestricted scenario* in 2050). For the REDS target for RE *excl. hydro power* in the power sector, it is the same case, but for this indicator the *C3 Energy efficiency scenario* does not fulfil the target in 2050. This indicates that the lack of policy measures or high penetration of EE technology alone is not enough to ensure REDS targets for the power sector to be met.

Looking across all the indicators, a combination of efforts promoting RE and EE while limiting new investments in new coal-fired power plants allows to achieve the best results when considering system cost, climate effects, RE integration and reduced fuel import (*C4 Combination scenario*). However, while the modelled scenarios show the benefits of accelerating the green energy transition in Vietnam, further analyses, deliberation and prioritization by policy makers are all needed to determine the recommended energy development pathway for Vietnam.

Table 3: Key indicators for the analysed scenarios in 2030 and 2050 for the entire energy system and for the power sector

			System costs (Bn. USD)	CO_2 emissions (Mt)	RE Share* (%)	RE share excl. hydro (%)	W&S share (%)	Fuel imports (PJ)	Fuel imports (Bn. USD)	Fuel import dependency (%)
All sectors	**2030**	***C0 Unrestricted***	118	515	17%	13%	3%	4,460	42	60%
		C1 RE target	119	521	17%	13%	3%	4,510	42	59%
		C2 No new coal	121	468	20%	16%	5%	3,940	44	54%
		C3 Energy efficiency	116	438	20%	16%	3%	3,660	33	54%
		C4 Combination	116	424	21%	16%	4%	3,380	34	51%
	2050	***C0 Unrestricted***	282	1015	15%	13%	5%	11,090	121	75%
		C1 RE target	285	942	18%	16%	8%	10,360	114	72%
		C2 No new coal	300	722	22%	20%	11%	8,490	112	66%
		C3 Energy efficiency	255	705	19%	16%	6%	7,810	85	69%
		C4 Combination	259	572	24%	21%	10%	6,640	82	63%
Power sector	**2030**	***C0 Unrestricted***	25	279	33%	15%	13%	1,880	7	50%
		C1 RE target	25	279	33%	15%	13%	1,890	7	49%
		C2 No new coal	25	226	43%	25%	22%	1,360	6	38%
		C3 Energy efficiency	22	236	37%	18%	14%	1,430	6	42%
		C4 Combination	21	220	40%	20%	15%	1,270	5	39%
	2050	***C0 Unrestricted***	59	546	32%	23%	22%	4,780	20	68%
		C1 RE target	63	468	43%	34%	33%	3,970	17	60%
		C2 No new coal	68	258	50%	41%	40%	2,450	23	45%
		C3 Energy efficiency	40	324	43%	30%	27%	2,450	10	51%
		C4 Combination	43	185	59%	46%	42%	1,150	8	29%

** Including wind, solar, bioenergy, small and large hydro*

4

Energy resources

4. Energy Resources

4.1 Status and Trends

During the last decades, Vietnam has experienced increased economic activity, industrial development, urbanisation, increased transport demand, improved energy access and rising living standards. These are major drivers for growing energy consumption.

During the period 2007-2017, Vietnamese total primary energy supply (TPES) grew at 4.7% p.a., thereby increasing from 1,900 PJ in 2007 to 3,000 PJ in 2017. Hydropower experienced the highest growth at 14.5% p.a., followed by coal at 11.3% p.a. The share of coal increased from the third largest fuel source in 2007 to the largest in 2017. Meanwhile, the share of biomass fell from being the largest contributor in 2007 to the third largest in 2017. Oil, growing at the rate of 4.3 % per annum, is the second largest fuel source. Solar and wind have historically only contributed to a very small share in TPES. An overview of the historical Vietnamese TPES is presented in Figure 9.

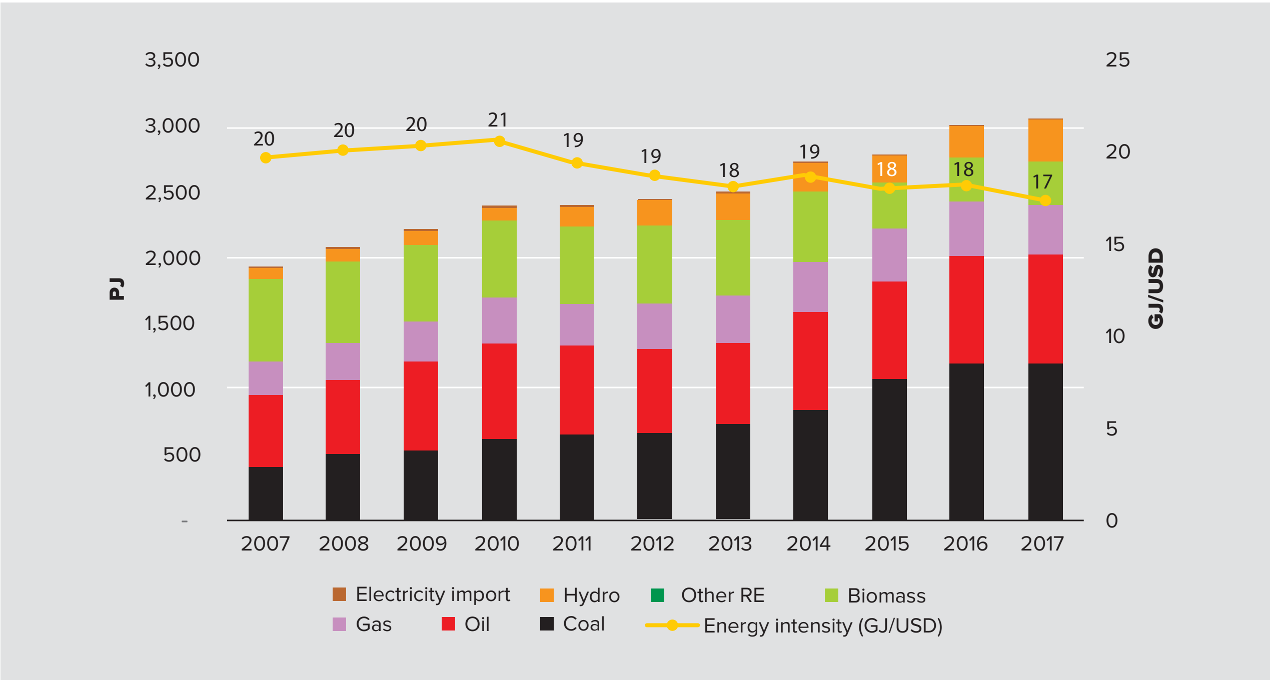


Figure 9: Historical Vietnamese TPES from 2007-2017 by fuel type. The relatively stable energy intensity implies a coupling between TPES and GDP. TPES (2007-2014) is based on (IE, 2017). TPES (2015-2017) is based on (GSO, 2019).

While having been a net energy exporter for a long time, Vietnam became a net energy importer in 2015, due to a recent increase in domestic activities and a policy limiting coal exports[13]. This rate continued to grow quickly, primarily driven by increased coal imports. The historical development of the energy import/export balance and the related import dependency is displayed in Figure 10 for the period 2007-2017.

[13] Prime Minister Decision No. 403/2016/QD-TTg

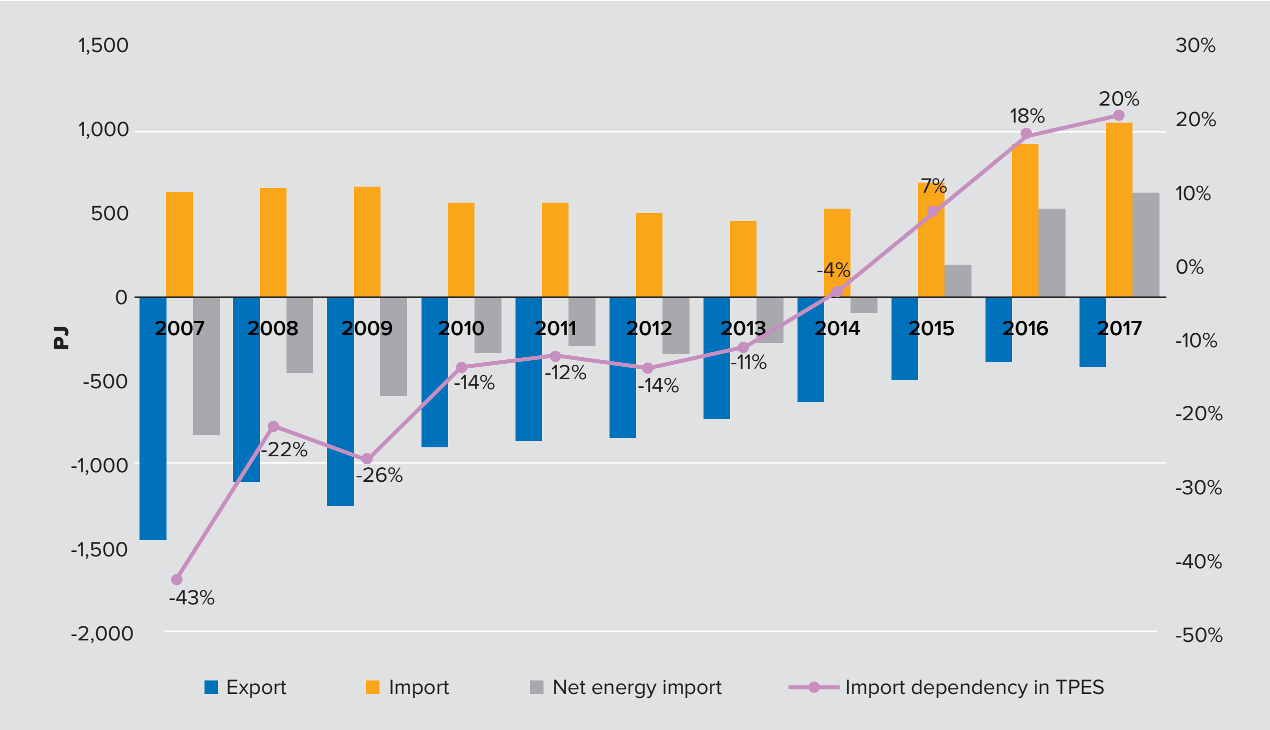


Figure 10: Historical development in energy import/export balance and the related import dependency in the period 2007-2017. TPES (2007-2014) is based on (IE, 2017). TPES (2015-2017) is based on (GSO, 2019).

Vietnam has abundant coal resources (anthracite and subbituminous) in the North region. However, domestic coal exploitation has supply bounds due to technical (underground location) and economic (uncompetitive compared to other resources) reasons. Crude oil and natural gas are being extracted mainly offshore in the South, but the reserves are expected to be depleted by 2020-2030.

An important gas field in the Central region is expected to start production by 2023-2024, so as to supply the power generation and the petrochemical industry. With the limited domestic supply, and being in the early stages of RE development, Vietnam is expected to rely much on imported energy sources in the coming years.

4.2 Energy Resource Outlook

Which resources will characterize the energy mix?

With the increasing trend for TPES, coal will be the main fuel source followed by oil in the upcoming period (Figure 4). The projected growth in road transport activity will require increasing amounts of oil products in the future, which will mainly be supplied through foreign fuel imports in the long term. Fossil fuels will therefore still account for the largest shares of primary energy supply across all scenarios. RE (incl. small and large hydro) accounts for about 20% of the TPES throughout the analysed period. However, while EE technologies and measures alone can have limited effect on boosting the RE share, a restriction on coal-fired power plants (as implemented in the *C2 No new coal* and *C4 Combination scenarios*) provides an ample opportunity for RE development, thereby possibly increasing the RE share. The RE share may increase well over 20% in 2050, if a restriction on new coal generation is in place.

Most domestic fuels are fully utilized in all scenarios (i.e. coal, natural gas, crude oil, and biomass); therefore, solar and wind energy, as well as imported fuels (i.e. oil, coal, and LNG), will be central for supplying the demand. While the consumption of domestic coal, hydro, and biomass presents similar trends across scenarios, the main differences in the domestic TPES are found in the shares of solar, wind, and imported fuels (Figure 11).

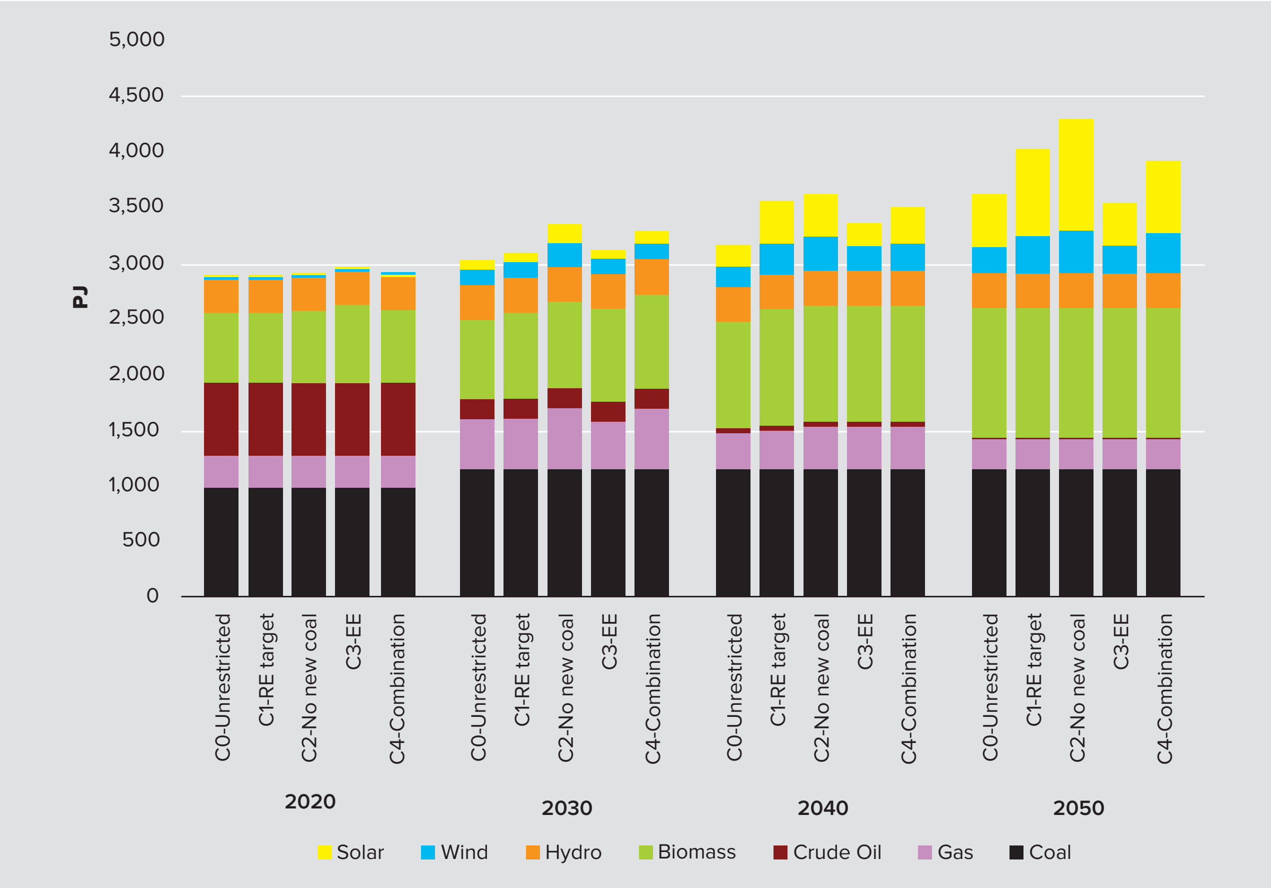


Figure 11: Consumption of domestic resources across analysed scenarios in the period 2020-2050

Biomass resources are allocated among power generation, industries, and residential sectors. A shift may occur from the residential uses (i.e. cooking) towards industrial facilities in the medium term and towards power generation in the long term, if EE technologies are implemented to a wider extent (Figure 12).

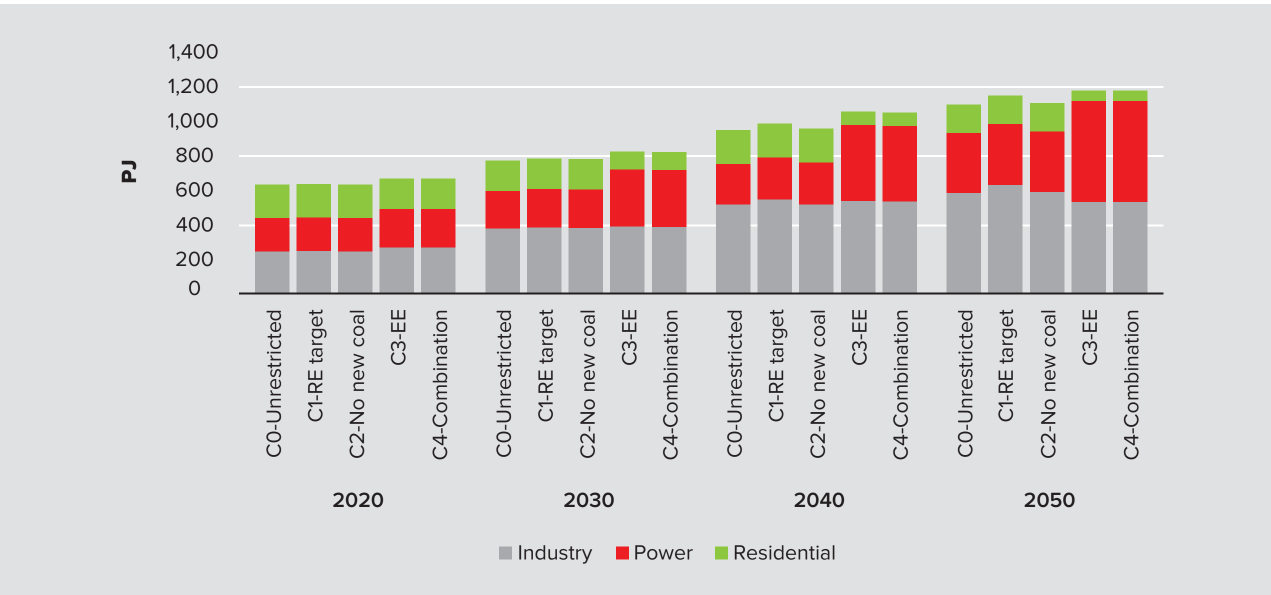


Figure 12: Optimal allocation of biomass to the different sectors across scenarios

If no new coal-fired power plants are developed after 2025, a combination of solar PV, natural gas and wind will substitute the coal use up to 2030. Afterwards, in the period 2030-2050, imported LNG will be the major fuel alternative to supply especially the industry sector, albeit at a higher total system cost (Figure 13).

The effects of EE measures on the demand side will mainly reduce the consumption of fossil fuels like coal and oil, with the development of solar PV also being affected by the lower electricity demand in the EE scenarios (*C3 No new coal* and *C4 Combination scenarios*).

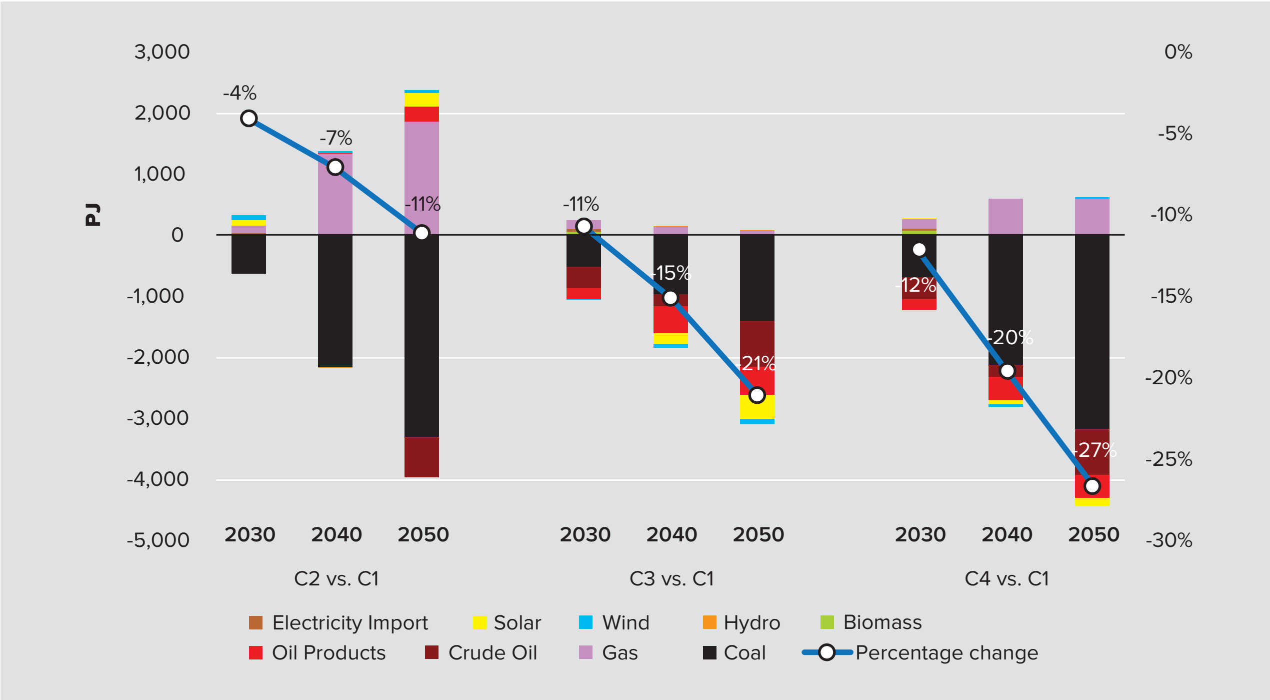


Figure 13: Changes in TPES by fuel due to *C2 No new coal*, *C3 Energy efficiency* and *C4 Combination* compared to the *C1 RE target*

How dependent on fuel imports will Vietnam be?

Import of fossil fuels will play a key role; however, increasing RE shares and enhancing EE measures can reduce the need for import of fuel for power generation. Coal, oil and gas are needed to meet the energy needs of the growing Vietnamese economy in the coming decades, with the share of imported energy expected to increase in the future. Imported coal is mainly used to supply the power generation. Crude oil and oil products are mainly required for transport activities. Imported LNG will be valuable for industries as well as for the power sector, especially in a future with no new coal power plants. Imported fuel dependency will increase quickly to 51% - 60% by 2030, then to 63 -75% in 2050 across scenarios (Figure 14).

In the *C1 RE target scenario*, imported fuels will contribute to almost 60% of TPES by 2030 and 72% by 2050 with very large amount of coal and oil products. Bearing in mind the increasing trends of import dependency, measures for reducing imported fuels will enhance the national security of energy supply in the coming decades. A combination of EE efforts and a restriction on new coal power plants may reduce the reliance on imported fuels to 63% by 2050, with some decrease in the total system cost (about 7.7% by 2040 and 9.3% by 2050, when comparing the *C4 Combination scenario* with the *C1 RE target scenario*). EE measures help reduce energy demands, thereby lowering the imported fuel requirements. On the other hand, an increased import of LNG as the main alternative to substitute coal will raise the total system cost, due to the higher fuel price and large fuel infrastructure expenditures, while partly mitigating the GHG emissions from the power and industry sectors. In the transport sector, results show that a successful transformation of the transport fleet to new and efficient vehicles can lead to 25% reduction of oil imports.

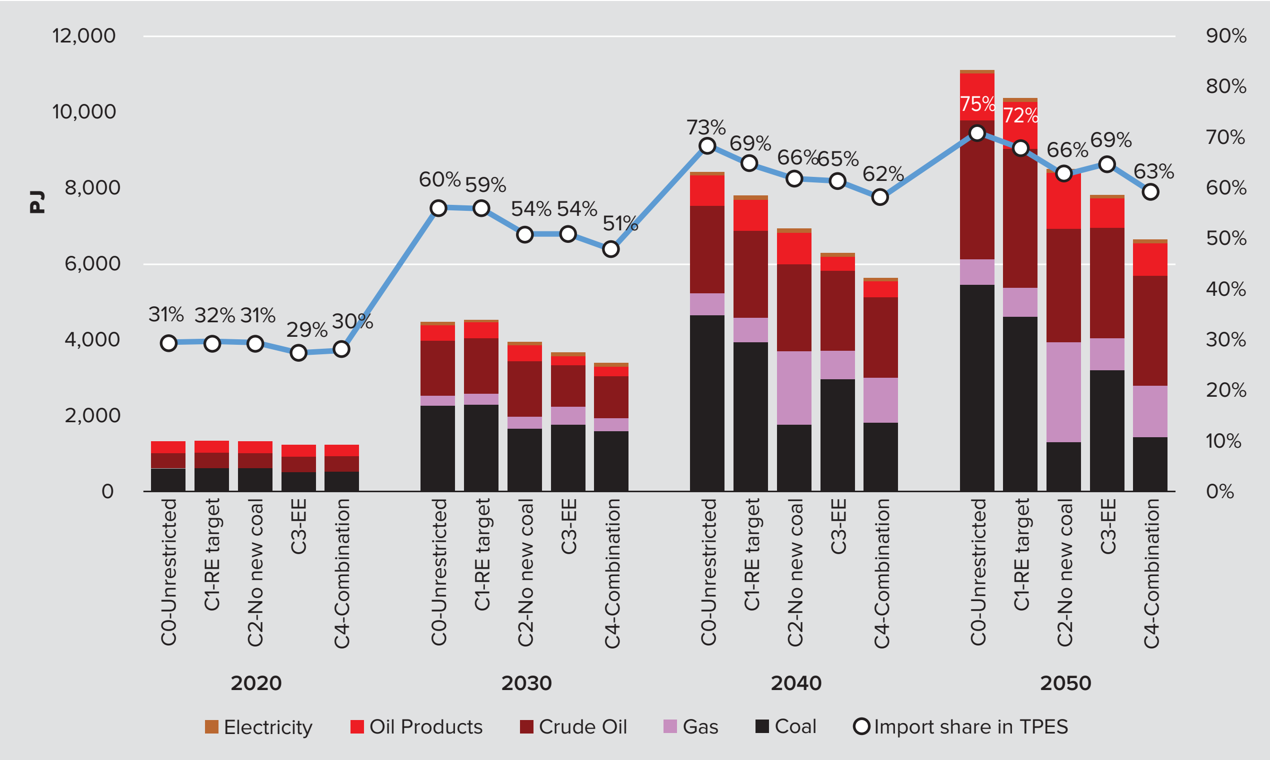


Figure 14: Net imported fuels and share of net energy imports in TPES across analysed scenarios

A sensitivity analysis has been carried out to assess the robustness of the least-cost solution described above to price changes of imported fuels. Results show that the solution is robust to price variations across the analysed scenarios, with only minor substitution effects between oil and gas. A major reason for this is that the need to comply with the yearly RE requirement has higher influence on the composition of the energy mix than the fuel prices. More information can be found in the background Technical Report (EREA & DEA, 2019a).

4.3 Policy Outlook and Recommendations

The expected continuation of the trend in the energy demand growth in Vietnam, coupled with the foreseen full exploitation of domestic fossil, hydro power and biomass resource potentials in the future (especially crude oil and natural gas reserves), can pose a challenge to sustainable supply of energy at the lowest system cost. A continued commitment to the RE targets for the power sector established in the REDS can reduce the reliance on energy imports after 2030, particularly coal, by mobilizing the domestic RE resources to supply the power generation (i.e. mainly with solar but also wind power). Moreover, a stronger penetration of energy efficient technologies can further reduce the final energy demand, thus increasing the level of energy independence in Vietnam.

Early actions to reduce the future coal demand are needed.

Vietnam is today a net energy importer, registering a rate of around 20% import dependency in 2017. Considering the relevance of securing a reliable and safe energy supply at the lowest cost, a diversification of the energy mix can provide additional hedging against risks of shocks in the market affecting a specific commodity, thus increasing the resilience to price volatility and uncertainty.

Across the analysed scenarios, the general trend sees an increase in the imports of coal for power generation. To avoid coal lock-in effects[14], action in the short term is needed to reduce coal (import) dependence in the long term. In this perspective, a constraint on coal consumption already before 2030, not least stemming from the pressure posed by coal-fired power plants on the environment and

[14] A situation where a country or region is tied to using coal because once the capacity, which usually has long technical lifetime, has been built it will be the cheapest form of power production.

people's health, and the difficulty in financing new coal-fired power plant projects, would bring the combined benefit of reducing the import of coal and limiting air pollution.

Although effective in the long term, the implementation of such a transition should take into account the existing lifetime of coal-fired power plants, commissioning and decommissioning plans in the short term, eventual refurbishment projects including the introduction of emission control measures and the projected domestic coal reserves. Furthermore, when considering LNG as a future option to supply the industry and power sectors in the mid to long term (from 2030 onwards), its impact on the total cost of imported energy, as well as the possible effects on GHG and pollution emissions reduction should be taken into account.

To increase security of supply by lowering the reliance on foreign energy imports and diversifying the fuel mix, additional measures can be considered targeting a regulation on fuel imports:

- In the short term, it is advisable to undertake a market analysis to evaluate the future supply options, including fuel types, suppliers, locations, transportation and transformation costs, development of receiving ports, terminals, storage solutions and required fuel infrastructure.
- In addition to costs, the development plan for additional terminals and fuel infrastructure should consider the climate, environmental, social, and other benefits for the different options (i.e. mainly coal and LNG): LNG can offer the advantage of being a cleaner energy source from both a climate and air pollution perspective, as well as it could enhance the operational flexibility of the power system when integrating higher shares of RE.

Focus on enhancing energy efficient vehicles by economic incentives and minimum efficiency standards to reduce oil import dependence.

The transport sector in Vietnam, as for most countries in the world, is currently relying on oil products. According to the analysis of the reserves' projections, these will firstly be domestically refined from local crude oil (up to 2030) and mainly imported from abroad afterwards. A combination of measures could both reduce the energy demand and the reliance on foreign resources, primarily through the introduction of higher fuel efficiency standards, followed by the promotion of fuel switching from the oil products to low-carbon option (e.g. electricity), as well as, on a minor scale, modal shift from private to public modes.

The introduction of fuel efficiency standards would ensure the transformation of the transport fleet to new and efficient vehicles, both in the passenger and in the freight segments. A gradual increase of the efficiency standards can be considered, allowing the introduction of this regulation already in the short term and in alignment with the market landscape. Although not analysed in this report, blending requirements for biofuels might be also investigated, especially for the heavy-duty segments. Importantly, at the same time, the development of the adequate fuel and transport infrastructure (e.g. charging stations, railway expansion) should accompany this transition.

Mobilizing the domestic biomass potential for energy production can reduce the import of fuel for industry and power sectors.

A policy focus on RE and EE offers the opportunity to better utilize domestic resources, reduce the reliance on energy imports and abate GHG emissions. Untapped domestic energy potentials for power generation include RE sources, in particular, solar, wind (both onshore and offshore), and biomass.

Domestic bioenergy resources can supply the power generation, industry, and residential sectors in Vietnam with a total potential around 1200 PJ. The optimal allocation of the Vietnamese bioenergy potential to the different end-uses analysed in the EOR19 illustrates how future energy needs might be increasingly met through the sustainable mobilization of biomass resources with a shift away from the (rural) residential use towards the industrial sectors. The introduction of favorable tariffs and other market mechanisms for biomass use in the industrial sector could support this shift, as well as promote a fuel switch from coal towards biomass, including for industrial CHP plants.

5

Energy efficiency

5. Energy Efficiency

5.1 Status and Trends

During the period 2007-2017, the total final energy consumption (TFEC) increased from 1,691 PJ in 2007 to 2,500 PJ in 2017, with a growth rate of 4.0% p.a. In 2010-2017, total GDP increased by 6.1% p.a. with the highest growth rate in the industrial sector (7.4% p.a.) and the commercial sector (6.8% p.a.). This economic growth resulted in an increase in energy consumption, with the industrial sector showing the largest average annual growth during the period (9.3%)[15], followed by the commercial and transport sectors with 6.4% and 5.2% p.a. respectively (Figure 15). On the other hand, the final energy consumption in the residential sector decreased during the period due to a trend involving displacing of traditional biomass use with electricity and other fossil fuels (especially for cooking purposes in rural areas). By 2017, the industry represented 53% of TFEC, followed by transport and residential sector with the share of 23% and 17% respectively.

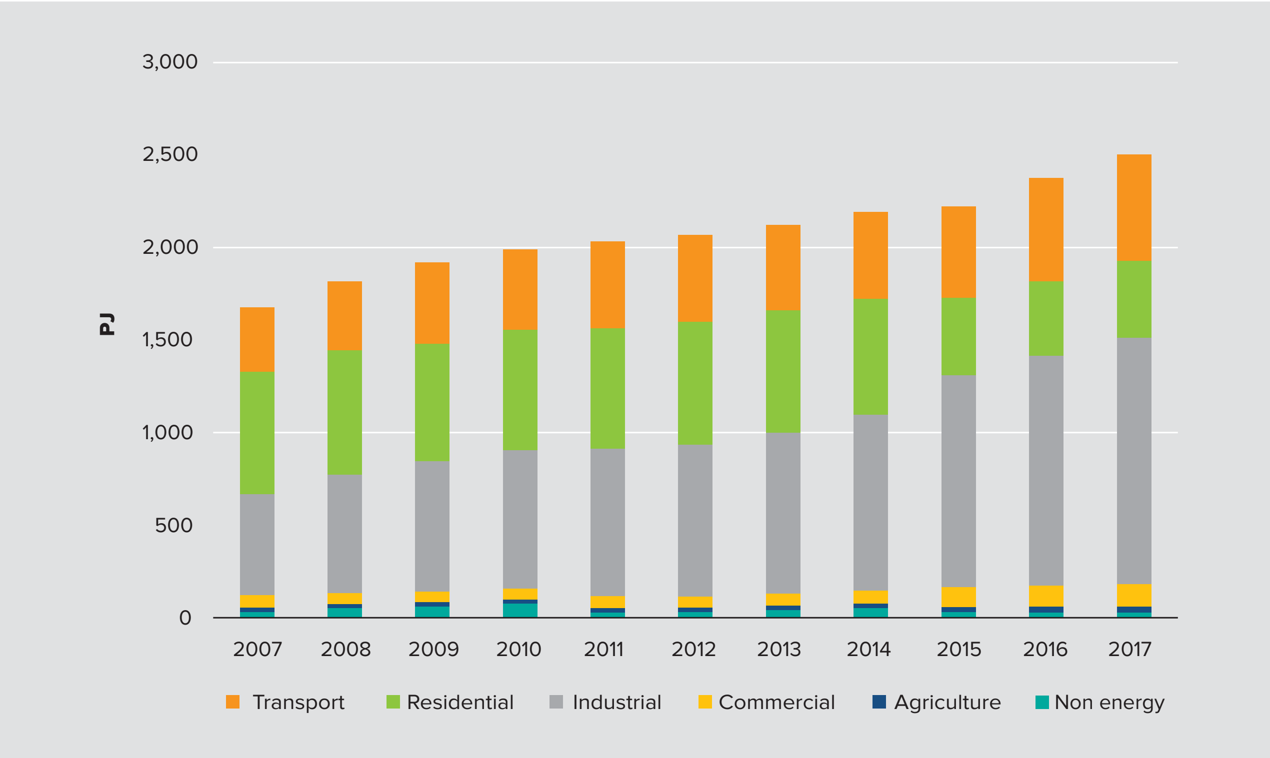


Figure 15: Trends for TFEC in 2007-2017. TFEC (2007-2014) is based on (IE, 2017). TFEC (2015-2017) is based on (GSO, 2019).

Vietnam features a high energy intensity compared to other international contexts. In 2015, the primary energy intensity with respect to GDP was 20 GJ/USD[16] (IEA, 2017), while the world average amounted to 8 GJ/USD. With the issuance of Law on Energy Efficiency and Conservation in 2010, many EE activities have been carried out throughout the country covering different economic sectors, with good progress in the application of EE measures for user appliances and partly also in industrial facilities. On the other hand, EE has not been well promoted in the building and transport sectors.

[15] Note however that this large growth figure for industry includes a large difference from 2014 to 2015, which is partially due to a change in data collection methods that resulted in more detailed data being collected from industry.

[16] For comparison, energy intensities for other fast-growing economies are: Thailand 14.2 GJ/USD, China 13.8 GJ/USD, Malaysia 10.9 GJ/USD, Indonesia 9.6 GJ/USD, the Philippines 8.4 GJ/USD.

Energy efficiency policies and targets

The National Target Programs on Energy Efficiency and Conservation were implemented by MOIT in the period 2006-2015 (VNEEP1 and VNEEP2), and comprised many activities ranging from legal framework, capacity building, obligations for designated energy users, support for energy audits, soft loans, standard setting, energy labeling, non-financial and financial incentives. VNEEP1 and VNEEP2 achieved the energy saving ratios of 3.39% and 5.65% respectively (IE, 2016). Compulsory labeling[17] and minimum energy performance standard (MEPS) programs under VNEEPs have been implemented for many domestic and industrial appliances:

- Household: CFLs, fluorescent lamps, electronic and magnetic ballasts, air conditioners, refrigerators, washing machines, rice cookers, electric fans, televisions, LEDs and storage water heaters;
- Service: photocopy machines, monitors, printers, fridges and laptops;
- Industrial: distribution substations and electric motors;
- Transport: passenger cars (less than 9 seats) and motorcycles;
- Power (MEPS only): coal-fired (efficiency of 41% for unit from 600 to 800 MW), open cycle gas turbines (efficiency of 39% for units greater or equal to 300 MW) and combined cycle gas turbines (efficiency of 58.5% for unit of gas turbines greater or equal to 300 MW)[18].

The main financial support for EE activities has been provided under VNEEPs, Vietnam Environment Protection Fund (VEPF) and several loan packages by development partners (WB, DANIDA etc.). However, sustainable financial sources for EE activities remain major barriers for realizing the EE potential in Vietnam.

The National Program on Energy Efficiency and Conservation for the period 2019-2030 (VNEEP3) has been approved by GOV in March 2019 with targets for reducing the TFEC by 5-7% in 2025 and 8-10% in 2030 compared to the baseline development. Besides these main targets, the program also has different detailed targets for reducing electricity losses, energy savings for different industrial subsectors, scale of EE and green buildings, share of industrial units with energy management system, fuel economy for vehicles, etc.

The major supporting schemes under the VNEEP3 include: legal framework, enhancement of legislation enforcement, promulgation of EE standards, establishment of energy service companies (ESCO), technical and financial support, capacity building, creating energy information systems, and establishing an EE fund.

5.2 Energy Efficiency Outlook

What will be the impact of energy efficiency?

One of the main effects of the application of EE measures is a reduction of the total energy system costs already in 2030, where a large decrease in fuel costs and a reduction of the power demand can more than offset the increase in the investments in the end-use sectors. Compared to *C1 RE target scenario*, the *C3 Energy Efficiency* and *C4 Combination scenarios* are built with high penetration levels of EE technologies which allow the whole economic energy saving potential to be realized (penetration rates correspond to 50% by 2030 and 100% by 2050). Moreover, these scenarios feature an increased application of industrial combined heat and power (CHP) plants, based on biomass and natural gas.

Even though additional investment in EE technologies amounted to 7 and 16 billion USD (annualized) in 2030 and 2050 respectively, a large share of fuel costs and investments in the power sector can be saved, thus resulting in an overall reduction of the annual total system cost of 8.9% and 10.6% in 2030 and 2050 (Figure 16).

[18] Compulsory labeling started from 2012: 665 products in 2012; 1532 products in 2013, and 2655 in 2014.

[19] Decision 24/2018/QD-TTg dated 18 May 2018 of the Prime Minister: for coal-fired generation units, the efficiency at the low thermal value and rated capacity of the generation unit is determined at the cooling water temperature of 28°C and ambient temperature of 30°C; gas-fired generation units using simple cycle gas turbines, the efficiency of the gas turbine unit (under ISO conditions); gas-fired generation units using combined cycle gas turbines, the efficiency of the combined cycle gas turbine assembly (under ISO conditions) is determined according to the capacity of the simple cycle gas turbine.

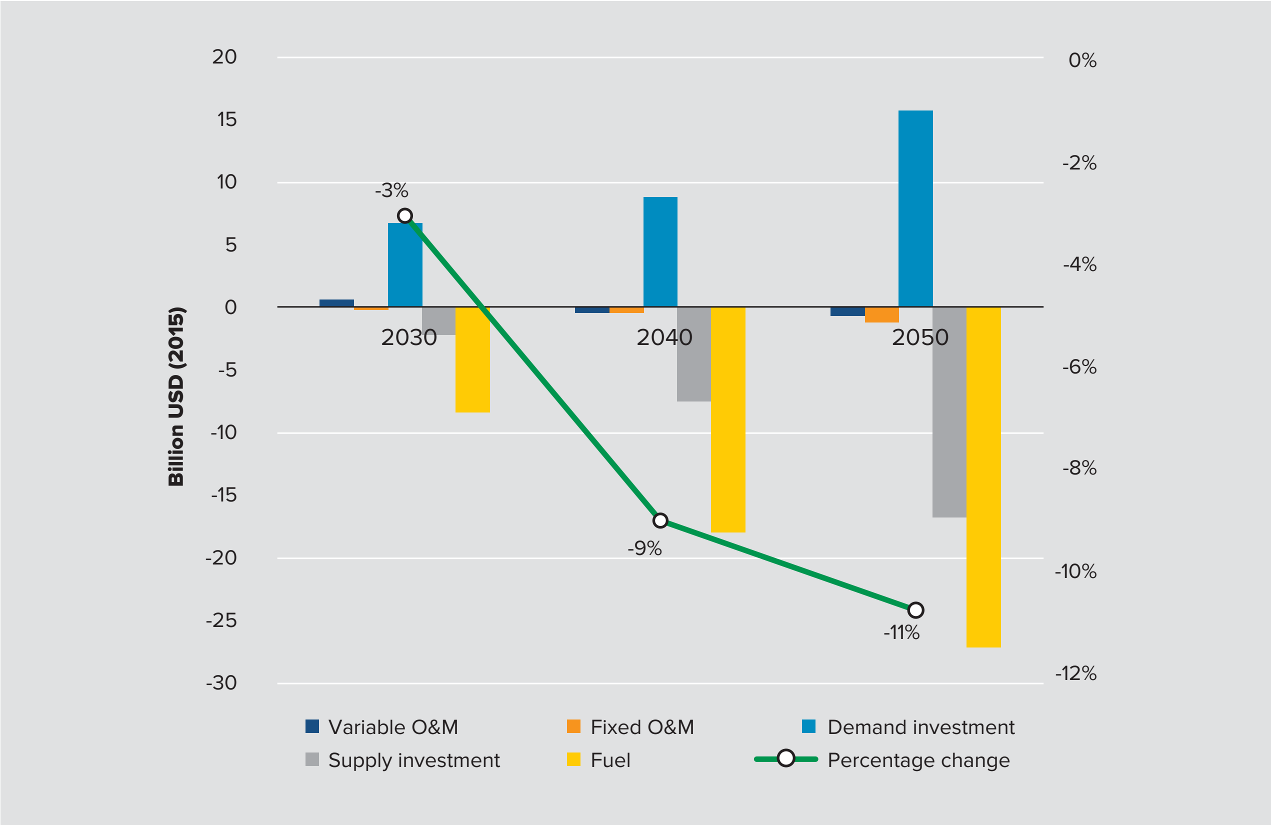


Figure 16: Changes in annual discounted system cost in *C3 Energy Efficiency scenario* compared to *C1 RE target scenario*

With the application of EE measures, up to 630 PJ by 2030 and 1,970 PJ by 2050 can be saved in the TFEC, compared to the *C1 RE target scenario*, which is based on energy use intensities of current technology stocks in 2014 and an assumed limited penetration of energy efficient demand technologies. This corresponds to a reduction in the TFEC by 12% in 2030 and 20% in 2050, primarily due to a decrease in oil consumption in the transport sector and power demand in the industry and residential sectors. Moreover, the EE activities can save annually 83 Mt CO2 by 2030 and 237 Mt CO2 by 2050, as a sum of the effects in the power, industry and transport sectors.

While no baseline scenario for the VNEEP3 targets has yet been consolidated, if using the C1 RE target scenario as baseline, the reductions in TFEC when full EE potential is unlocked (*C3 Energy Efficiency scenario*) are higher than what is aimed in the VNEEP3 with the energy saving targets of 5-7% in 2019-2025 and 8-10% up to 2030. This indicates that it is cost effective to introduce even more EE measures than what targeted in VNEEP3. Figure 17 shows the percentage change in TFEC in the *C3 Energy Efficiency scenario* with respect to *C1 RE target scenario,* as well as the comparison with the targets aimed in VNEEP3.

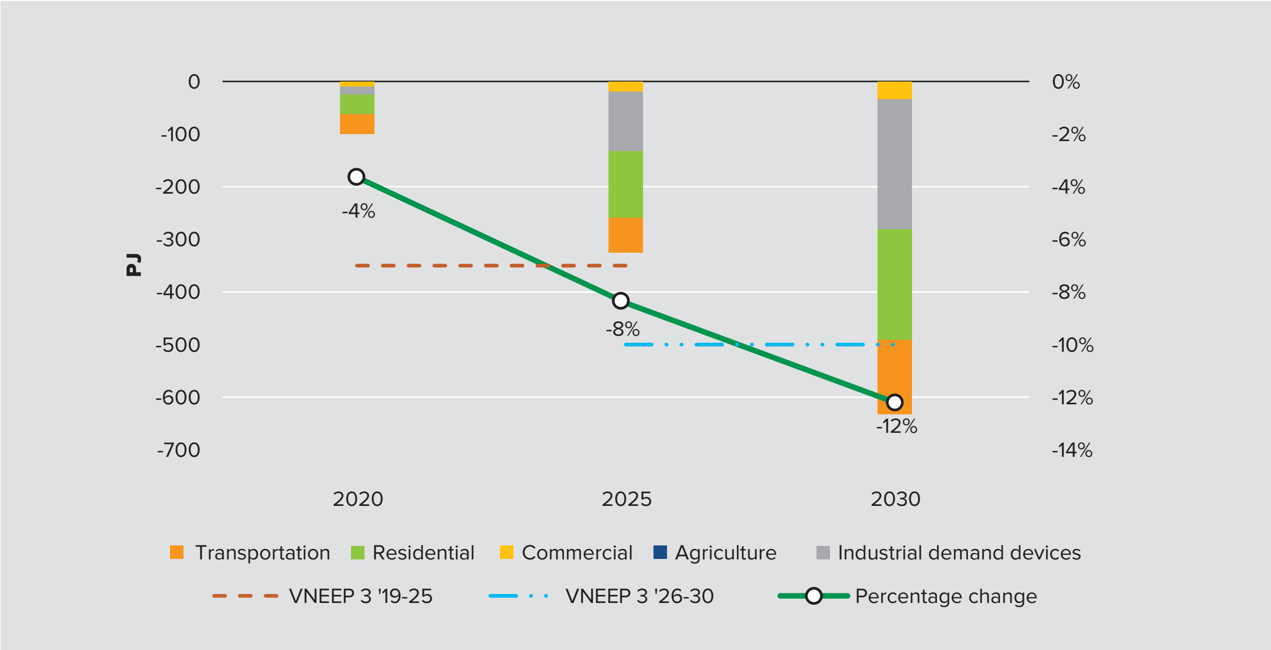


Figure 17: Percentage change in TFEC in the *C3 Energy Efficiency scenario* with respect to *C1 RE target scenario* and VNEEP3

EE activities reduce electricity generation requirements for centralized power plants by reducing electricity demand. At the same time, electricity generation from decentralized power sources (industrial CHP and decentralized solar PV) increases in the long term as a result of the least-cost optimization and assumed larger potential for industrial CHP in the future. EE activities in the *C3 Energy Efficiency scenario* may save up to 10% of centralized electricity generation in 2030 and 29% in 2050, with respect to the *C1 RE target scenario*. Decentralized sources may generate up to 2.9% in 2030 and 8.6% in 2050 of the total electricity demand in the *C3 Energy Efficiency scenario*. The cross-sectoral EOR19 least-cost analysis shows that investing in EE technologies is more cost-effective than investing in 6,000 MW and 23,000 MW of coal power in 2030 and 2050, respectively. Figure 18 illustrates the effects of EE activities on electricity demand and electricity generation requirements.

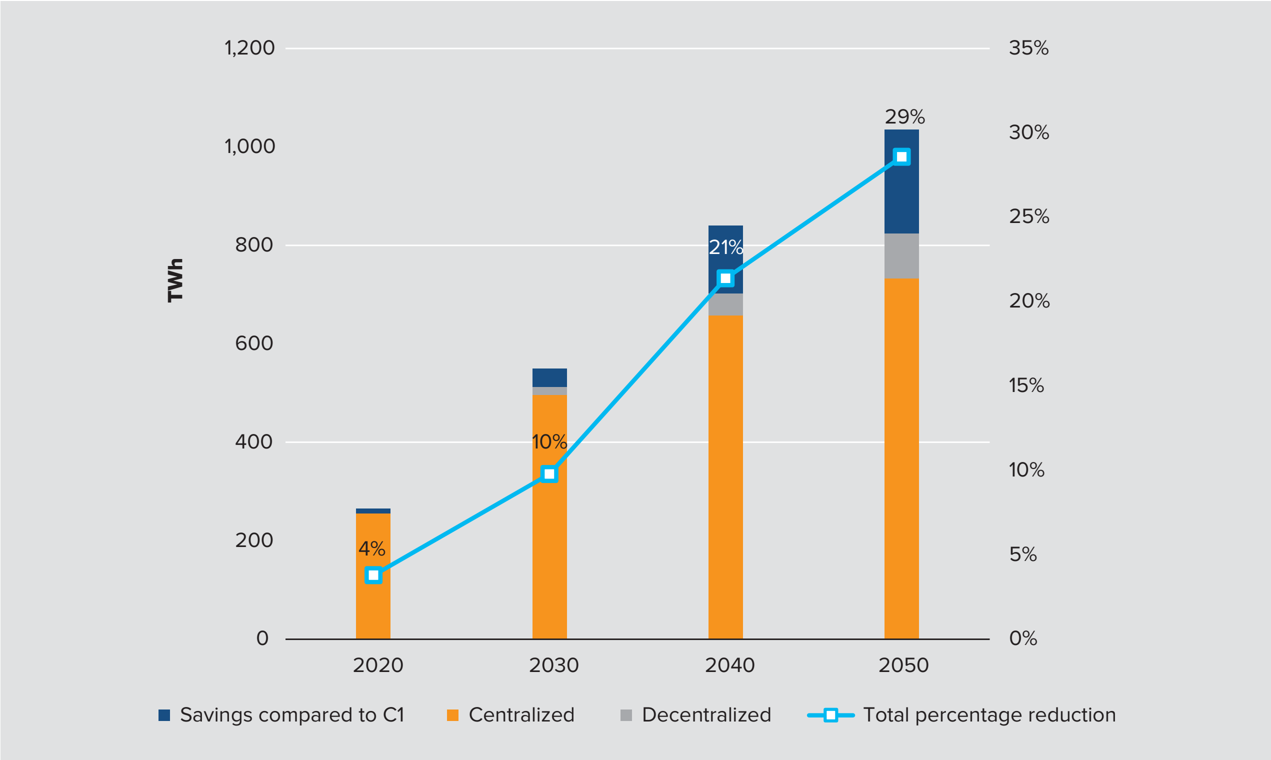


Figure 18: Effects of EE measures and industrial CHPs in *C3 Energy Efficiency scenario* with respect to the *C1 RE target scenario*. "Decentralized" consists of approximately 80% industrial CHPs and 20% decentralized solar PVs.

Which are the most important areas for EE?

Different sectors feature different levels of energy savings, when introducing high penetration rates of EE technologies in the *C3 Energy efficiency scenario* compared to the *C1 RE target scenario*. By 2030, EE measures will reduce the TFEC by 8.9% (247 PJ), 11.0% (34 PJ), 22.7% (210 PJ) and 13.4% (142 PJ) for industrial, commercial, residential and transport sectors respectively (Figure 19).

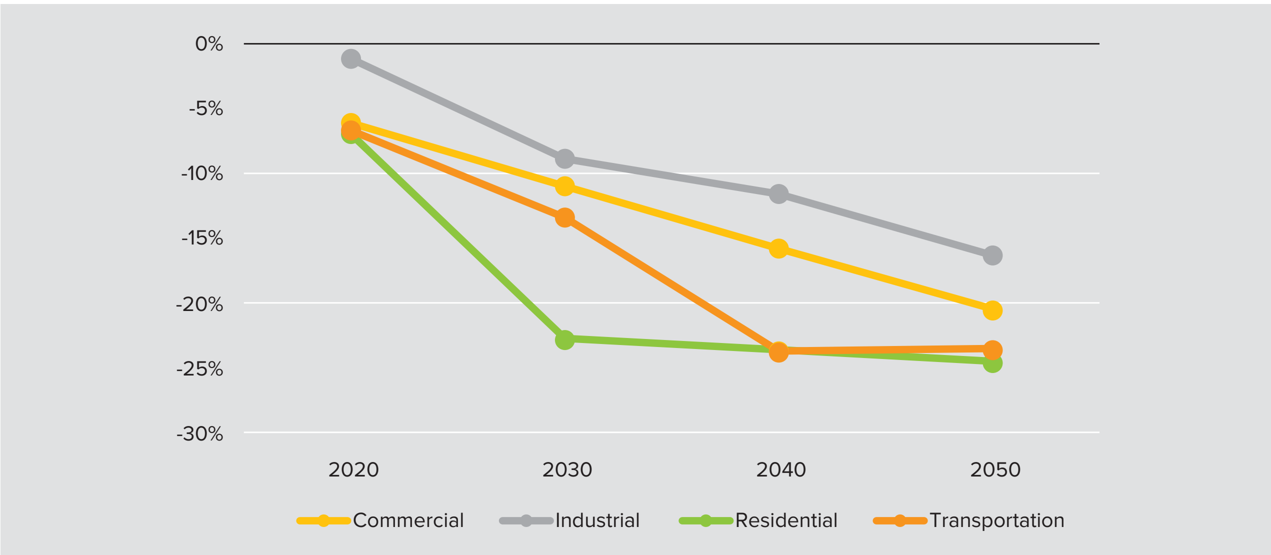


Figure 19: Percentage change in TFEC by sector in the *C3 Energy Efficiency scenario* with respect to the *C1 RE target scenario*

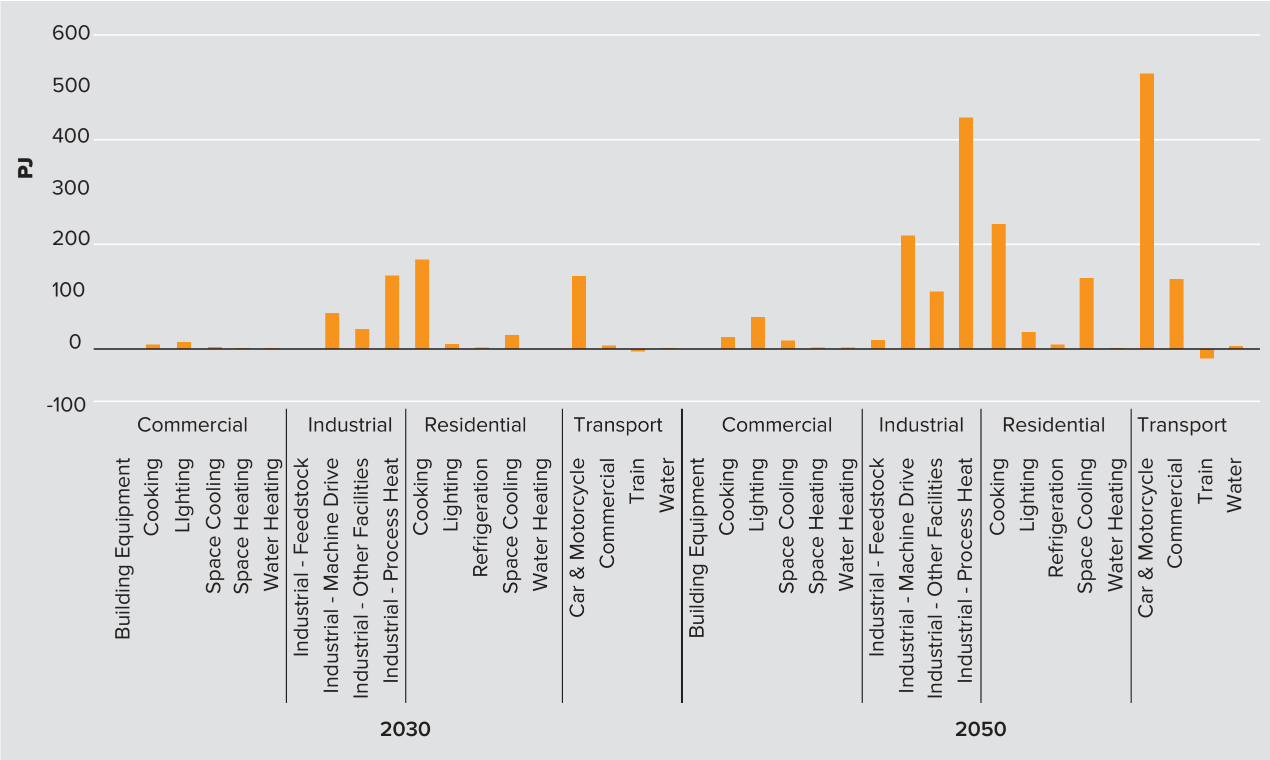


Figure 20: Economic energy saving potential by end-use and by sector in the *C3 Energy Efficiency scenario*, compared to the *C1 RE target scenario*

In the industrial sector, the cement, iron and steel, textile and food are the main subsectors for EE improvements. EE measures in heat processes contribute to 61% of the total energy saved followed by machine drive (21%) and facilities (18%) by 2030 (Figure 20). In the period to 2050, EE improvement in the process heat for the cement, iron and steel, pulp and paper, food, and textile subsectors is the most important area for realizing the energy saving potential. Under industrial machine drive, efficient motors and variable speed drive applications are also important in all subsectors, especially for iron and steel and textile production after 2030. Additionally, efficient lighting (as part of the EE improvement in industrial facilities) is needed in all industrial subsectors and should be prioritized by industrial factories.

In the residential sector, efficient cooking, space cooling and lighting are the three main areas for EE improvements. Employment of efficient cook stoves and fuel switching to LPG and electric cooking stoves in rural households are very important to reallocate biomass resources from residential use to more efficient industrial CHPs or other central power plants. In addition, with the projected increase in the cooling demand, the introduction of efficient air conditioners plays a central role in reducing energy consumption in the residential sector.

In the commercial sector, lighting is the main area for EE improvements with employment of efficient lighting devices. Cooking and space cooling are also important areas for energy savings with e.g. installation of efficient air conditioners.

In the transport sector, road transport is one of the main areas for EE improvements with significant contributions from car, motorbike and other commercial vehicles (bus and truck) mainly due to the introduction of higher fuel economy standards. An increasing large share of oil products for transport is imported, thus making EE in transport a very important focus area.

Power use in transport has not been analysed in the EOR19, yet the international trends in development and cost reduction of e-vehicles[19] support the expectation that electro-mobility might become a focus area for Vietnam as well. If the electrified transport is supplied by the expansion of RE, it will have the potential to increase EE, reduce air pollution and reduce oil import dependency.

[19] EA (2019), "Global EV Outlook 2019", IEA, Paris, www.iea.org/publications/reports/globalevoutlook2019/.

5.3 Policy Outlook and Recommendations

The successful and cost-effective transition of the energy system requires both higher penetration of renewable energy and a reduction in energy consumption through EE and energy conservation measures. Vietnam has a large potential for EE, and the EOR19 shows that EE can significantly reduce total energy system costs through investments in energy efficient technologies and improvement of manufacturing processes. Investments in end-use efficient devices (e.g. industry and residential sectors) have the potential to reduce the energy demand, in turn resulting in a reduced need for investments in additional power plant capacity. However, Vietnam faces the challenge of efficiently exploiting the full potential in energy savings, due to barriers at the institutional and financial level.

> Ambitious energy efficiency measures should be highly prioritized in PDP8.

The EOR19 reveals a large economic and emission-abating potential for energy efficient technologies, albeit the accounting of costs for carrying out EE policy measures (audits, reports, information campaigns, etc.) is not included in the analyses. EE can bring about the combined effect of fuel and cost savings, with effects across all economic sectors, thereby reducing the amount of imported fuel as well as environmental and climate impacts. The least-cost implementation of EE can give 5% and 11% savings in energy system costs in 2030 and 2050 respectively, as well as provide important CO_2 savings compared to the C1 RE target.

The potential for power demand savings is great if EE is successfully implemented; large savings in power plant investments can be realized. The coming PDP8 should take EE into account and focus on harvesting both the economic and environmental potential of EE. Making the utility companies co-responsible for energy savings could inspire Vietnam on how to integrate EE in the PDP8, bringing financial benefits for the utilities and their customers, as well as economic benefits for the society in general.

> It is recommended to continue and enhance the current EE policy (VNEEP3).

The VNEEP3 promotes an important strategy for an increased level of EE investments. A continuation and adherence to the program is critical for ensuring the transition of the energy system towards affordable and reliable energy access and a more efficient use of energy resources. The EOR19 shows that the analysed EE activities achieve and exceed the high targets in VNEEP3 in 2030. This means that the investments in energy savings proposed in the EOR19 are cost-effective and will introduce even more EE by 2030 compared to the VNEEP3. This could be achieved, among other things, by introducing or enhancing the following measures:

- Minimum efficiency performance standards (e.g. appliances in buildings, air conditioning) and mandatory energy labeling for energy appliances;
- Fuel economy standards in transport, through economic incentives for EE and low-carbon transport vehicles, as well as preparing infrastructure for electric vehicles;
- Energy audits and energy management systems (ISO 50,001++) in all major energy-intensive facilities;
- Voluntary agreement schemes with fiscal and financial incentive schemes for quantified and certified energy savings;
- Introduction and pilot testing of trading of energy savings (e.g. auctions and competitive tendering of certified energy savings) with a focus on electricity savings;
- Diversification and expansion of the demand for EE service providers, such as licensed energy managers and energy auditors, as well as energy efficient technology suppliers through improved marketing and improved and diversified training.

Focus should be set on barriers to facilitate large investments in energy efficient technology in the demand sector.

Large cost-effective energy saving potentials can be found in all sectors: transport, industry, commercial and residential sectors, with the EOR19 analyses pointing towards the most cost-effective areas and subsectors for EE investments. However, the implementation of EE can have many informational, regulatory, financing and market barriers not covered by the EOR19 which focuses on least-cost technology deployment. Some of these barriers can be addressed by trading energy savings. International experiences have demonstrated that this can optimize the effort and channel investments towards the lowest hanging fruits. One example comes from Denmark, where utilities have taken responsibilities for implementation of EE measures and have initiated auctions for energy savings.

It is recommended to implement incentives to support investments in industrial CHP plants.

The combined effects of EE and new investments in industrial CHPs could reduce electricity generation for centralized plants by 10% in 2030 and 29% in 2050. Such investments could prioritize the use of local resources, e.g. biomass. However, incentives are needed for the enhanced CHP applications in industries to overcome barriers for fuel supply availability and economies of scale for industrial cogeneration.

In the industry sector, especially all manufacturing industries requiring simultaneously large amounts of process heat and power, CHP plants can reduce the energy requirements through the combined provision of process heat and power. The expansion of this technology option should be supported by adequate regulation, e.g. cost reflecting tariffs (also on hourly base) and options of selling excess power to the grid. Importantly, the regulation should cover measures on emission control for all plants, as the current regulatory framework covers only large CHP installations (4-15 GW capacity).

6

Renewable energy

6. Renewable Energy

6.1 Status and Trends

Vietnam has a high potential for RE, including hydro, solar, wind, biomass, and waste. The RE share in the total primary energy supply (TPES) was 37% in 2007. However, this share has been gradually reduced to 22% in 2017. Biomass and hydro power have been the main types of RE in Vietnam up to now. In 2017, biomass and hydro accounted for app. 51% and 49% of the RE energy mix, respectively, while solar and wind accounted for very small amounts in TPES.

Up until 2019, the medium and large hydropower sources (about 20 GW capacity potential[20]) have been almost fully utilized. The small hydropower resource has a total potential of about 6.7 GW, with more than 3 GW already in operation. The total technical potential of biomass resources is about 7 GW for power production, while solid waste power is 1.5 GW, of which currently only 0.3 GW is utilized. RE sources with high future potential for development are wind and solar power. There was only a small amount of solar and wind capacity in operation before 2018, but it has been increased strongly in 2019 (with 4.5 GW of solar and 0.45 GW of wind at the end of June 2019) (EVN, 2019).

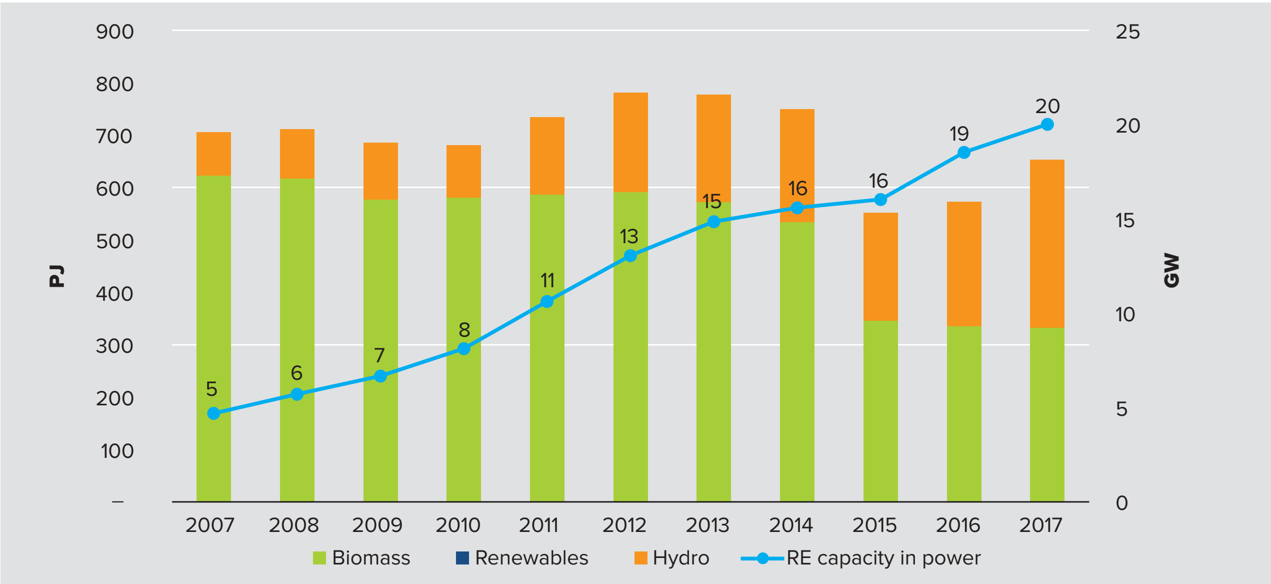


Figure 21: RE (TPES) development in Vietnam in the period 2007-2017 (left axis) and RE power capacity (right axis), both incl. small and large hydro. Note that the large jump from 2014 to 2015 in biomass supply is partially due to change in data collection methods. RE (TPES) for 2007-2014 is based on (IE, 2017) and 2015-2017 is based on (GSO, 2019) while the RE capacity is based on (NLDC, 2018).

In Vietnam, solar PV has the greatest potential, although limited by the demand for land use (the average land use rate is about 1.1-1.2 ha/MW depending on efficiency[21]). The solar potential used in the models is up to 380 GW (economic potential[22] in (Institute of Energy, 2018)), but the distribution is not uniform across regions but concentrated in the South, South Central, and Highlands regions. Due to the solar promotion mechanism ending in June 2019, solar power projects are currently booming in Vietnam. By August 2019, the total size of registered investment projects reached about 32 GW of which 10.3 GW is approved for additional planning up until 2025; however, not all may be realized. With the large expansion being approved, the transmission grid development has difficulties in meeting the operational schedule of all projects since procedures for construction investment and capital arrangement are causing delay in transmission projects.

[20] Potential of RE from the draft report on Vietnam RE Development Plan to 2035, Institute of Energy, 10-2018.

[21] Decision 11/2017/QD-TTg, dated 11/4/2017.

[22] For the least-cost modelling, the technical potential is the preferred input from which the model determines economic feasibility. For solar PV, the lack of input data means that using the technical potential would result in an overestimation of competitive potential for PV. To avoid this, the economic potential has been chosen as input for solar PV.

The total potential of onshore wind power used in the models is around 217 GW (considering wind speed over 4.5 m/s, height of 80 m, technical potential in (Institute of Energy, 2018)), mainly concentrated in the South, Highlands, and South Central regions. With Vietnam's new mechanism, many investors have submitted wind power projects with the total capacity reaching 10 GW of which about 5 GW is approved for additional planning, mostly in the South and South Central regions. As mentioned for solar PV, the transmission grid may not be developed in time to connect all wind projects in the period up to end of 2021, when the support mechanism ends. Although wind power has a large potential and only takes a limited amount of land (limit of direct land-use is 0.35 ha/MW[23]), only the best wind locations can compete with the rapidly decreasing costs for solar power.

In addition, Vietnam has a long coastline and a great potential for offshore wind, especially in the South and South Central regions, which have a relatively shallow seabed, convenient for offshore wind construction. For example, according to an assessment (ESMAP & World Bank, 2019) for offshore wind in Ninh Thuan sea area, the average wind speed is about 10 m/s; for the area extending to the Southern coastline, the average wind speed is 7 m/s. This area has the technical potential for offshore wind up to 76 GW. However, offshore wind potential needs to be studied more in the coming period.

A number of challenges are being raised when developing large amounts of wind and solar power sources, including the ability to integrate and balance wind and solar power into the energy system, the ability to reinforce and expand the transmission grid and land use requirements, especially for large solar parks.

Renewable energy policies and targets

Existing mechanisms to encourage and support RE development in Vietnam are as follows:

- *Solar power development incentive mechanism - Decision No. 11/2017/QD-TTg dated April 11, 2017:* implementation of Feed-in-tariff mechanism, where the solar electricity purchase price is 9.35 US cents/kWh for projects put into operation before July 2019. This decision is valid until June 2019, and now a new tariff mechanism is being drafted and has not yet been approved.
- *Wind power development encouragement mechanism - Decision No. 39/2018/QD-TTg dated September 10, 2018:* the purchase price is 8.5 US cents/kWh for onshore wind projects and 9.8 US cents/kWh for offshore projects in operation before November 2021.
- *The mechanism of supporting the development of grid-connected biomass power projects in Vietnam - Decision 24/2014/QD-TTg dated March 24, 2014:* the feed-in tariff for biomass power is 5.8 US cents/kWh.
- *The mechanism to support the development of solid waste electricity projects - Decision No. 31/2014/QD-TTg dated May 5, 2014:* the purchase price for direct solid waste-fired power plant is 10.05 US cents/kWh, the purchase price for landfill solid waste-fired power plant is 7.28 US cents/kWh.

Renewable energy policy targets in Vietnam can be mentioned:

- *Vietnam renewable energy development strategy (REDS) until 2050* was approved by the Prime Minister in Decision No.2068/QD-TTg dated November 25, 2015, stating that the share of produced electricity from renewable energy (incl. both small and large hydro) in the total national electricity production should reach about 38% by 2020; 32% in 2030, and about 43% in 2050.
- *Revised PDP7:* it is expected that RE sources (including small hydropower, wind, solar and biomass) will account for 21% of the national power generation capacity by 2030.

[23] Circular No.02/2019/TT-BCT, "Regulation on implementation and sample power purchase agreement for wind projects", dated 15 January 2019.

6.2 Renewable Energy Outlook

What will be the development of renewable energy technologies?

Biomass and hydro power are the two major sources of RE that are currently used in Vietnam. In the future, the use of these sources will continue and is expected to be supplemented by power from wind and solar PV. The costs of wind and solar power have been reduced dramatically over the last five years. Vietnam has excellent solar resources, mainly in the Southern part of the country. The wind resources are in general low to medium; however, at specific sites good wind resources exist. Additionally, very good wind resources exist offshore, e.g. close to the coast of Ninh Thuan.

The EOR19 shows that the primary RE sources are mainly biomass (wood, bagasse, rice husk, etc. used in households and industry) and hydro in the short term with significant increases in solar and wind energy in the longer term (Figure 22). RE shares in TPES have a slightly decreasing trend in future years, primarily due to a large increase in fossil fuel consumption. Unused hydro power potential is small, bioenergy has a potential to play a larger role in industrial CHP and power production, but the two main RE building blocks of the energy system is solar and wind. While the REDS targets for the RE share in the power sector are met in all scenarios, the RE shares for TPES are significantly lower than the REDS target, even in the most ambitious combination scenario (32% in 2030 and 44% in 2050). This indicates that the REDS targets for the RE share in the TPES are over-ambitious and not harmonized with the targets in the power sector. See more in section 8.3 where target harmonisation is recommended.

The energy output from hydropower has been calculated based on a normal weather year. During a dry year, production from hydropower sources is lowered by up to 25%. A sensitivity analysis to test the impact of such a reduction shows that more wind and solar will be added (about 5-10 GW in 2030, 2040 and 2050) to fulfil the RE requirement, and the total system costs will increase by about 6% in 2030 and about 3% in 2050 in the *C1 RE target scenario.*

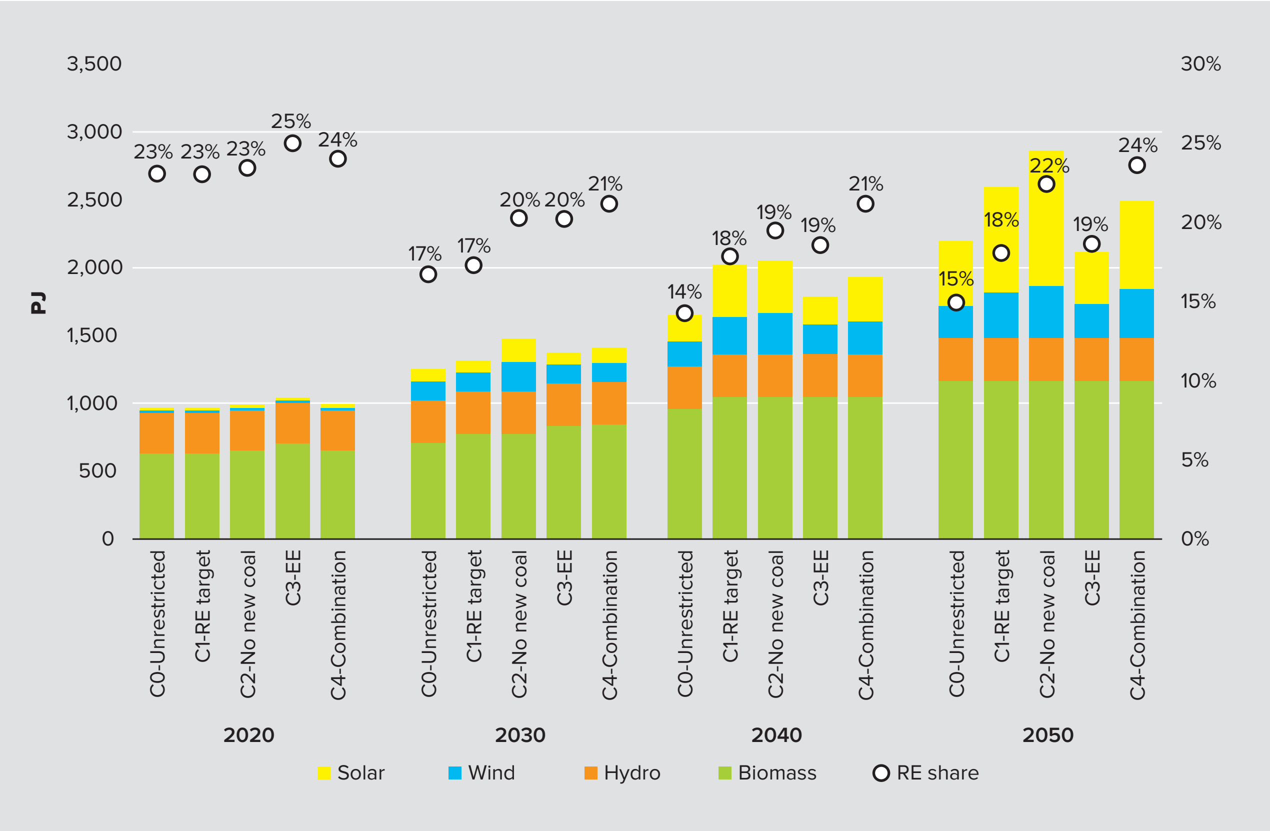


Figure 22: Renewable energy sources and their share in TPES (incl. small and large hydro) for all analysed scenarios

What will be the role of wind and solar in the power system?

In the EOR19, it becomes clear that wind and solar power will play an important role in the future. Even in the theoretical *C0 Unrestricted scenario*, where there are no renewable energy requirements, there is significant generation from wind and solar. This indicates that wind and solar technologies are attractive even without subsidies, as a result of lower costs for wind and solar than e.g. coal-fired generation. From a least-cost perspective, more than 20 GW of the best locations for wind and solar will be cheaper than coal in 2030, increasing to about 90 GW in 2050.

Wind and solar power are attractive in the scenarios, as they have low operation and maintenance costs and no fuel costs. The upfront investment costs have been decreasing over the years and now result in competitive LCOE (Levelized Cost of Electricity) values. Additional analysis to the EOR19[24] shows that with increasing wind and solar shares, the total energy system cost slightly increases across scenarios, with a rapid increase in capital costs (e.g. in 2050, a share of 30% wind and solar, can be achieved with capital cost constituting 53% of the total power system costs; with 70% wind and solar, this share becomes 80%). Therefore, in the transition from conventional power production to wind and solar, access to capital becomes more crucial, even considering the expectation that the investment costs of wind and solar PV will decrease drastically in the coming 30 years. The Vietnamese Technology Catalogue (EREA & DEA, 2019f) provides the complete overview of the projected cost development of wind and solar (as well as other technologies), as used in the EOR19.

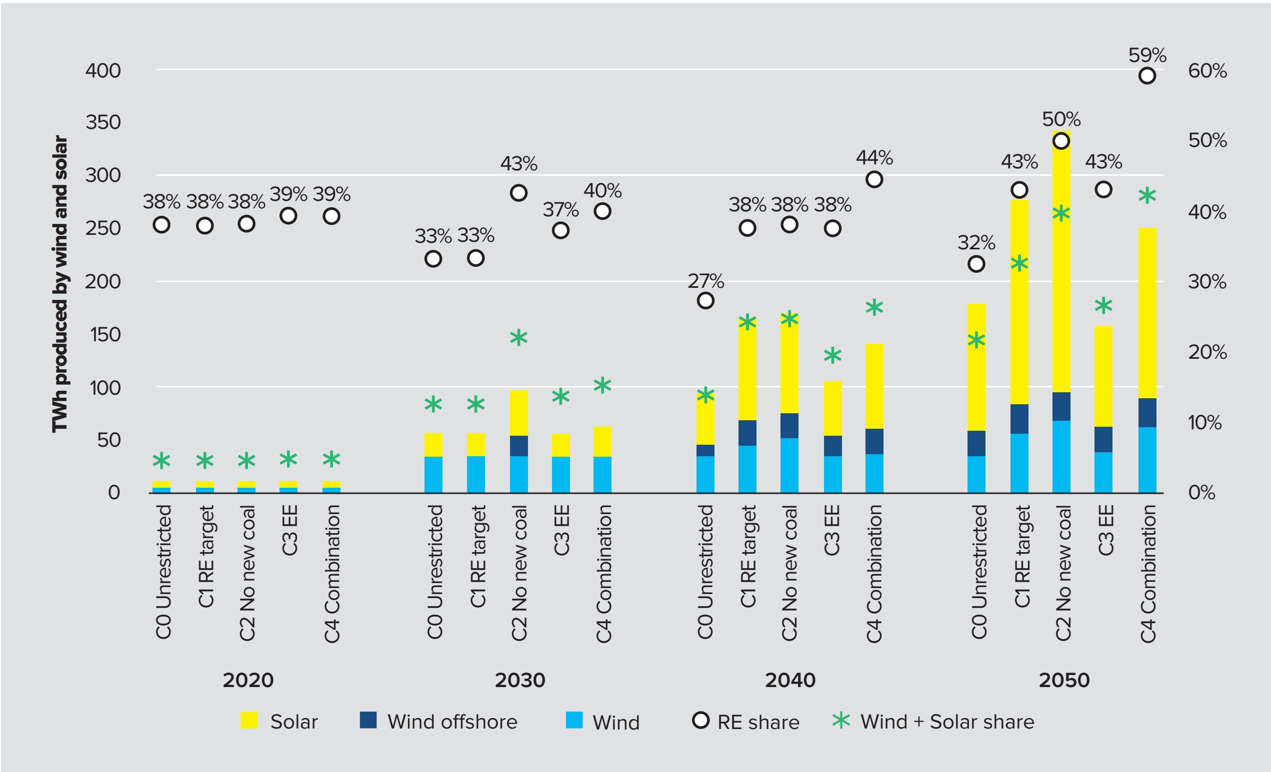


Figure 23: Electricity generation (TWh) from wind and solar together with RE share (incl. both small and large hydro) and the solar and wind share

[24] More analysis is described in the technical report (EREA & DEA, 2019a).

Figure 23 shows the development of wind and solar in the EOR19. Across all scenarios, the generation from wind is larger than that from solar in 2030. Wind produces more power (TWh) per GW than solar, as it operates at higher full load hours. Across scenarios the least-cost power mix requires a capacity build-up equal to 1 GW/year for wind and 1-2 GW/year for solar PV in the period 2020-2030. However, when further cost reductions are realized and the best onshore wind sites are fully utilized, solar will dominate along with development of offshore wind.

Further important observations include:

- The scenarios show, that after 2030, the adherence to the RE power sector targets in the REDS (*C1 RE target scenario*) results in much higher shares of wind and solar (13% and 33% in 2030 and 2050, respectively).
- If no new coal power plants are built after 2025 (*C2 No new coal scenario*), even more wind and solar become part of the least-cost power mix (22% and 40% in 2030 and 2050, respectively), with the RE share reaching 50% in 2050.
- Reduced power demand of around 30% in 2050 (*C3 Energy efficiency scenario*) means that the RE target can be met with lower absolute generation from RE. In this scenario, wind and solar power will be reduced while hydro and biomass remain the same.
- Combining no new coal and EE (*C4 Combination scenario*) results in the highest long-term RE share of 59% in 2050, with the highest wind and solar share of 42%. However, the reduced power demand results in a less extensive expansion of capacity than the *C1 RE target scenario.*

Solar power

Utility-scale PVs require land for the installation. Typical key values are 1.1-1.2 ha/MW. In the *C1 RE target scenario*, the least-cost investment in PVs amounts to 117 GW in 2050 (see Table 4). This will require a total land area of 1,545 km^2 or 0.5% of the total land area in Vietnam. The largest solar capacity deployed in the *C1 RE target scenario* is in the South region (76 GW in 2050), corresponding to 1.6% of the total region area. Only unused land is considered in the scenarios, and a standard and a high land cost are used to qualify different locations for PV installations. Across scenarios, only land with low costs has been utilized (50% of the total potential in each region). The only exception is C2, where 10% of the high cost land area is used in the South region in 2050.

The expansion of solar PV in the EOR19 is concentrated in the South region. Solar PV in this region is attractive from a least-cost perspective, because of the good solar resources and the large power consumption in Ho Chi Minh City. Even though it represents a small share of land, the 76 GW of solar capacity in the South region in 2050 implies a huge development in one single region with an average of more than 2 GW every year all through the period to reach the capacity in 2050.

Table 4: PV expansion and land areas in the *C1 RE target scenario* for the year 2050

Region	Total area (km^2)	Total potential (GW)	PV capacity (C1, 2050, GW)	Required area (C1, 2050, km^2)	Share of total area	Share of potential
North	116,459	7	3	44	0%	50%
North Central	41,587	1	0	5	0%	50%
Center Central	26,536	9	1	8	0%	7%
Highland	54,508	127	23	304	0.6%	18%
South Central	27,527	85	14	179	0.7%	16%
South	64,335	152	76	1,005	1.6%	50%
All	**330,952**	**381**	**117**	**1,545**	**0.5%**	**31%**

Alternative solar power

The type of solar PV technology analysed in the EOR19 is utility-scale PV. Other types may compete with this technology and become more attractive. Currently the fixed tilt PV solutions are the most attractive; however, one or two axis tracing solution could also be economic in the future. Also concentrated solar power (CSP) can be an option. With CSP, the energy is collected as thermal energy, making it possible to store energy in a thermal storage – and generate the power independently of the actual solar influx.

Rooftop PV can also supplement the utility-scale PV, bringing the benefit of space optimization, as no land is needed for the installation. Since the rooftop PV provides decentralized generation, i.e. *on top of the electricity demand*, investment in grid reinforcement may be lower. However, if the installation is small (1-20 kW_{ac}), the cost of the installation is likely to be more expensive (per kW) (IRENA, 2017). In a least-cost perspective, economy of scale is likely to make utility-scale PV more attractive. Rooftop PVs exist in large volumes in many countries[25]. This has often been motivated by simplified taxes and subsidies or net-metering system that allow free interaction with the local grid. Medium size PV installations (e.g. 100 kW – 1 MW) connected to industry and commercial end-users can have the benefit of scale for installation, while still being close to the demand.

Wind power

The expansion of wind power in the EOR19 is concentrated in the South Central and Highland regions (Table 5). While in the *C1 RE target scenario* it is attractive to expand wind power in the next 10 years in the South Central, Highlands, and South regions, after 2030 the expansion is focused on the South Central region.

For each region, three different wind profiles have been used: high, medium and low wind class. None of the low wind areas are attractive for investments across the analysed scenarios. Compared to solar PV, onshore wind requires much less land, and international experiences show that onshore wind can easily be combined with agriculture, which makes it easier to integrate in Vietnam.

Table 5: Wind power expansion per region and the total potential per wind class for the *C1 RE target scenario*. Green: potential is used completely; orange: potential is used partially by 2050.

					Unit: GW	Potential		
Region		**2020**	**2030**	**2040**	**2050**	**Low**	**Medium**	**High**
North	Onshore			0.5	0.5	12.1	0.4	0.1
North Central	Onshore		0.0	0.2	1.4	9.3	1.2	0.2
Center Central	Onshore	0.1	0.2	0.2	0.2	9.8	1.2	0.2
Highland	Onshore	0.1	3.6	3.6	5.0	57.0	13.8	3.6
South Central	Onshore	0.6	3.8	7.1	9.2	25.6	5.5	3.7
South Central	*Offshore*		2.5	5.0	6.0	-	-	6.0
South	Onshore	0.5	2.5	2.5	2.5	56.6	16.8	0.3
Total		**1.3**	**10.1**	**19.1**	**24.8**	**170.4**	**38.9**	**14.1**

[25] In 2016, utility-scale PVs represent around 60% of the total global PV capacity, while residential and non-residential PV each was around 20% (IRENA, Cost and competetivenes of solar PV, 2017).

Offshore wind is attractive in Vietnam

In the EOR19, lack of data means that offshore wind has only been represented by six sites, all close of Ninh Thuan in the South Central region. These sites are examples of offshore locations with the highest wind speeds (average wind speed of 10 m/s), each with a potential of 1,000 MW. However, as a complete mapping of the offshore potential has not been performed, future studies could focus on the resource assessment and mapping of offshore wind potential at national level, including considerations on wind speed variability, sea bed conditions, navigation routes and distance to coast.

The assessed offshore wind potential becomes attractive in 2040 across all scenarios or even in 2030, if there is a stop for new coal power plants (*C2 No new coal scenario*). The offshore wind has higher investment costs and much higher production compared to onshore wind. In the past years, a strong international technology development within offshore has resulted in a drastic decline in costs for off-shore wind. This decline is expected to continue as described in the Vietnamese Technology Catalogue (EREA & DEA, 2019f). Offshore wind also has the advantage of not taking up land, which is a main concern in Vietnam.

In 2040, the EOR19 concludes that 36% of the assessed offshore potential is a part of the least-cost power mix even without RE targets (*C0 Unrestricted scenario*), which means that this specific potential is highly competitive even compared to coal power already in 2040. In 2050 across all scenarios, close to all analysed areas will be fully utilized, which emphasizes that offshore wind should be a part of the future power mix in Vietnam.

6.3 Policy Outlook and Recommendations

While Vietnam has a limited potential for bioenergy and expansion of hydro power, the potential for wind and solar renewable energy is great. Currently, only a small amount of this potential is utilized, and the challenge ahead is to ensure deployment of RE at the lowest cost and to integrate it into the power system for the benefit of fuel import reduction, climate, and environment.

The EOR19 shows that for Vietnam the least-cost power generation in the *C4 Combination scenario* includes app. 40% RE share (incl. both small and large hydro) in 2030 and almost 60% in 2050.

RE must be in focus in the coming PDP8 to ensure the necessary basis for RE expansion in the next 10 years.

The forthcoming PDP8 will be a crucial framework for the energy system development, especially on a 10-year horizon. Reaching 40% power generation from RE in 2030 will require a planning focus on wind and solar power, which must be addressed in the PDP8:

- Ensuring **investments in the power grid** is crucial to enable more RE integration and avoid costly curtailment of wind and solar.
- Solar PV is booming in Vietnam, so a **special attention must be given to wind power,** which in a least-cost perspective should be developed to generate more power than solar in the next 10 years. Wind power has a strong advantage in taking up little land compared to solar PV, and the integration of agriculture and wind power is a common practice in other countries, e.g. Denmark.
- An ambitious RE target in the power mix in 2030 based on detailed scenario analysis should be included to have a clear and stable vision for RE expansion.

For a successful wind and solar development in Vietnam, it is crucial to have stable, simple, transparent, and competitive enhancing framework conditions for RE projects.

Such a framework should be characterized by:

- **Simplicity:** A **one-stop shop** where developers have a single point of contact and where all information, approval, EIA, grid connection, and licenses are handled.
- **Stability: Stable and long-term plans and targets** for RE expansion reduce the risk for investors and support building up a local supply chain.

- **Transparency:** A **transparent process** for developing RE projects and **close dialogue** with market players along with an **international standard PPA** builds trust and reduces risk, thus attracting more investors for large-scale RE projects.
- **Competition:** For large-scale wind and solar PV projects, it is important to **expose the developers to competition** to drive down prices, as international experiences with RE auctions have shown (IRENA, 2017). While a FiT regime is well-suited to kick-start a market for RE, it also has drawbacks as it is difficult to adjust the FiT to the dynamic market conditions. The competitive nature of auctions is the state-of-the-art measure of cost efficient large-scale RE deployment.

A framework for the development of offshore wind should be established already in the short term as offshore wind power is a knowledge-intensive technology and requires high upfront investments.

The assessment of potential locations for offshore wind near Ninh Thuan in the EOR19 shows that this technology is attractive in 2040 or even in 2030 depending on the power system development. While offshore wind can present higher full load hours and thereby higher outputs compared to solar PV, as well as occupying little land area, it is an investment, technology and knowledge-intensive industry. Obtaining the least-cost potential for offshore wind will require a solid framework already in the coming years, including:

- Pilot projects for offshore wind farms;
- Official targets for offshore wind expansion;
- Data availability including wind speeds, sea bed conditions and environmental impact assessment (EIA);
- Preparation for education of workforce to be able to carry out the projects;
- Continuation of the Feed-in-Tariff regime to support the new market until it is ready to be exposed for competition.

The awareness of local authorities, citizens, and stakeholders should be enhanced to ensure acceptance and facilitate local citizens to benefit from RE projects.

The EOR19 shows that large expansion of up to app. 75 GW of solar PV in the southern region of Vietnam in a long-term perspective (2050) is cost efficient. To realize such an extensive expansion not only national energy planning but also provincial involvement must be activated. The Planning Law[26] already stipulates the increased involvement of local authorities in the planning processes but also awareness, acceptance and ownership of citizens, private sector and NGO's are needed for the transition to be a success and for the local society to embrace the opportunities of knowledge, job creation, and technology transfer. An example of a measure to increase ownership is to ensure that the neighbors of RE plants get a share of the profit, e.g. by offering them shares in the RE plant.

[26] Law No. 21/2017/QH14 issued by the National Assembly dated November 24, 2017.

7

Power system balancing

7. Power System Balancing

7.1 Status and Trends

Power systems must balance second by second, i.e. demand and generation must match. Traditionally, the main challenge has been to balance the variation in demand. In Vietnam, coal-based plants have been used as base-load generation; natural gas-based plants have been working in the medium demand range, and hydropower has been supplying the peak demand. Many existing coal-based power plants in Vietnam have a low flexibility, e.g. with minimum generation of 70% of full load. This is in line with the function as base load. However, the role as base load capacity could be changed when more variable RE, mainly wind and solar, will be integrated into the energy system. Coal-based power plants may internationally have minimum loads as low as 25%[27].

By 2018, the entire power system in Vietnam has around 49 GW of installed generation capacity, of which large hydropower plants account for 35%, coal thermal power plants for 38%, gas turbine for 15%, small hydro power plants for 6%, and others including oil, power import and RE for nearly 6%. The peak load of the entire power system in 2018 was 35 GW (NLDC, 2018), resulting in a raw reserve rate of the power system up to 40.7%. The total electricity generation from the system amounts to about 220 TWh in 2018, of which the coal thermal power production (91.6 TWh) contributes with the largest share (42%), hydro generation with 38%, and gas thermal generation with 19% (Figure 24).

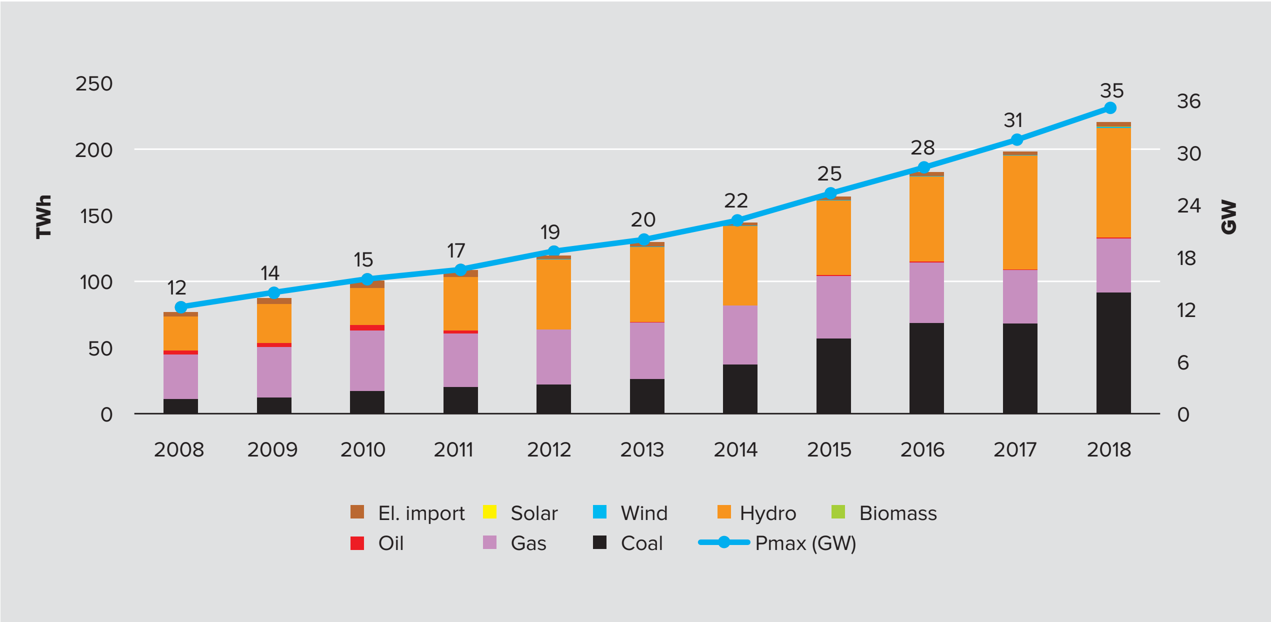


Figure 24: Power production (left axis) by fuel type and peak load (Pmax, right axis) in the period 2008-2018. Data is based on (NLDC, 2018)

The high proportion of hydropower in Vietnam represents the main source of flexibility in the power system, which represents a favorable condition for integrating variable RE sources. On the other hand, existing thermal power plants have low flexibility.

Installed capacity in the North and North Central regions is becoming redundant due to the large coal-fired power plants which will come into operation in the coming years, while the South tends to lack local power capacity due to a series of power plant constructions being behind schedule. In the North, there are two main power generation types, coal and hydro, while hydropower generation is the main power source in the Central region. The South has three main power generation types, i.e. gas, coal and hydro. Gas power plants currently hold the largest power production.

[27] See reports about power plant flexibility: *Flexibility in thermal power plants. With a focus on existing coal-fired power plants* (Agora Energiewende, 2017); *Flexibility in the Power System. Danish and European experiences* (Danish Energy Agency, 2015); and *Thermal Power Plant Flexibility* (Clean Energy Ministerial, 2018).

When looking deeply into the development of the power sources for the Northern, the Central and the Southern part of Vietnam, the power system could face some obstacles. The development of the power installations is not balanced with the load demand required in each region, thus causing great pressure on the transmission system. In addition, as hydropower accounts for a large share of the power generated, the seasonality of water resources can affect the operation of the power system.

The revised PDP7 lists the power sources which are expected to be developed in the period up to 2030, as approved by the Prime Minister in March 2016. However, by the beginning of 2019, there have been many changes in the energy landscape and the viewpoint on development of the power system by the Vietnamese Government in the coming period.

The most significant of them are the cancelation of the planned Ninh Thuan Nuclear power plants[28] (total capacity of 4,600 MW) and the investment of the "Third 500kV transmission line" from Quang Trach – Doc Soi – Pleiku 2. In order to offset the missing capacity of the nuclear plant, the LNG plants Nhon Trach 3 and 4 have been supplemented into the planning[29] (along with many other plants which are being considered to include: Ca Na, Long Son, Bac Lieu, etc.); RE is growing strongly because of the governmental incentive mechanism for wind and solar[30] and the intensification of power imports from Laos and China. According to the official agreement, which runs until 2030, the allowed import capacity is 5GW from Laos[31].

In addition, the potential of wind and solar power in the South Central and Highland regions, where the demand is low, results in adding new transmission lines and substations to release power of those plants, such as 500kV substation Thuan Nam in Ninh Thuan and the 500kV transmission line Thuan Nam – Chon Thanh[32].

Regarding power system balancing, Vietnam has a quite high potential of pumped hydro storage with 8 investigated sites of total 8900 MW (EVN & JICA, 2004). The potential amounts to 4100 MW, 2400 MW, and 2400 MW in the North, Central and the South respectively, where 2400 MW is included in the revised PDP7.

7.2 Power System Balancing Outlook

The EOR19 studies power system balancing by focusing on the *variability* of the system. That is, how dynamic is the balancing? What is the average and near maximum change in the system balance from hour to hour? The latter is used as a simple indicator for variability, and it can be based on the electricity demand or the residual demand (demand minus generation from wind and solar).

How can Vietnam balance the future power system?

Across all analysed scenarios for the Vietnamese power sector, a significant development in the capacity of solar and wind power is expected. As shown in Figure 23, wind power generation dominates over solar in the first period, while the situation is reversed in the longer term, when solar takes over in renewable power generation.

The EOR19 least-cost analysis shows that the main long-term power system building block is solar PV combined with short-cycle (few hours) battery storage. When comparing across scenarios for a specific year, it becomes evident that a higher wind and solar share requires more battery and transmission capacity to balance the system (Figure 25). As an example, going from a wind and solar share of 33% in 2050 in the *C1 RE target scenario* to 40% in the *C2 No new coal scenario* results in an additional capacity expansion of batteries of 19 GW and transmission expansion of 6 GW. The following sections will elaborate on this development.

[28] Resolution No. 31/2016/QH14 of the National Assembly dated November 22, 2016.
[29] Decision No. 212/TTg-CN dated February 13, 2017 of the Prime Minister.
[30] Decision No.11/2017/QD-TTg dated April 11, 2017 and Decision No.39/2018/QD-TTg dated September 10, 2018 of the Prime Minister.
[31] MOIT of Vietnam and the Ministry of Energy and Mining of Laos signed a memorandum of understanding on September 16, 2016 about the possibility of cooperation in electricity exchange and trading between Vietnam and Laos.
[32] Decision No.1891/TTg-CN dated December 27, 2018 of the Prime Minister.

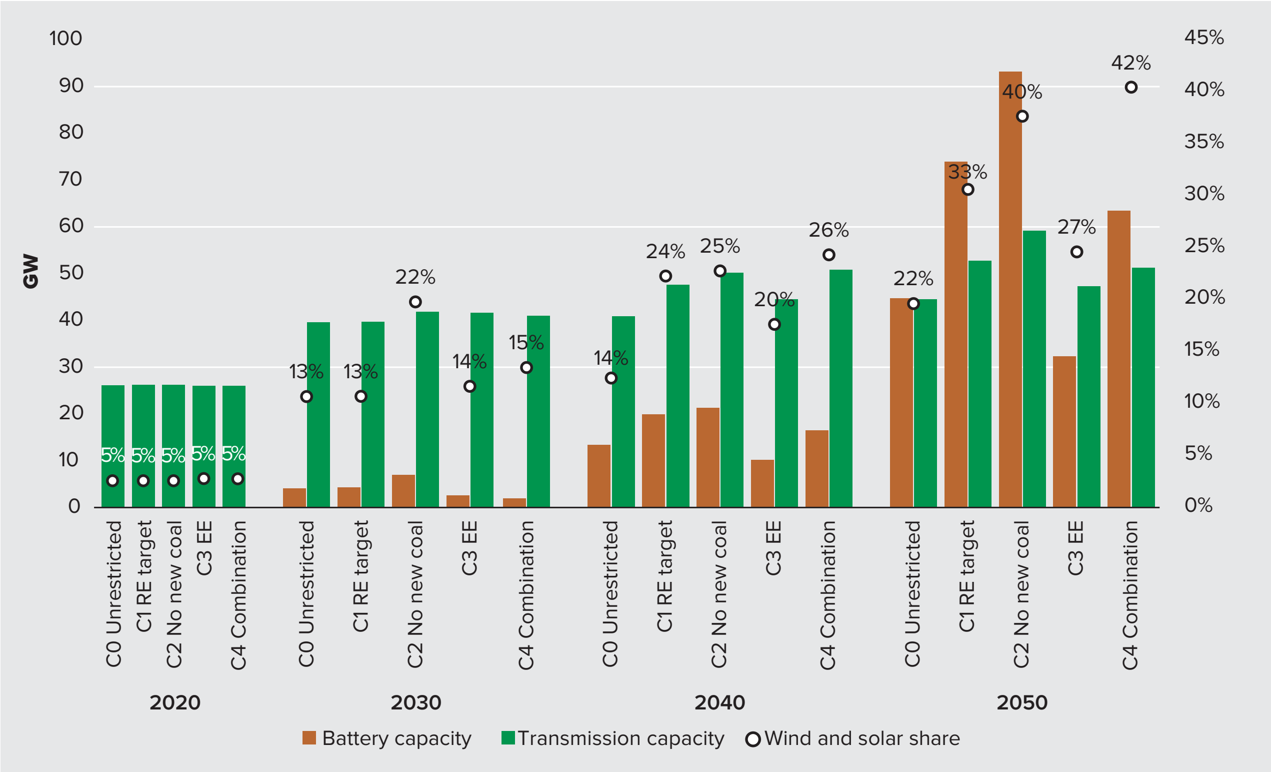


Figure 25: Battery and transmission capacity across analysed scenarios. The wind and solar share in the power mix is indicated.

Variability and power system dynamics

With a significant amount of generation from wind and solar (i.e. share of 20% of generation and above), the challenge with power balancing can be illustrated by the *residual demand,* calculated as the total demand minus what is delivered by wind and solar. A simplified way to describe the power system dynamics at increasing shares of wind and solar generation is to compare the hourly variation in the total demand and in the residual demand. The EOR19 shows that, as long as the shares of wind and solar are less than 20%, the dynamics of the residual demand does not differ much from that of the total demand, and the impact of wind and solar variability is low (Table 6). In the later years (2040 and 2050), wind and solar constitute more than 20% of the total generation, thus increasing the dynamics of the system significantly. This is in line with other studies, e.g. (IEA, 2017). As illustrated above in Figure 25, increasing the wind and solar share and thereby the dynamics of the system also leads to an expansion of battery and transmission capacity and thereby increased balancing needs.

Table 6: Key values for the dynamics of the system – *C1 RE target scenario*

	2020	2030	2040	2050
Average hourly demand per year (GW)	30	61	92	113
Yearly generation from VRE* compared to demand[33]	5%	12%	23%	31%
Average absolute change in demand (GW/h)[34]	1.2	2.4	3.6	4.3
Average absolute change in residual demand (GW/h)	1.2	2.6	5.4	8.6

**Wind and solar power*

[33] Please notice that this share is different from other VRE shares mentioned in this report. Other VRE shares are calculated compared to domestic generation of power and not demand.
[34] Computed by calculating the hour-to-hour change for each hour of the year for each region. In the EOR19, detailed information about the hourly demand in each of the six transmission regions is used. However, the same profile is used for all years. The average absolute change in demand is therefore proportional to the demand (4% of the average demand).

Figure 26 illustrates the system balance hour-by-hour for a week in 2020 and 2050 for the C1 RE target scenario. While hydropower balances the variation in demand in 2020, the variation in solar power generation is larger than the variation in demand in 2050. As balancing by hydropower is not sufficient, a gradual shift occurs in the balancing role from hydropower installations to battery storage technology in the long term. Coal-based power plants will still mainly function as base load capacity, while also absorbing some of the variation in the residual demand.

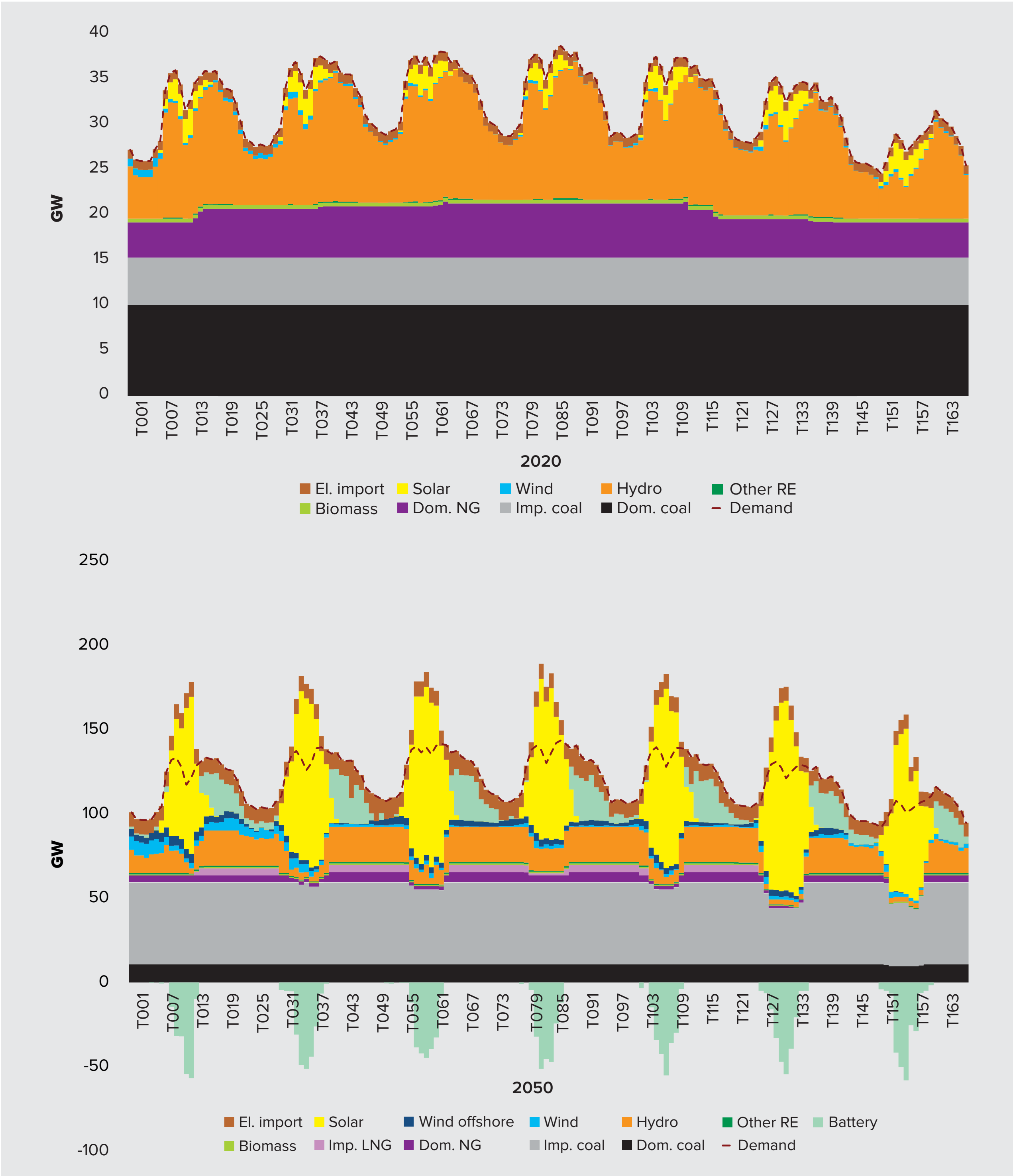


Figure 26: Hourly dispatch in the *C1 RE target scenario* in week 39 (high demand). Figure above is 2020 and below 2050.

Balancing needs for wind and solar

Both wind power and solar power need balancing capacity to integrate the variable nature of their generation, though their balancing needs are diverse due to differences in generation profiles. Figure 27 shows the duration curves for wind and solar generation. Both curves have a sharp peak around the maximum generation. However, where solar is not producing for around half of the hours of the year, the wind generation is decreasing linearly to zero generation in only a few hours. Furthermore, generation from solar power is very concentrated during mid-day, while wind generation is not heavily correlated to any specific timeframe during the day. Wind generation profiles are also more geographically dependent than solar profiles.

Due to these differences, solar generation has a need for short-term storage capacity (e.g. batteries), which enables moving generation from mid-day to hours with high residual demand. The EOR19 shows that batteries are charged during mid-day when generation from solar power is peaking and de-charged in the evening with high demand. While also integrated with the help from short-term storages, wind power benefits also from transmission line expansions for smoothening the generation across a larger region with geographical differences in wind speed profiles.

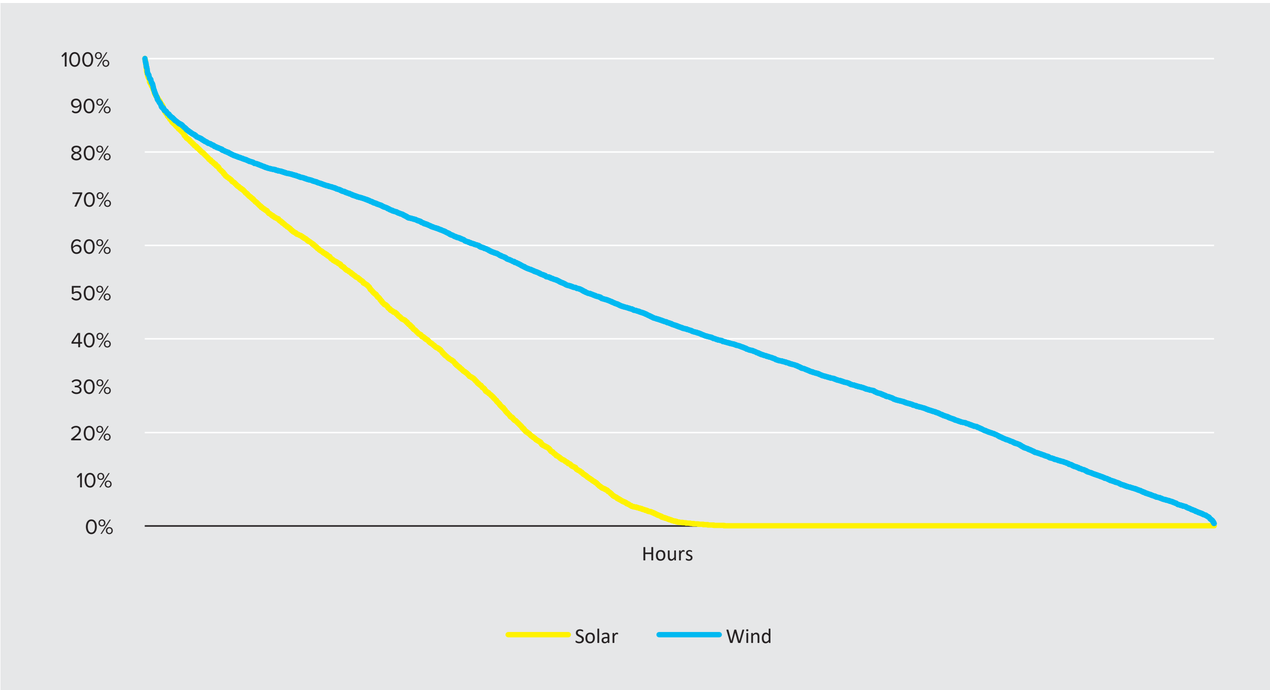


Figure 27: Duration curve for the total generation of wind and solar power for the *C1 RE target scenario* (2030). X-axis represents all the hours of the year.

The need for storage

Storage solutions will increasingly contribute to system balancing in the future. In the analysed scenarios, two storage technologies have been tested: Lithium-Ion battery and hydro pumped storage. Across all scenarios (see key values for the *C1 RE target scenario* in Table 7), increased generation from solar power goes hand in hand with large investments in batteries. As such, power storage is key to balancing of wind and especially solar on the long term– with around 0.5 MW battery capacity for each MW of wind and solar in 2050. Batteries are expected to continue the current trend of rapid decrease in costs[35], which makes them the least-cost investment solution for balancing the very large solar peaks while moving the generation to hours with high residual demand.

[35] A price drop in investment costs of 69% from 2020 to 2050 is expected (EREA & DEA, 2019f).

Table 7: Key values for solar and battery technologies in the *C1 RE target scenario*

	2020	2030	2040	2050
Solar (GW)	4	14	59	117
Battery (GW)	0	4	20	74
Battery/Solar capacity (GW/GW)	0.00	0.31	0.34	0.63
Share of wind and solar generation in power mix	5%	13%	24%	33%

In the EOR19, the batteries are optimized individually for capacity (MW) and storage volume (GWh). In most cases, the optimum is between 1.5 and 2.5 MWh/MW. In contrast, pumped storage projects typically have a relatively larger storage/capacity ratio (9 MWh/MW), based on 8 concrete cases of pumped hydro. Compared to the latter, batteries have a higher investment cost per MWh, but the cost per MW is lower and the round-trip efficiency (i.e. charging and generating) is higher. Therefore, the need for short-term (few hours) storage favours batteries in a least-cost storage solution.

The EOR19 results with high levels of investments in large Lithium-Ion batteries are quite robust to variations in investment costs, with some changes in the long term: if battery prices do not decrease as expected, wind and pumped hydro will have a higher share in the future, but PV and batteries will still be the main RE building blocks. This has been shown by fixing the investment costs for batteries to the 2020 value until 2050 (no development after 2020), resulting in three changes (*C1 RE target scenario*):

- 1/3 less battery capacity in 2050 (-20 GW);
- Investment in pumped storage in 2050 (+6 MW);
- The RE target is fulfilled with more wind (+7GW) and less solar power (-10 GW). Solar power requires more storage than wind power because solar resources present a synchronized generation (peak mid-day, and no generation at night).

Other technologies than batteries and pumped hydro can deliver the needed flexibility to the system. Concentrated solar power (CSP) technology has not yet been studied but could be included in future work. With CSP, solar energy is captured as heat, and high temperature storage may extend the power generation beyond day time, thereby reducing the need for electricity storage. Moreover, demand response (e.g. electricity demand that can be controlled by dynamic pricing schemes) can function as virtual storage, thereby providing part of the needed flexibility. This can include e.g. industrial demand or charging of electric vehicles.

Transmission capacity

Reinforcement of the transmission capacity helps balance the system. A larger transmission capacity can bring several advantages:

- More power plants can be used for balancing. With more active power plants, the balancing can be achieved by adjusting output (part load) instead of starting/stopping power plants, to a higher degree. Adjusting can be performed more quickly and at lower costs;
- Balancing over a larger geographic area has the benefit of significant smoothing, as variation in both solar (to a lesser extent) and wind power is reduced for a large area, with particular effect on wind power smoothing;
- In relation to the smoothing, it is easier to predict the generation from wind and solar for a large area;
- Avoiding expensive curtailment of variable RE sources. A larger transmission capacity will reduce congestion issues and make RE investments more feasible.

With larger solar and wind capacities, investments in transmission become more attractive, though not at the same rate (*the Trans/Wind and solar capacity* ratio is decreasing, see Table 8).

Table 8: Key values for wind, solar technologies and transmission in the *C1 RE target scenario*

	2020	2030	2040	2050
Transmission capacity (GW)	26	40	48	53
Solar capacity (GW)	4.1	14	59	117
Wind capacity (GW)	1.4	10	19	25
Trans/Wind and solar capacity (GW/GW)	4.80	1.65	0.61	0.37
Trans/Wind capacity (GW/GW)	18.73	3.92	2.49	2.13

To test how the regional transmission expansion depends on the RE share, Figure 28 illustrates the results of increasing the RE share in 2050 beyond the REDS target of 43% (incl. large hydro). The results show that grid expansion will mainly take place in three out of seven sections considered; there is the link between Highland and Centre Central, North Central and North, and North Central and Centre Central. This is due to the large RE expansion happening in the Central and South areas which will need more transmission capacity to distribute electricity to the North.

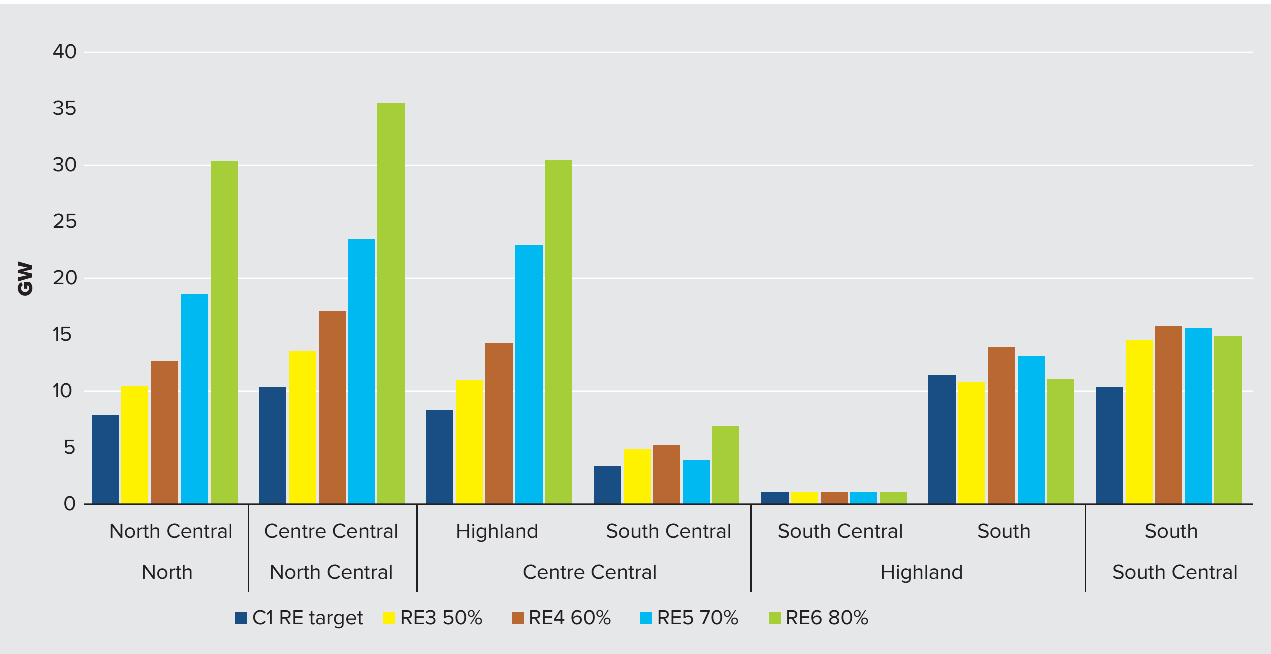


Figure 28: Transmission capacity under increasing penetration rates of RE (*C1 RE target* (43%), 50%, 60%, 70% and 80%) for 2050

In some cases, it could be relevant to curtail generation from wind and solar instead of investing in additional transmission and storage capacity – especially if curtailment is only needed in a limited number of hours. From a socio-economic perspective, the cost of lost generation should be compared to the investment cost of batteries and transmission lines. However - depending on the PPA - curtailment issues might hinder private investments in solar and wind, even though being feasible for society.

In the EOR19, curtailment issues are marginal; the curtailment rate in 2050 is less than 1% in the normal *C1 RE target scenario* and below 3% if the RE share is increased up to 80% (Figure 29). This shows that with the right investments in transmission and storage, curtailment of wind and solar will not be a concern.

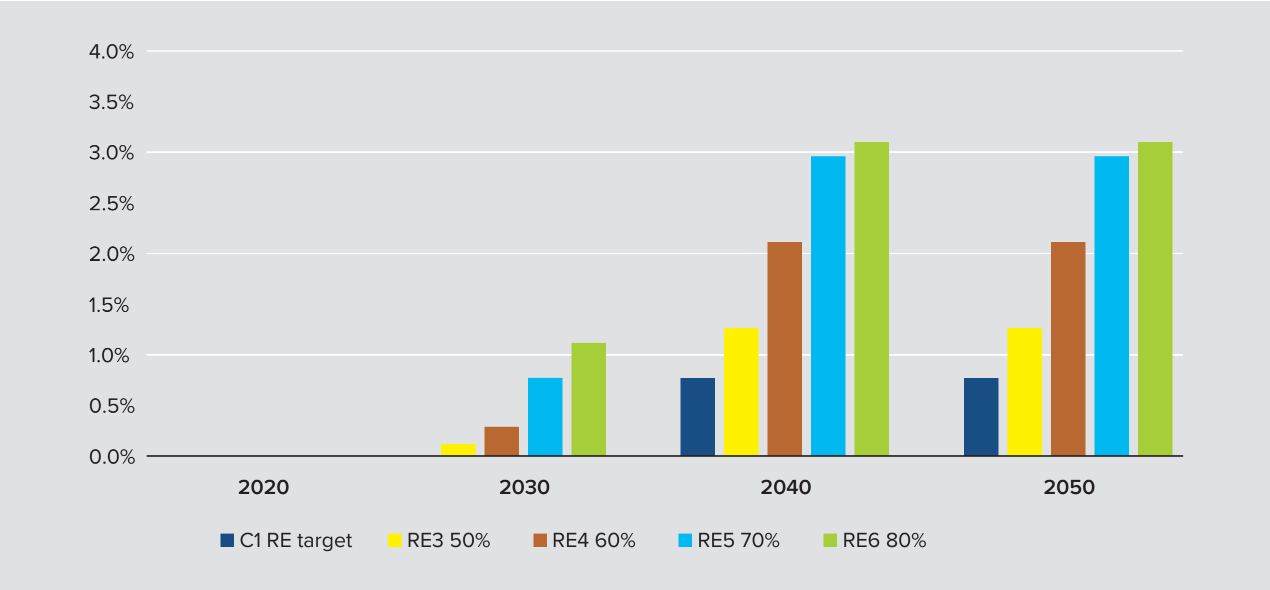


Figure 29. Curtailment of wind and solar at increasing shares of RE generation (*C1 RE target* (43%), 50%, 60%, 70% and 80%)

Figure 30 shows the generation per fuel and the annual demand for each of the transmission regions. Here it can be seen that the transmission grid enables moving generation from locations with high wind and solar resources to the demand centers in the North and the South.

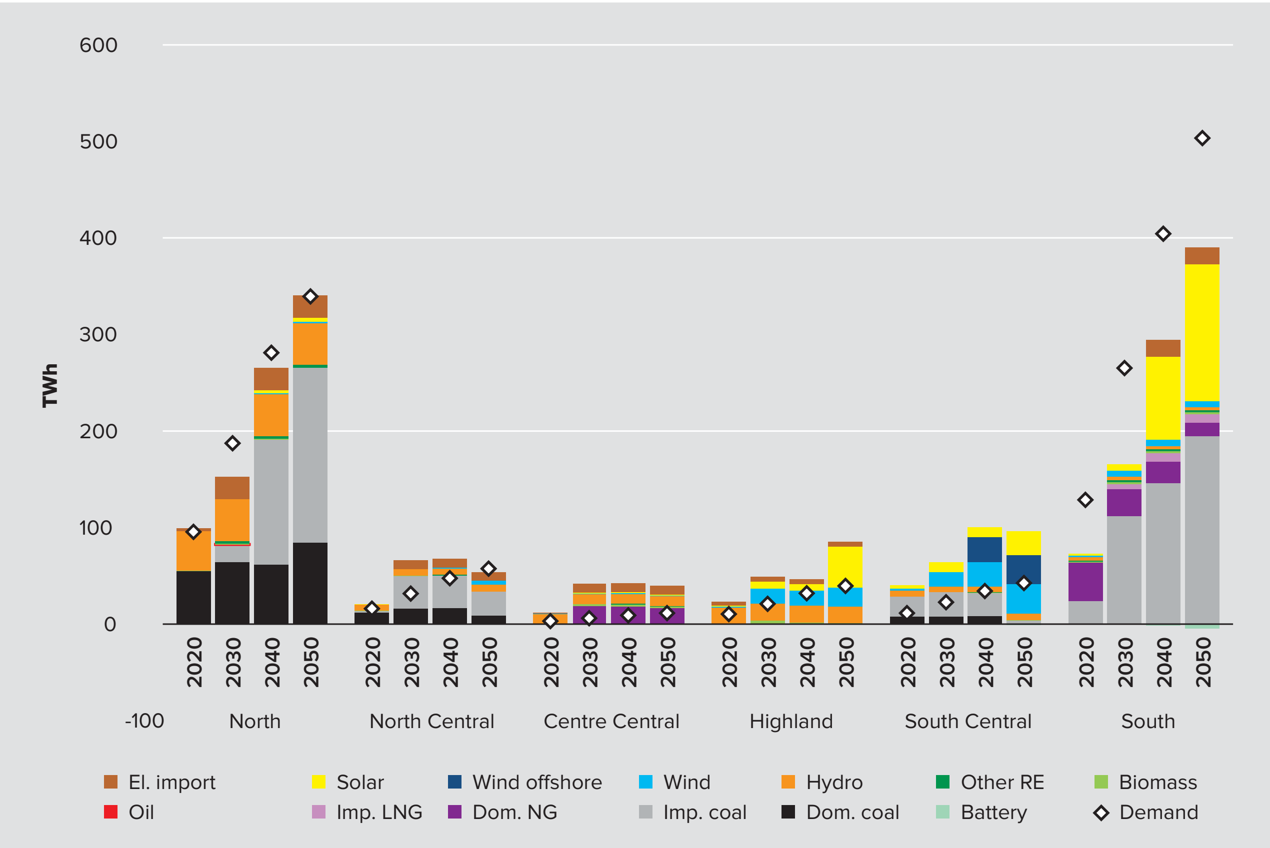


Figure 30: Electricity generation, electricity import from neighbouring countries, and annual demand per region for the *C1 RE target scenario*

Detailed grid evaluation using the PSS/E model

The above analysis of transmission expansion does only include a rough estimation of the needed transmission grid to link the 6 regions, leading to an underestimation of the true transmission expansion costs. Additional simulations using the PSS/E model in the EOR19 provides a more detailed and more realistic analysis, both taking into account load levels and voltage requirements (see Annex 4 and the report *Detailed grid modelling of the Vietnamese power system* (EREA & DEA, 2019d). Results from the EOR19 show that the total power system cost will increase by 5% in the *C1 RE target scenario*, when including the needed grid reinforcements, as computed in the PSS/E model. In total, the necessary investment in grid capacity in 2030 amounts to approximately 30% of the total system investment[36].

7.3 Policy Outlook and Recommendations

Increasing power demand and increasing share of wind and solar point out a central challenge for Vietnam, i.e. ensuring a stable energy supply while integrating fluctuating solar and wind power. The planning of the future power system in Vietnam should ensure that the required technology and market components are in place to secure a timely balancing of the system. In particular, in addition to the classic daily variations in the power demand, future systems will have to cope with increased levels of generation from variable RE sources.

> A stepwise approach to integration of wind and solar power is recommended: In the short term, focus should be on expansion of transmission capacity. In the long term, storage is needed.

The development of the transmission grid will be required to integrate the increasing shares of VRE, as e.g. balancing over a larger geographic area brings the benefit of achieving greater smoothing of the variable power generation. Investments in grid reinforcement and additional transmission lines between regions should therefore be considered as part of the power planning, thereby allocating the required financial resources both at the national and regional level. Moreover, timelines for grid development projects are not to be underestimated, as timely grid expansion would be needed for ensuring cost-effective energy. Furthermore, the issue of allocating land for new transmission line corridors will also have to be in focus. The assessment of the whole transmission grid indicates that in 2030, necessary grid investments amount to 30% of the total system investments.

In the long term, the large capacity increase in solar PV in the EOR19 results drives investments in short-cycle (few hours) battery storage to balance the daily variation. Nonetheless, balancing the power system is technically and economically feasible, even with high shares of VRE.

> Removal of market barriers to ensure timely introduction of electricity storage should be investigated and addressed, thus laying out the favorable market conditions.

Battery storage represents a robust solution for power system balancing of variable renewable energy in the long term, considering both the projected trend in cost reduction for battery technology and the expected increase in solar power installations, with around 0.5 MW battery capacity for each installed MW of wind and solar in 2050. If battery prices do not decrease as expected, wind and pumped hydro will have a higher share in the future, but PV and batteries are still the main RE building blocks.

In this perspective, any market barriers to ensure timely introduction of batteries as well as electricity storage technology in general should be investigated and addressed, thus laying out the favorable market conditions. For instance, the size and localization of batteries are important aspects to consider, particularly in the context of reducing the pressure on the transmission grid. In this sense, package technology solutions (PV + battery) could possibly become relevant. Furthermore, some considerations are due: lifecycle assessment of batteries should be undertaken to provide a more comprehensive picture of their impact on the environment and resources, especially in the production phase and at the end of their lifetime. Before investing in large scale storage facilities, important technical experience can be gained by encouraging R&D activities.

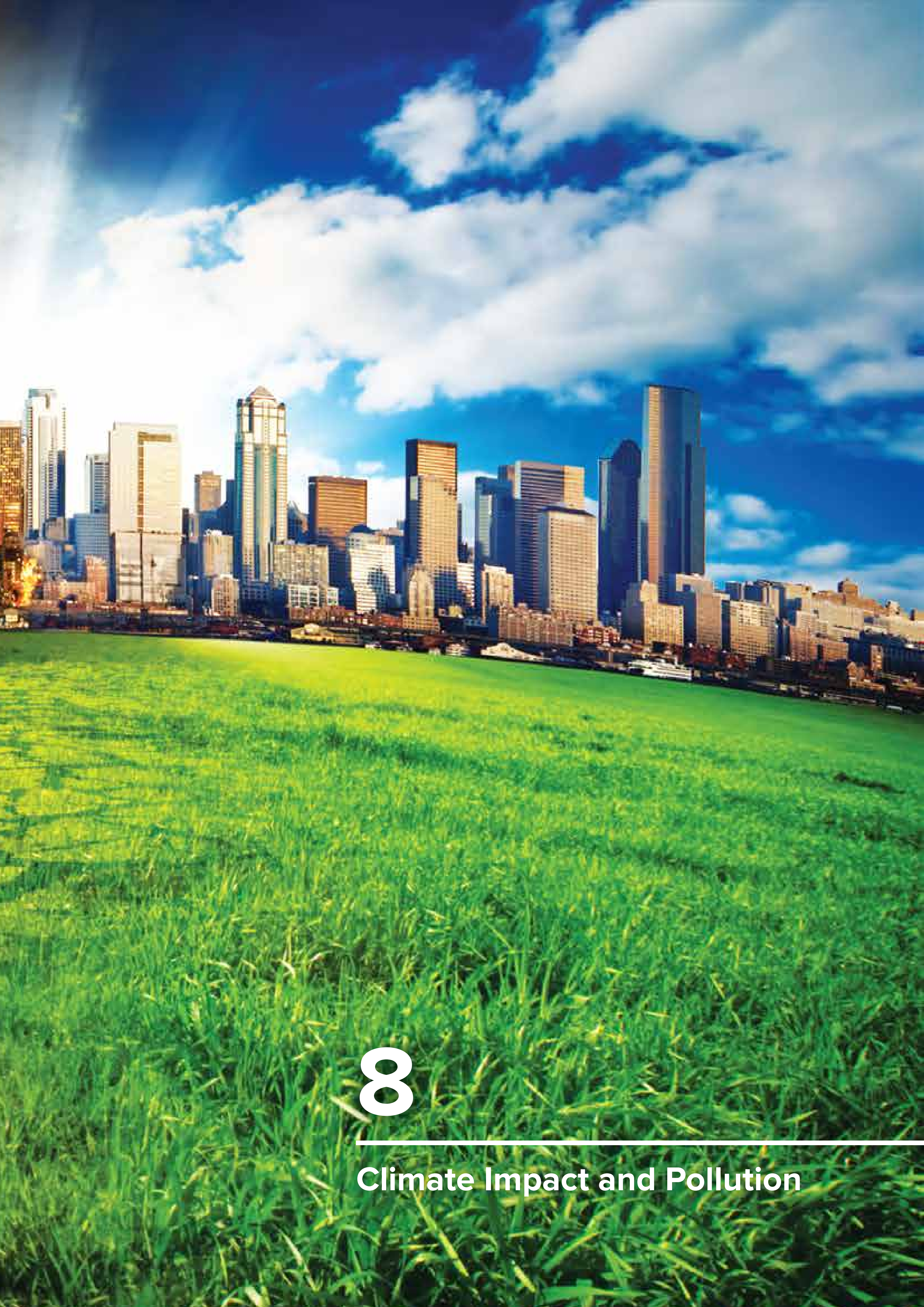
36 Only approximate numbers since calculations only include endogenous investments.

Other means for balancing the system and reducing the need for storage not analysed in the EOR19, such as market-based trade with neighboring countries and flexibility of thermal power plants, should be addressed.

Market-based trade with neighboring countries can reduce the need for local storage. Market integration options and the ensuing underlying conditions should therefore be explored for Vietnam (e.g. the North European NordPool or other regional power markets). Market integration also could bring about other benefits, including improved competition, security of supply, sharing of reserves, reduced need for storage, improved balancing in relation to hydro (wet/dry years), wind and solar.

Increasing the power plant flexibility through e.g. plant upgrade, could also reduce the need for storage. Moreover, the potential effectiveness of demand response can help system balancing, especially in the short term (i.e. in the scale of hours).

In general, the development of adequate forecasting systems is the key for integration of increasing shares of VRE generation in the system. The implementation of state-of-the-art, centralised forecasting systems gathering real-time data from VRE power plants, can support the effective scheduling of power plants and other operational decisions.



8

Climate Impact and Pollution

8. Climate Impact and Pollution

8.1 Status and Trends

In 2014, the total GHG emissions in Vietnam amounted to 283.9 Mt CO_2eq, with 60% contribution from the energy sector. Agricultural and industrial processes accounted for 31.6% and 13.6% of the total GHG emissions, respectively. Table 9 reports the evolution for GHG emissions in Vietnam during the period 1994-2014.

Table 9: GHG emission inventories in Vietnam in the period 1994-2014 (Mt CO_2e). Source: (MONRE, 2014).

Sector	1994	2000	2010	2014
Energy	25.6	52.8	141.2	171.6
Industrial processes	3.8	10	21.2	38.6
Agricultural production activities	52.5	65.1	88.4	89.8
LULUCF	19.4	15.1	-19.2	-37.5
Waste	2.6	7.9	15.4	21.5
Total	104	151	247	284

Energy consumption in recent years has increased quickly to meet socio-economic developments. Consequently, GHG emissions from energy uses, processes and extraction have increased from 141.2 Mt CO_2eq in 2010 to 171.6 Mt CO_2eq in 2014 (MONRE, 2014), with one third associated to electricity generation in 2014 (Figure 31). High energy demand growth and increased reliance on imported coal creates challenges for the GHG emission abatement in Vietnam in the years to come.

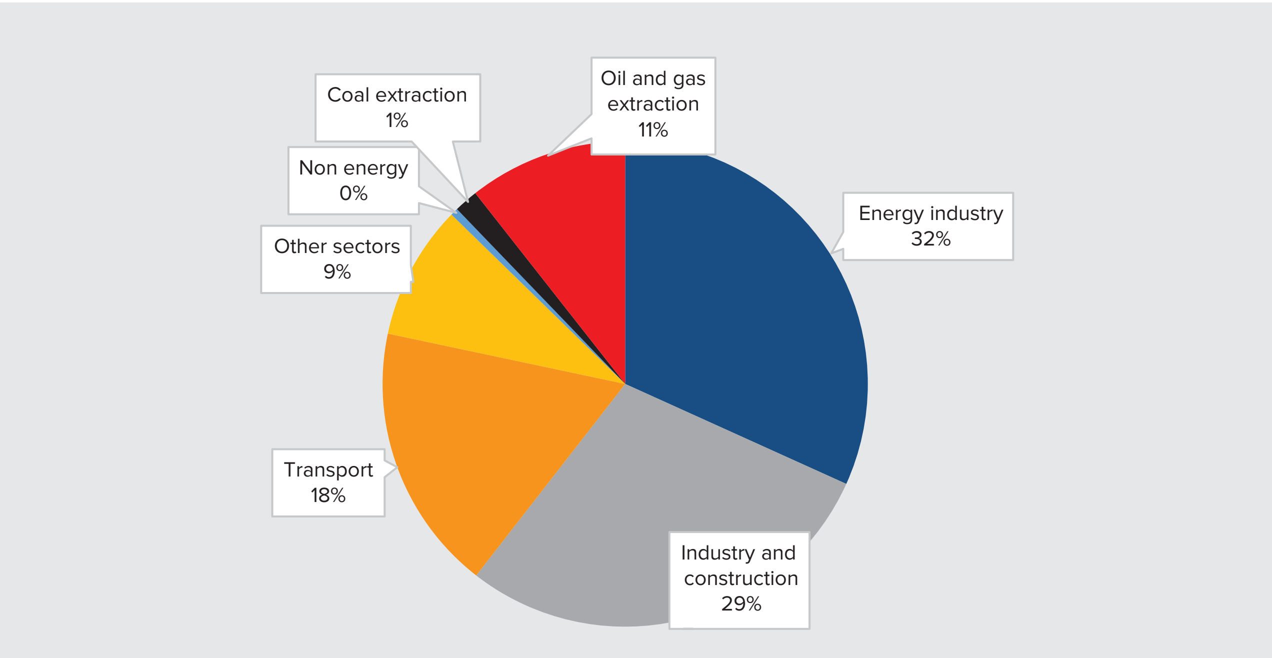


Figure 31: GHG emission by energy sector in 2014

Air pollution in the larger cities of Vietnam today poses significant health risks. Data from the WHO state that more than 60,000 deaths in Vietnam are linked to air pollution (WHO, 2018). In 2016, the mean values of fine particle concentration PM2.5, which is considered one of the most dangerous forms of pollution, were almost five times higher in Hanoi than the values recommended by WHO. The close link between energy consumption and air pollution makes this an area of high relevance for energy system planning.

Climate and pollution policy and targets

As projected by MONRE, GHG emissions from the energy sector will increase to 320 Mt CO_2eq in 2020 and 643 Mt CO_2eq in 2030 (GIZ, 2018b). Vietnam has issued several targets for reducing GHG emissions, as follows:

- *Vietnam Green Growth Strategy (VGGS):* 10-20% by 2020 and 20-30% by 2030 as compared to business-as-usual development;
- *Intended Nationally Determined Contributions (INDCs):* Submitted to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC), and Vietnam's statement at the COP21 conference in Paris: Vietnam will reduce 8% of greenhouse gas emissions compared to the baseline development scenario in 2030. Vietnam can reduce its GHG emissions further by 25%, pending international support;
- *Renewable Energy Development Strategy (REDS):* 25% (for the energy sector) by 2030, and 45% by 2050 as compared to business-as-usual development.

In 2015, Vietnam successfully submitted its Intended Nationally Determined Contribution (INDC or NDC1) to the Secretariat of UNFCCC. The Vietnam's NDC1 is implemented at the national level in relevant sectors, including energy, agriculture, Land Use, Land Use Change and Forestry (LULUCF) and waste sector. Currently, the NDC target is being reviewed and updated in Vietnam by line ministries (MONRE, MOIT, MOT, etc.) for the next round of submission to UNFCCC in 2020.

The following contains some important policies on pollution:

- Strategy for using clean technology in the period up to 2020, with a vision to 2030[37].
- National Strategy for environmental protection up to 2020, with a vision to 2030[38]: The 2020 objective is to limit the increase in environmental pollution and to reverse the increasing trend in 2030.

8.2 Climate Impact and Pollution Outlook

What is the impact of the future energy system on GHG emissions?

In the *C1 RE target scenario*, CO_2 emissions from the energy sector are increasing quickly at 7.4% p.a. in 2020-2030 and 4.4% p.a. in the whole period of 2020-2050. Power generation is the main contributor for the increased CO_2 emissions followed by industrial and transport sectors. Figure 32 reports the trends for CO_2 emissions from the energy sector across the analysed scenarios.

[37] Decision No. 2612/QD-TTg dated December 30, 2013, approved by the Prime Minister.
[38] Decision No. 1216/QD-TTg dated September 5, 2012, approved by the Prime Minister.

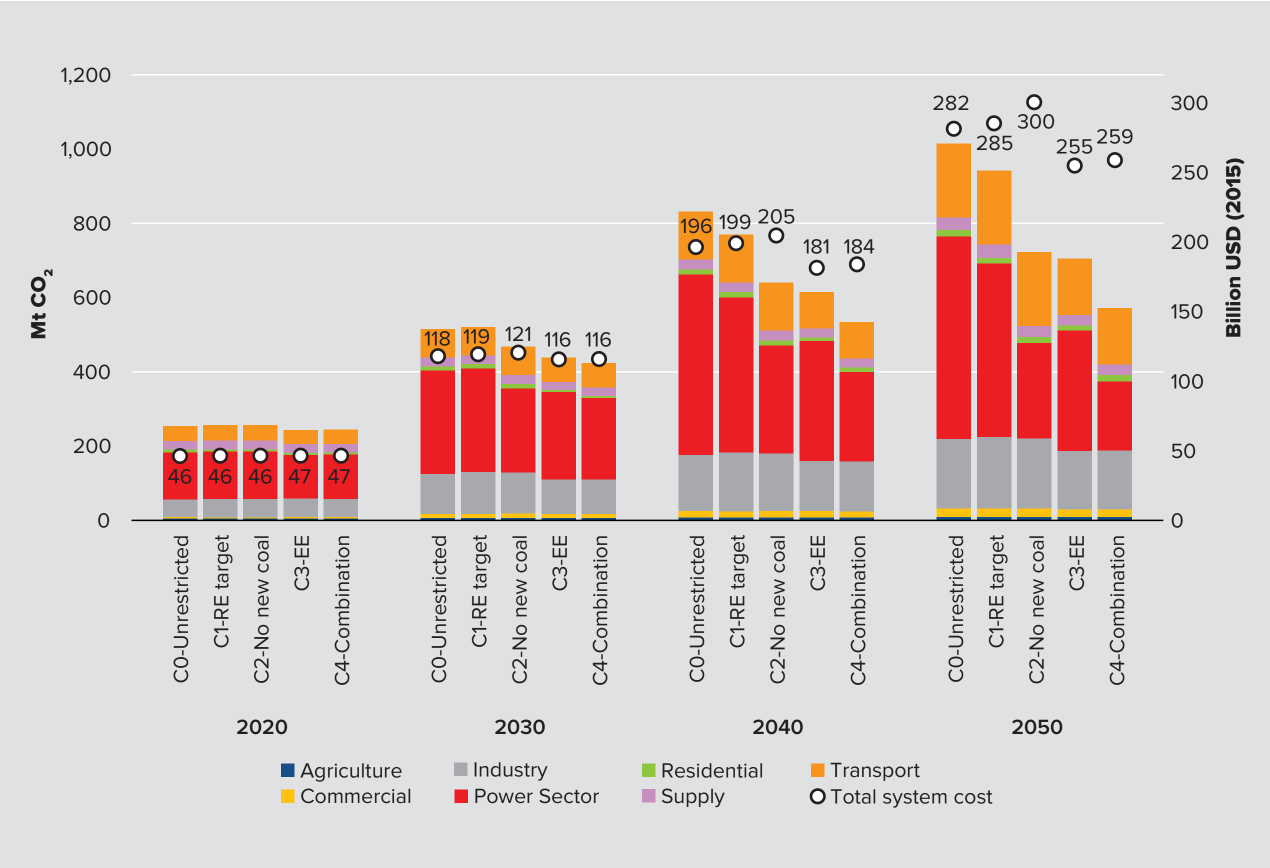


Figure 32: Trends for CO_2 emissions (left axis) by sector and total system cost (right axis) in all five scenarios

In the EOR19, coal use contributes to 65%-75% of total CO_2 emissions from the whole energy system in different scenarios. CO_2 emissions in the *C0 Unrestricted scenario* are similar to the *C1 RE targets scenario* in 2020 and 2030, while they are 8% higher in 2040 and 2050. This shows that the REDS has no impact on the least-cost CO_2 emissions in the short and medium term, because RE affordability would have improved beyond the targets of the strategy. After 2030 the strategy targets do result in a moderate CO_2 emission reduction.

Going away from new coal investments (from *C1 RE target scenario* to *C2 No new coal scenario*) leads to an increased consumption of LNG. Along with increased RE share, this reduces CO_2 emissions by 10% in 2030, especially caused by a large reduction (53 $MtCO_2$) in the power sector. At the same time, the total system cost increases by approximately 1 billion USD, caused by the substitution of coal to LNG. In 2050, CO_2 emissions are reduced by 23% at an increased system cost of 5 billion USD.

In the *C3 Energy efficiency scenario*, EE measures can reduce the CO_2 emission growth rate in 2020-2050 from 4.4% p.a. in C1 RE target scenario to 3.6% p.a. CO_2 emission reductions are mainly obtained in the power sector (switching from coal to RE and natural gas), industry and transport sector (when EE measures are successfully implemented). The combined effect of EE, RE and LNG (*C4 Combination scenario*) to reduce coal and oil consumption can in turn reduce the total CO_2 emissions by 19% in 2030 and 39% in 2050. The reduction takes place primarily in the power sector (Figure 33).

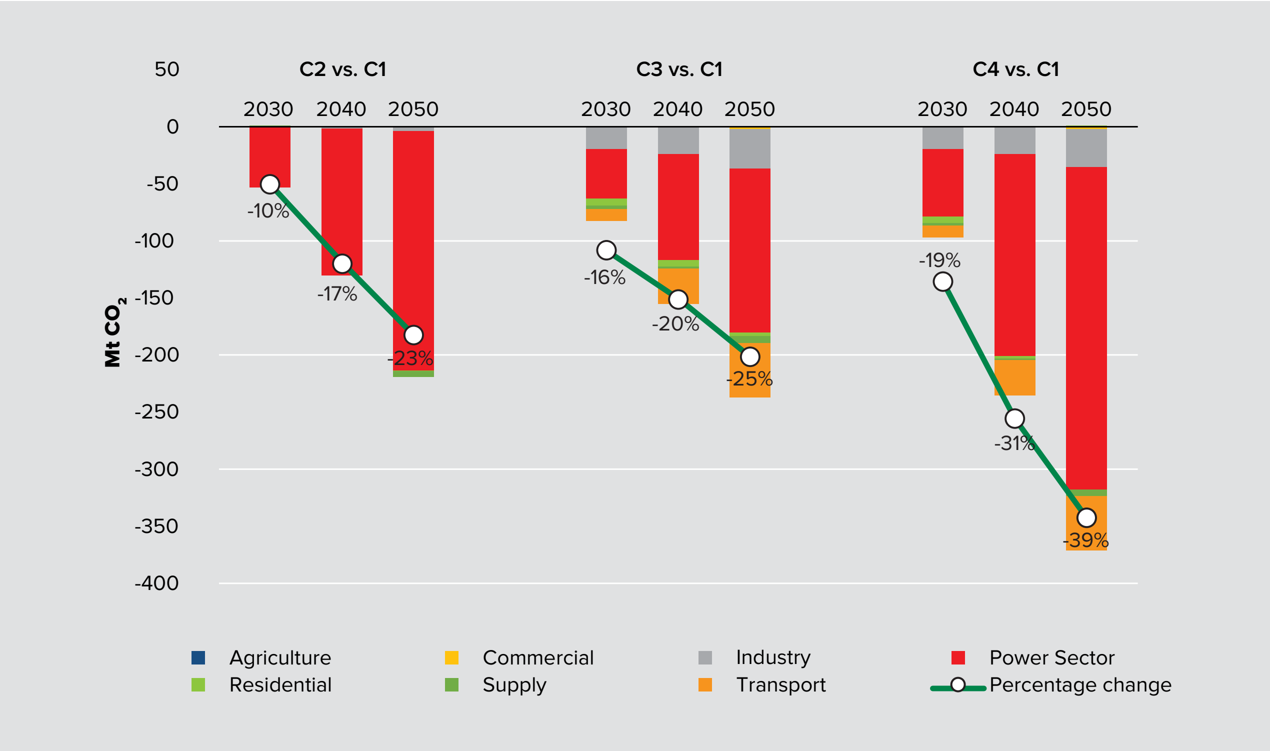


Figure 33: CO_2 emission reduction by sector in C2, C3 and *C4 scenarios* with respect to the *C1 RE target scenario*. C2 vs. C1 (left) - C3 vs. C1 (mid) - C4 vs. C1 (right)

When comparing the change in the total system cost across scenarios, the *C2 No new coal scenario* is the only scenario that results in a cost increase, compared to the *C1 RE target scenario*. Both the *C3 Energy efficiency scenario* and the *C4 Combination scenario* have lower system costs compared to *C1*, because of the economic benefits from EE. At the same time, these scenarios also achieve CO_2 reductions, which indicates the possibility of simultaneous cost and CO_2 savings. In 2030, the system costs in *C3* and *C4* are the same, while the CO_2 savings in *C4* are 17% higher than in *C3*. In 2050, the cost savings in *C3* are higher than *C4*, while the CO_2 savings in *C4* exceed those in *C3* by 133 Mt. This demonstrates that the most cost-effective reduction of CO_2 emissions requires a combination of supply side and demand side interventions.

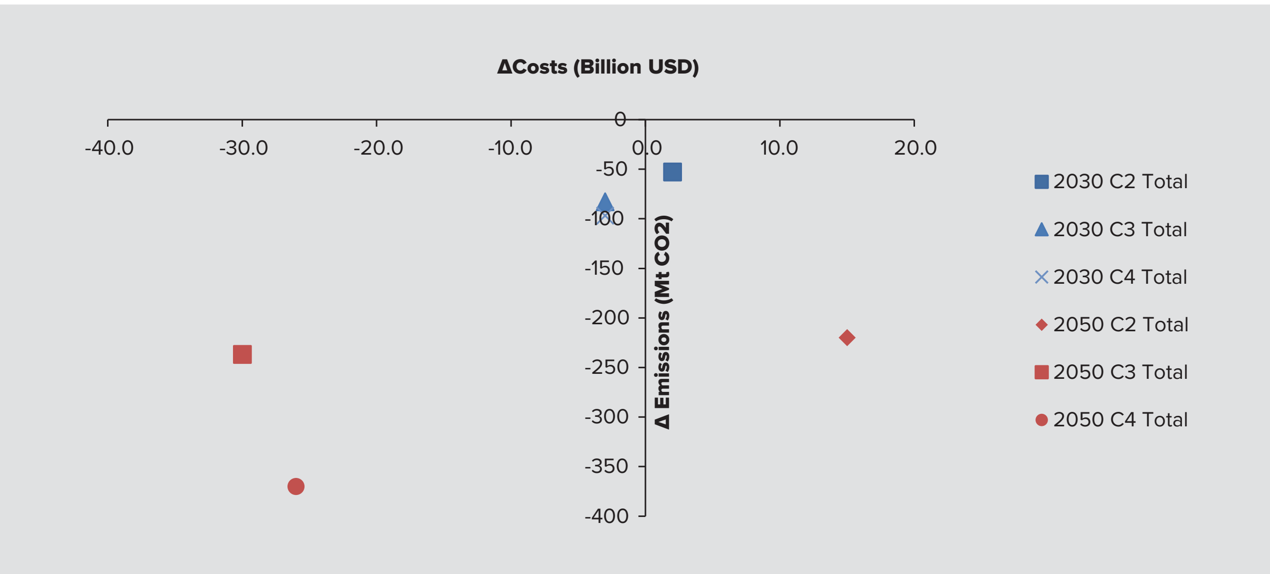


Figure 34: Change in total system costs (horizontal axis) and total CO2 emissions (vertical axis) compared to *C1 RE Target scenario.*

In the draft updated NDC-BAU scenario by MONRE (GIZ, 2018b), the total GHG emission from the energy sector equals 643 $MtCO_2eq$ in 2030. The NDC-BAU is the baseline to which the unconditional and conditional NDC's are compared. The CO_2 emission reduction in the energy sector in *C1 RE target scenario* reaches 19% in 2030, compared[39] to the NDC-BAU scenario (the national *unconditional* NDC target is 8% reduction in 2030), see Table 10. The remaining scenarios (*C2*, *C3* and *C4*) all have well higher reduction than 25% (the national *conditional* NDC-target is of 25%), with the reduction of 27%, 32% and 34%, respectively.

Table 10: CO_2 emissions across the scenarios in comparison with NDC-BAU and mitigation scenarios

Scenario	Emissions in 2030 (Mt)	Reduction compared to NDC-BAU (Mt)	Percentage reduction compared to NDC-BAU (%)
C1-RE target	520	123	19%
C2-No new coal	468	175	27%
C3-EE	438	205	32%
C4-Combination	424	219	34%
NDC-BAU	643	0	0%
NDC-Unconditional 8%	592	51	8%
NDC-Conditional 25%	482	161	25%

What is the impact of the future energy system on air pollution and health?

In addition to the climate impacts of GHG emissions, the combustion of fossil fuels also causes local air pollution and damage to human health. The combustion of coal, gas and oil releases SO_2, NO_X and PM2.5 particles, which can cause illness and premature deaths. These negative health effects impose an economic loss to society and can be regarded as economic externalities. In the EOR19, the externalities are not part of the least-cost optimization but have been post-calculated[40], using fuel consumption values from the model output. The methodology for calculating externalities rests on simplifications, and values should only be interpreted as indicative numbers.

Figure 35 illustrates the cost of air pollution across all scenarios for the power sector only, excluding fuel consumption in industry, residential and commercial sectors. In 2030, all scenarios result in an estimated socio-economic cost of pollution in the range 7-9 billion USD/year, corresponding to approximately 2% of GDP. In the scenarios without coal limitations, the pollution costs increase towards 2050 due to an expansion of coal power and because the economic loss to society per unit emission increases when GDP per capita is growing. In the scenarios with coal limitations (*C2 No new coal* and *C4 Combination scenarios*), the pollution costs are low compared to *C1 RE target scenario*, especially after 2030 because less coal is being consumed.

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39 The EOR19 compares CO_2eq reduction targets with pure CO_2 emissions reductions, which is a simplification. Since the contribution from non-CO_2 GHG is considered small relative to CO_2, it is assumed not to have any important influence on the final conclusions.

40 The methodology for estimating the externalities is based on the IMF publication *Getting Energy Prices Right: From Principle to Practice* (IMF, 2014). Here, the Vietnamese externality costs are estimated as follows: for natural gas 2027 USD/t (NO_X), 3274 USD/t (SO_2) and 3988 USD/t (PM2.5) and for coal 4060 USD/t (NO_X), 5823 USD/t (SO_2) and 7243 USD/t (PM2.5) (all prices are 2010 values). These costs are based on the value of statistical life/mortality risk (denoted V) which is assumed to vary across economies following the relationship $V_1 = V_2 \cdot (I_1/I_2)^{0.8}$, where I denotes the GDP pr. capita at PPP in two different economies 1 and 2. The formula is also used to extrapolate externality cost from 2010 to 2020, 2030, 2040 and 2050 by using future GDP (PPP) growth from *The Long View: How will the global economic order change by 2050?* (PWC, 2017) and population forecast towards 2050 according to the GSO's population projections and GDP according to the revised PDP7. Specific geographical population density variations for Vietnam have not been taken into account.

Assuming no increase in the level of flue gas cleaning, in the *C1 RE target scenario,* the cost of air pollution from the power sector reaches 23 billion USD/year in 2050 (2.2% of GDP). Coal is by far the most polluting fuel and releases a considerably larger amount of polluting particles than natural gas. Even though natural gas constitutes 15% of total energy consumption from thermal power plants in 2050 (*C1 RE target scenario*), gas only accounts for 0.4% of total externality costs of the power sector.

In the medium term (2030), the limitation on coal power and increased EE implementation has the largest impact on reducing pollution costs. In the longer term (2040 and 2050), the limitation on coal power is the single most important measure to reduce pollution. In the *C2 No new coal scenario*, the consumption of LNG, which is less polluting, substitutes coal to some extent. This reduces the cost of pollution from the power sector by 15 billion USD/year in 2050, compared to the *C1 RE target scenario*. If full EE implementation is added, cost savings increase to 16 billion USD/year.

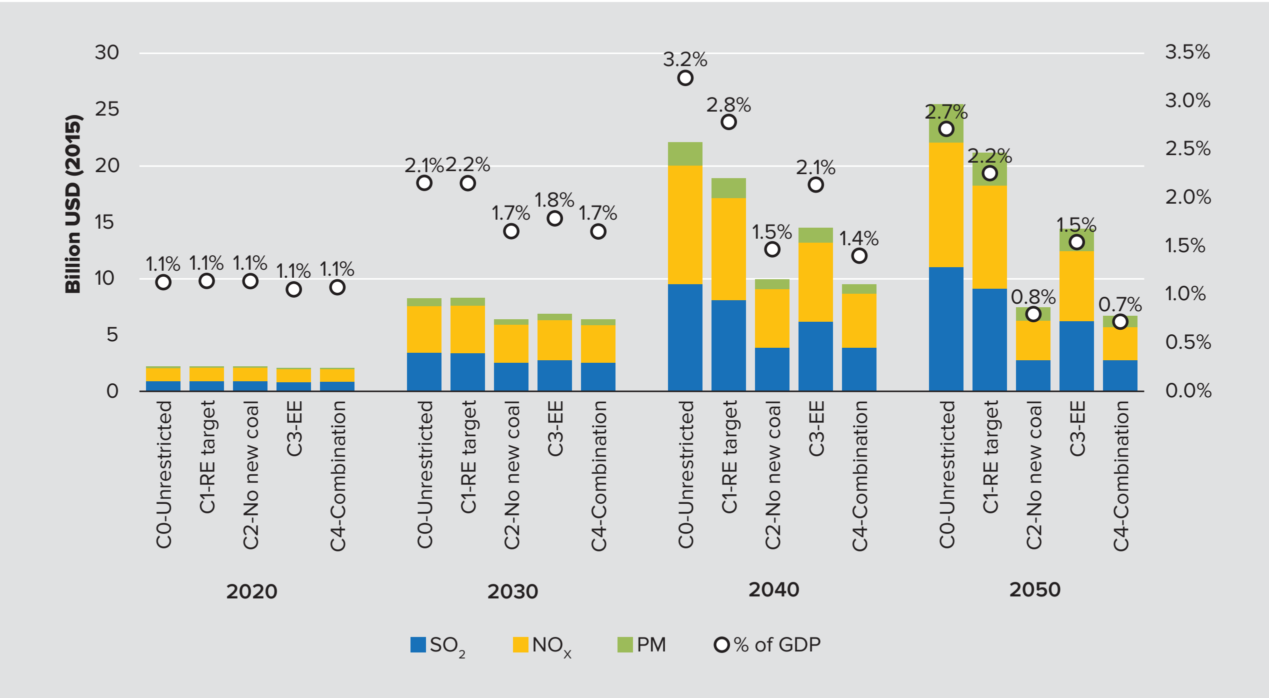

Figure 35: Cost of pollution by type in all five scenarios for power sector only

Externality costs are often not considered in economic evaluations of future energy planning. The above numbers show that the society could save 15 billion USD/year in 2050 in pollution costs if no new coal power plants are built after 2025. This number should be compared to the increased power system costs related to substitution of coal towards natural gas and other power sources, which is estimated to be app. 5 billion USD/year (Table 3). In summary, this indicates that the improved health effects from limiting coal consumption largely outweigh the increased cost from alternative power production, pointing to the fact that coal power is not the cheapest technology if health effects are taken into account. As mentioned, externality costs are not part of the least-cost modelling, and inclusion of externality cost would have made coal power less attractive across all scenarios.

8.3 Policy Outlook and Recommendations

To date, 185 countries - including Vietnam - have ratified the Paris Agreement, which seeks to limit the global temperature increase to 1.5 degrees compared to pre-industrial levels. On a global scale, the successful implementation of the Paris Agreement depends crucially on large CO_2 emission reductions in emerging economies like Vietnam. Locally, air pollution especially from coal is growing, which both imposes large costs on the society and spurs public resistance towards coal power plants. Both CO_2 emissions and other pollutants are expected to grow quickly in the future, but the combined effect of EE, RE and limitation of coal use could reduce both climate impact and local air pollution.

> It is recommended to introduce incentives to reduce CO_2 emissions and other air pollutants including taxes, emission trading schemes, or other forms of market systems.

CO_2 emissions from the energy sector are increasing quickly at 7% p.a. in the period 2020-2030 and 4% p.a. in the whole period 2020-2050 in the *C1 RE target scenario.* To counteract this development, the combined effect of EE, RE and limitation on coal use could reduce CO_2 emissions by 39% in 2050.

This would require a system-wide transformation of the energy system with changes across the power and demand sectors. Possible policy measures targeting specific sectors have been highlighted in the preceding chapters, but general economic incentives to reduce CO_2 emissions should also be considered. As a measure across all sectors of the economy, the gradual introduction of incentives to reduce CO_2 emissions including e.g. taxes, emission trading schemes (ETS) targeting CO_2 or other forms of markets systems, would support RE investments and promote a phase-out of carbon-intensive fossil generation plants.

> Harmonization of all government RE targets and emission targets for future planning.

Energy sector regulation is complex and implies a large array of system interdependencies ranging over several ministries. It is important to consider the harmonization and alignment of policies across sectors to ensure an efficient effort in emission reduction. This includes a continuous comparison of RE targets, energy system efficiency, and emission targets. Specifically, this would entail that the upcoming PDP8 and Energy Master Plan should be aligned with government targets on GHG emissions, e.g. in the NDC or in line with the Paris agreement.

> It is recommended to tighten air pollution control measures in power generation and industry and to include health costs of pollution in energy system modelling and planning, including PDP8.

Coal use is on the rise and contributes from 65% to 75% of total CO_2 emissions from the whole energy system in different scenarios and across years in the EOR19. At the same time, awareness of the negative health effects from local pollution has led to public resistance[41] towards further expansion of coal power plants. It is important that energy planners take such signals into account.

The health costs associated with local air pollution from fossil fuels are large, and negative health effects need to be addressed. This can be done by tightening air pollution control measures in both central and decentral installations (power generation and industry) and by an early stop for construction of new coal power plants, which would greatly reduce the use of fossil fuels.

Further, it is recommended to use a wider approach to economic evaluation of energy planning, where not only capital and operational costs are included, but also health cost caused by air pollution. Inclusion of such measures, e.g. in the PDP8, would highlight the real cost of energy, which is especially relevant for coal power.

> It is recommended to adjust the 2030 CO2 target to be more aligned with restrictions on coal, realization of cost-efficient EE measures and expansion of RE technologies.

Solely by meeting the power sector RE targets of the REDS, CO_2 emissions in the energy sector will be reduced by 19% in 2030 compared to the NDC-BAU scenario (the national unconditional NDC target is 8%). When no further adding of new coal fired power plants after 2025 and a 50% penetration of cost-effective EE technologies (*C4 Combination scenario*), total CO_2 emission reductions will be more

[41] E.g. see (MekongEye, 2019).

than 30% in 2030 (the national conditional NDC target is 25%). This shows the large potential for enhancing the CO_2 targets, which can also bring direct advantages on reduced fuel import dependence, less air pollution, and even lower total energy system costs.

Furthermore, pursuing ambitious CO_2 mitigation policies could also have wide cross-sectoral co-benefits. A report from the UNDP summing up the projected macro-economic effects of different GHG mitigation policies in Vietnam shows that both GDP growth and employment growth are positively correlated with enhanced mitigation (UNDP, 2018).

In a global perspective and in order to pursue the 1.5-degree target set out in the Paris Agreement, global emissions must reach net zero around 2050. This requires a huge effort form all countries, including emerging economies like Vietnam. The development pathways outlined in the EOR19, all show a trend of increasing CO_2 emissions towards 2050. A first step to reverse this trend is to strengthen the CO_2 target in the next round of NDC submission, which is due in 2020. Further studies and continued updates of energy models, technology and consumption data should guide Vietnam in this process of continuing its sustainable transition and delivering its contribution in achieving the long-term global climate targets.

Annex: Modelling framework and key assumptions

A.1. Energy modelling framework and key assumptions

This Annex provides further background on the modelling framework adopted for the EOR19, with an overview of the model characteristics, scope and interlinkages. Moreover, the key assumptions for the modelling are herein described, while the reader is invited to refer to the EOR background reports[42] for more comprehensive information on data inputs, methodology and detailed results on the complete set of analysed scenarios. Collection, harmonization and documentation of input data to Balmorel and TIMES models has been a key focus in the development of the EOR19. A Vietnamese technology catalogue was developed (EREA & DEA, 2019f) as well as a Vietnamese fuel price projection report (EREA & DEA, 2019e). A detailed overview of input data can be found in the data reports (EREA & DEA, 2019b) and (EREA & DEA, 2019c) for Balmorel and TIMES respectively.

Energy system modelling constitutes the basis for the conclusions and recommendations detailed in this report. Five alternative core scenarios are designed to explore different futures for the Vietnamese energy system. As such, the scenarios are not intended as the "recommended" energy system pathways, but rather meant as indicative "what-if" scenarios from which insights have been drawn on the relevant themes for the Vietnamese context. The five scenarios illustrate different development pathways for the Vietnamese energy system:

- ***C0 Unrestricted:*** This theoretical scenario simulates a future with no achievement of RE targets, or restrictions on coal-fired generation and without penetration of energy efficient demand technologies.
- ***C1 RE target:*** This scenario includes the RE target for the power sector, as set out in the current REDS and without penetration of energy efficient demand technologies.
- ***C2 No new coal:*** Additional to the *C1 RE target scenario*, this scenario implements a restriction limiting investments in new coal power plants starting from 2025, albeit domestic coal capacities are allowed to be maintained.
- ***C3 Energy efficiency:*** Additional to the *C1 RE target scenario*, this scenario allows for investments in energy efficient technologies, with a 50% penetration rate of energy efficient demand technologies being a part of the least-cost solution in 2030 and 100% in 2050[43].
- ***C4 Combination:*** This scenario combines the three previous scenarios, i.e. the REDS target, the coal restriction from 2025 and the high uptake of energy efficient technologies.

The scenarios presented in this report have been computed in the interlinked set-up comprising three energy models (Figure 36), in order of aggregation and coverage of the system:

- The TIMES model (Section A.2), covering the whole energy system of Vietnam, including both supply and demand side;
- The Balmorel model (Section A.3), covering a detailed representation of the power sector of Vietnam;
- The PSS/E model (Section A.4), representing the detailed power transmission grid of Vietnam.

[42] These include the Technical Report (EREA & DEA, 2019a), the Balmorel Data Report (EREA & DEA, 2019b), the TIMES Data Report (EREA & DEA, 2019c), the Fuel Price Projection Report (EREA & DEA, 2019e), the Technology Catalogue (EREA & DEA, 2019f), and PSS/E report: Detailed grid modelling of the Vietnamese power system (EREA & DEA, 2019d).

[43] For the transport sector, the mentioned penetration rates are not implemented; instead, the measures included in the C3 Energy Efficiency scenario are based on input from Ministry of Transport (more information in the Annex).

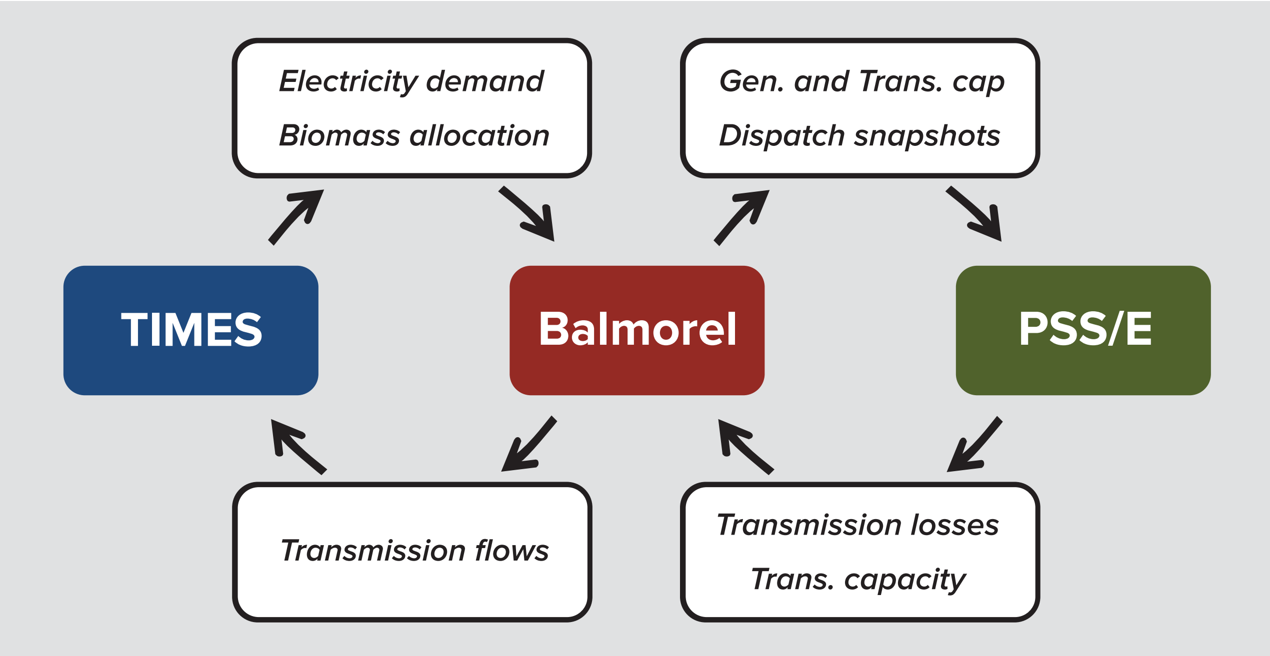

Figure 36. Energy modelling framework for the EOR19

Both TIMES and Balmorel perform a least-cost optimization under defined assumptions and constraints. Interlinking these two models improves the quality and reliability of model results, by harnessing the different model strengths, sectoral coverage, and temporal and geographical resolution. Moreover, the interaction between Balmorel and PSS/E ensures improved quality of the representation of the transmission grid in Balmorel, thus providing quality assurance of the scenario results.

The results reported in the EOR19 (i.e. plant capacity, energy consumption, RE shares, system costs and CO_2 emissions) are computed from the TIMES and Balmorel models: results for the demand sectors are derived from TIMES, while power-specific results are computed from Balmorel. Therefore, the results referring to the whole energy system are extracted and harmonized across the two models.

A.2. TIMES – Energy system model

The TIMES (The Integrated MARKAL-EFOM System) framework is a widely used least-cost optimization methodology employed to inform energy policy and strategic planning. It was developed and is maintained, advanced and promoted by the IEA-ETSAP consortium, the longest running Implementing Agreement of the IEA (International Energy Agency). Currently, 19 countries, the EU, and two private sector sponsors are participating to ensure the continual advancement of the methodology. TIMES documentation can be found at iea-etsap.org.

TIMES is a multi-sectoral optimization model generator, herein applied to study long-term energy planning for Vietnam. The TIMES-Vietnam model has been developed under the World Bank funded project “Getting Vietnam on a Low-Carbon Energy Path to Achieve NDC Target” (DWG, 2018), and it has been further adapted to support the scenario analysis of the EOR19.

The TIMES-Vietnam model covers all parts of the energy system, from primary energy resources to power plants and other fuel processing plants, ultimately to various demand devices in all five demand sectors.

Primary energy, in the form of domestic and imported fossil fuels, and a variety of domestic renewable energy sources are available to meet the energy demands of the country. Power plants and fuel processing plants convert the primary energy sources into final energy carriers, such as electricity, oil products, and natural gas, which are used in the demand sectors. There are both existing and potential future plants grouped by fuel and type, which are characterized by their existing capacity or investment cost, operating costs, efficiency, and other performance parameters. The final energy carriers are consumed in demand-specific end-use devices that are used to satisfy the demands for energy services in that sector.

The model contains five demand sectors: Agriculture, Commercial, Industry, Residential and Transportation. Each demand sector is characterized by a specific set of end-use devices that deliver end-use services (such as lighting, cooling, cooking, industrial process heat, motor drive, passenger and freight travel). These existing and potential new end-use devices are characterized by their existing capacity or investment cost, operating costs, efficiency and other performance parameters. Transport demands include road passenger, road freight, railway passenger, railway freight, airway passenger, airway freight and waterway freight. Transport demands are provided by different transport devices; their capacities and activities are exogenous in the current TIMES-Vietnam model and derived from the Ministry of Transport for different scenarios. These devices are characterized with investment and operating costs which allow the model calculate costs for the transport sector. The demands for energy services are determined by projecting the base year energy demands, which are derived from the energy balance 2014 (IE, 2017) as part of the calibration process, in accordance with sector-specific drivers, such as GDP growth, GDP per capita growth, industrial production projections, and space cooling growth expectations.

Power sector

In the power sector, primary energy sources are consumed by various power generation technology types to produce grid electricity, which primarily goes to the demand sectors. Imports and exports to/from neighbouring countries are also modelled. The power sector is organized into existing power plants, as specified in the Energy Balance and EVN data, and new power plant options that are available to meet future needs.

Several types of power plant technologies are modelled, including four types of hydro plants – extra-large, large, medium and small; several types of coal, natural gas, diesel and biomass-fired power plants, along with central PV and distributed rooftop PV systems for both residential and commercial buildings, and six types of wind power plants based on wind class and distance from transmission grid. The three modelled regions (i.e. North, Central and South) are interlinked by transmission lines in TIMES-Vietnam. There are two bi-directional links for electricity transmission between regions: (i) North to Central, (ii) Central to North, (iii) Central to South and (iv) South to Central.

Technical and economic data for the power generation technologies are based on (EREA & DEA, 2019f) as well as some other Vietnamese and international sources. The technology assumptions develop from 2020 to 2050, which means that the costs and efficiencies are assumed to develop depending on the learning curves of the specific technologies.

Demand sectors

Agriculture

The Agriculture and Fishing sector accounts for 3.3% of the base year final energy demand and consists of four end-use services. Diesel, gasoline and electricity are the key energy carriers supplied to the sector, and both biodiesel and bio gasoline can be made available to the sector as blended fuels with diesel and gasoline for possible use in the future. Data for the determination of the service demand shares and existing technology characteristics were primarily derived from *Calculator 2050 Vietnam*[44]. Agricultural demand devices are classified into existing (base year), standard and improved types, each characterized by different costs and efficiencies.

Industrial

The industrial sector accounts for 49% of the base year final energy demand, and is comprised of twelve industrial subsectors. The industrial sector cannot be modelled at the process level, due to the wide variations and detail in the industrial process lines and the lack of data resulting from concerns over proprietary information. Instead, each subsector is served by four main energy services: process heat, machine drive, facilities/other, and feedstocks needed to produce the output products.

The industrial sector is characterized by a wide range of fuel and energy types that can provide the four component energy services. Biomass fuels include bagasse, coffee husk, firewood, straw, and other organic residues. Biogas is also available from several sources. Auto-generation and co-generation are both an existing and future option for different subsectors. As with the other demand sectors, biodiesel and bio gasoline are available through mixing these fuels with conventional diesel and gasoline in the future. Industrial demand devices are classified into existing (base year), standard and improved types, each characterized by different costs and efficiencies.

[44] http://vietnamcalculator2050.atmt.gov.vn

Commercial

The commercial sector accounts for 2.8% of the base year final energy demand, and consists of eight service demands. TIMES-Vietnam contains a large suite of new technology options for each service demand that represent standard, improved, better, and advanced options, based on authors' desktop study of local appliances. There is a variety of energy carriers used in the sector, but electricity is by far the most dominant one. Biodiesel and bio gasoline are also available through mixing these fuels with conventional diesel and gasoline. Distributed PV systems provide electricity directly to the sector (for internal consumption) as well as feeding any excess electricity to the grid. Finally, building efficiency retrofit options are available to reduce building energy demands, primarily for cooling, lighting and water heating.

Residential

The residential sector accounts for 21% of the base year final energy demand and consists of seven end-use service demands. Although there is a variety of energy carriers used in this sector, electricity is by far most dominant, followed by important contributions from firewood and LPG. Owing to the inherent difference between urban and rural energy use patterns, as well as fuel and technology options, the residential sector is split into urban and rural subsectors. As for the commercial sector, distributed PV systems provide electricity directly to the sector (for internal consumption) as well as feeding any excess electricity to the grid. Finally, building efficiency retrofit options are available to reduce building energy demands, primarily for cooling and water heating. As for the other sectors, residential demand devices are classified into existing (base year), standard, improved and better types, each characterized by different costs and efficiencies.

Transport

As the Ministry of Transport is already assessing mitigation measures for transport (GIZ, 2018a), mode and fuel shares are exogenous inputs to TIMES-Vietnam, based on the scenarios developed through the EFFECT model at MOT. As a result, the transport sector in the TIMES-Vietnam model replicates the results from the EFFECT model, which includes several mitigation measures. This enables TIMES-Vietnam to reflect the integrated impacts of the transport sector's measures on the other portions of the overall energy system – specifically, their impacts on upstream supply requirements, electricity generation, and fuel competition between various sectors, as a simulation within the overall optimization.

Major demand drivers

The primary demand drivers include GDP growth, population growth, GDP per capita growth, and the number of persons per household. There are secondary drivers for each demand sector, such as the elasticity of energy use to GDP growth, industrial production projections, and market penetration rates for space cooling, refrigeration and electric appliances. Table 11 reports the main drivers used to project the future demand for energy services that must be met by TIMES-Vietnam in each period.

Table 11: Primary Demand Drivers

Demand Drivers	2014	2016	2020	2025	2030	2035	2040	2045	2050
GDP (US$ billion)	126.6	145.0	190.1	266.6	373.9	524.4	662.9	798.8	917.0
Population (million persons)	90.7	92.8	96.6	100.9	104.4	107.3	109.7	111.5	112.7
Number of persons per Household	3.80	3.76	3.69	3.60	3.51	3.42	3.34	3.25	3.17
GDP growth		7.00%	7.00%	7.00%	7.00%	7.00%	4.80%	3.80%	2.80%
Population growth		1.11%	1.03%	0.87%	0.69%	0.55%	0.44%	0.33%	0.22%

Source: GDP in revised PDP7 (IE, 2015) and population variables from GSO's population projections (GSO, 2016).

Resources

Resource potentials are modelled for each of the three regions with supply capability for every year. Supply potentials are based on several approved sectoral development plans. Supply capabilities are then extrapolated for the future years until 2050.

Domestic coal deposits are located in the North, crude oil fields are mainly located in the South with some fields abroad, and natural gas fields are mainly located in the South with one major future field in the Central region. Vietnam is also importing coal, oil products, and electricity from abroad. In future, LNG could be imported for power generation and other uses. In addition, Vietnam is exporting coal, crude oil, oil products, and electricity to other countries. Import fuel prices are reported in the EOR background report (EREA & DEA, 2019e). Electricity import prices and amounts are referred from (EA, 2019).

Hydropower is present in all three regions. Large hydropower (>30MW) almost reaches the maximum potential by 2020. Maximum capacity potential for small hydro is 4.088 GW in the North, 2.316 GW in the Central, and 0.35 GW in the South. Biomass types modelled in TIMES-Vietnam include wood, bagasse, rice husk, straw and others (IE, 2016). Biomass potentials by type and per region are taken from (IE, 2016), while biomass prices are referred from (EREA & DEA, 2019e).

Table 12: Import and export fuel prices

Supply source	Fuel	Fuel prices (USD 2015/GJ)		
	Year	**2020**	**2030**	**2050**
Import	Coal	3.61	3.74	3.90
	Crude Oil	10.20	11.50	10.40
	LPG	33.32	34.32	30.74
	Gasoline	23.27	28.54	39.03
	Jet Fuel	17.71	23.72	33.54
	Kerosene	17.71	23.72	33.54
	Diesel	23.38	29.68	40.07
	Fuel Oil	11.22	17.06	19.91
	Natural Gas	10.48	11.82	11.91
Export	Coal	3.25	3.63	4.30
	Crude Oil	9.69	10.93	9.88
	Gasoline	22.11	27.11	37.08
	Jet Fuel	16.83	22.53	31.86
	Diesel	22.21	28.20	38.07
	Fuel Oil	10.66	16.21	18.91

Table 13: Electricity import prices and bounds

Region	Fuel price (USD 2015/GJ)			Supply potential (PJ)		
	2020	**2030**	**2050**	**2020**	**2030**	**2050**
China - North	18.6	19.4	21.1	8.8	37.8	37.8
Laos-Central-North	18.7	19.6	21.3	0.0	16.4	16.4
Laos-Centre-Central	18.9	19.8	21.5	3.8	27.4	27.4
Laos-Central-Highland	19.1	20.0	21.7	7.0	24.6	24.6

Table 14: Biomass and waste potentials and prices

Region	Supply source/ Fuel	Fuel price (USD 2015/GJ)			Supply potential (PJ)		
		2020	2030	2050	2020	2030	2050
North	Rice Husk	1.9	2.3	2.3	25.3	25.6	30.7
	Municipal Waste	0.0	0.0	0.0	21.2	16.0	29.7
	Landfill Gas	0.3	0.3	0.3	0.0	0.7	3.9
	Primary Solid Biofuels	1.9	2.4	2.4	118.1	144.1	172.9
	Bagasse	0.2	0.2	0.2	5.6	6.1	9.2
	Biogasoline	24.6	27.4	35.8	4.5	15.5	52.7
	Straw	0.6	0.7	0.7	83.3	84.4	101.3
	Biodiesel	24.7	28.5	36.0	13.7	46.7	157.5
	Biogas	0.6	0.7	0.7		4.7	23.4
	Other Biomass	0.4	0.5	0.5	100.6	100.6	120.8
Central	Rice Husk	1.9	2.3	2.3	19.2	19.4	23.3
	Municipal Waste	0.0	0.0	0.0	10.9	8.2	15.3
	Landfill Gas	0.3	0.3	0.3	0.0	0.4	2.0
	Primary Solid Biofuels	1.9	2.4	2.4	164.3	196.2	235.5
	Bagasse	0.2	0.2	0.2	21.7	23.6	28.3
	Biogasoline	31.2	34.8	45.3	4.5	15.5	52.7
	Straw	0.6	0.7	0.7	63.2	64.0	76.8
	Biodiesel	31.3	36.2	45.6	13.7	46.7	157.5
	Biogas	0.6	0.7	0.7		4.7	23.4
	Other Biomass	0.4	0.5	0.5	85.2	101.5	121.8
South	Rice Husk	1.7	2.0	2.0	55.0	55.7	66.9
	Municipal Waste	0.0	0.0	0.0	32.2	24.2	45.0
	Landfill Gas	0.3	0.3	0.3	0.0	1.1	5.9
	Primary Solid Biofuels	1.9	2.4	2.4	84.5	98.2	117.8
	Bagasse	0.2	0.2	0.2	24.2	26.4	31.6
	Biogasoline	31.2	34.8	45.3	4.5	15.5	52.7
	Straw	0.6	0.7	0.7	181.3	183.6	220.3
	Biodiesel	31.3	36.2	45.6	13.7	46.7	157.5
	Biogas	0.6	0.7	0.7		4.7	23.4
	Other biomass	0.4	0.5	0.5	62.9	73.9	88.6

A.3. Balmorel – Power system model

Balmorel is a detailed techno-economical partial equilibrium model suited for analyses of power systems. The model can perform both investment and dispatch optimisation, under a set of constraints. More information on Balmorel can be found on the Balmorel websites (Ea Energy Analyses, 2018) (Hans Ravn, 2016).

In the investment mode, Balmorel is able to simultaneously determine the optimal level of investments, refurbishment and decommissioning of electricity generation and storage technologies, as well as transmission capacity between predefined regions.

In dispatch optimisation mode, the model determines the optimal utilisation of available generation and transmission capacity. The level of detail for time and geography can be adjusted according to the scope of the analysis, spanning from aggregated temporal resolution to hourly modelling, as well as allowing for a high level of geographical and technical detail.

The mathematical principle behind the Balmorel model is based on least-cost optimization, i.e. finding a solution for the dispatch and investments in the electricity system at the lowest total power system costs. To do so, Balmorel takes into account, among others, the development of electricity demand for the considered time horizon, technical and economic characteristics of all production units, fuel prices, grid constraints, spatial and temporal availability of primary renewable energy (Figure 37).

The model allows the definition of policies in the form of constraints on the power system, including e.g. a target for renewable energy share or a reduction goal for GHG emissions in a milestone year.

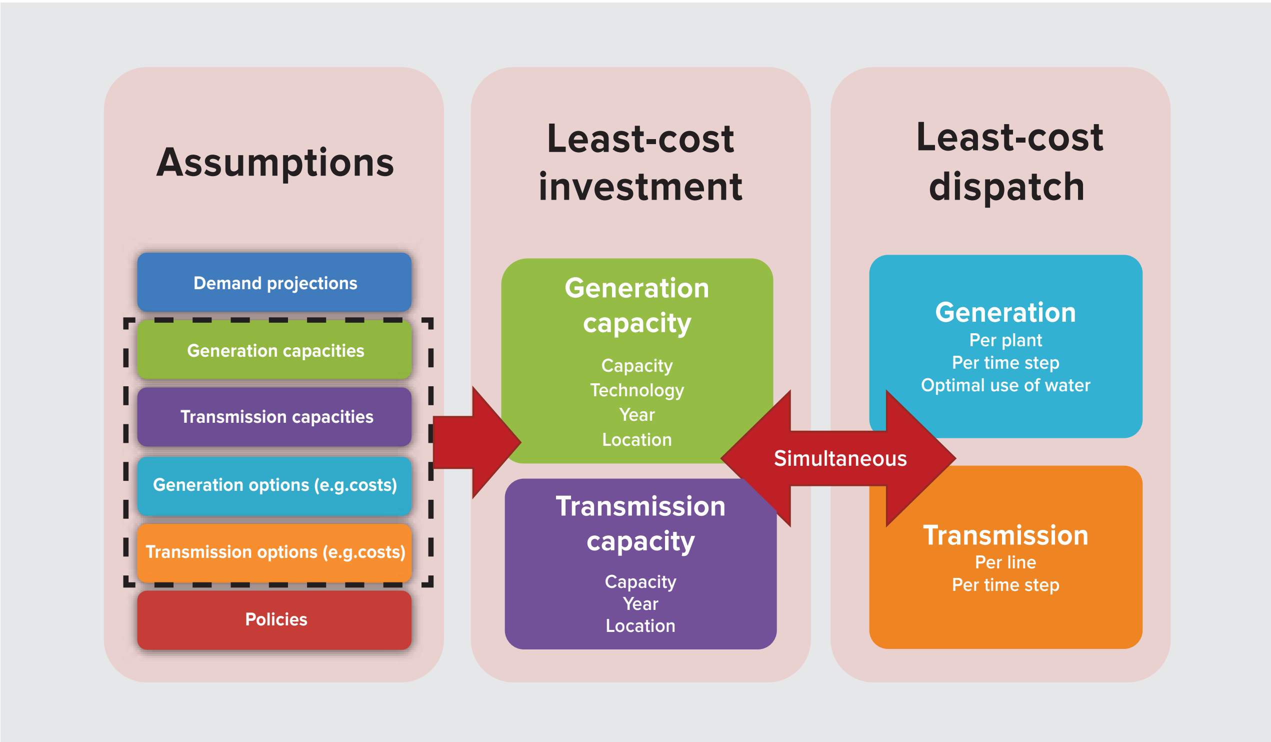

Figure 37: Concept of operation for the Balmorel model

The regional representation in Balmorel-Vietnam

Balmorel-Vietnam covers the power system of the whole country, including generation plants, storage technologies and transmission lines between regions. The power demand is concentrated in the Northern and Southern ends of the country. The Southern load accounts for nearly 50% of the total load demand, while 40% is located in the North and around 10% in the Central region. The revised PDP7 divides Vietnam's power system into three regions, i.e. North, Central and South, linked by a 500kV transmission system. This zoning is based on the self-balancing capacity between the demand for electricity and the power supply in each region, as well as considering the transmission capacity.

In the EOR19, the regional representation of the power system accounts for 6 power regions (Figure 38), as to ensure a robust analysis of existing and future congestion occurrences in the inter-regional transmission system. The regional representation of the power system is therefore aimed at determining the optimal capacity of the transmission lines. The division of the power system into 6 power regions, i.e. North, North Central, Centre Central, Highlands, South Central and South, is therefore based on the following considerations:

1. Scale of the power generation in the power region and length of the transmission interconnectors to neighbouring regions.
2. Role of the transmission interconnectors for the reliability of the supply-demand balance in the power region.
3. Occurrence of congestion episodes on the transmission link to other power regions.
4. Characteristics of the generation plants within the power region and the resulting power load curve.

With reference to the points above, the distribution of the renewable energy potential in Vietnam is uneven and concentrated in the Southern part of the country, mainly in the South Central, Central Highlands and South West regions, where the transmission distance to the main load centre is above 200km. Moreover, as the potential for domestic coal would not be sufficient to supply the coal-fired generation in the future, the Central region could constitute a convenient entrance point for imported coal, both for coal receiving terminals and coal-fired power plants based on imported coal. At the same time, the Central region has a low power load and a long-distance transmission interconnector. Finally, the major natural gas fields in the South of Vietnam could be soon fully exploited; thus, the optimal location for future LNG terminals should be assessed with consideration of the distance from future generation plants to load centres.

Transmission lines are represented by the total capacity available between the six power transmission regions. The available capacity is set as the net transfer capacity, based on results from the PSS/E model. The transmission losses were also calculated for the seven lines, and calculated at a transmission line load of 80% for each line. In addition to the transmission capacity for 2020 (Figure 38), Balmorel can further invest in transmission capacity, if this constitutes a least-cost solution.

The soft-linking with PSS/E grid model also resulted in feedback on the location of power plants seen from a transmission grid perspective rather than a geographical perspective. Following from the model linking with PSS/E for the year 2020, several power plants were re-allocated to the six transmission regions based on this feedback.

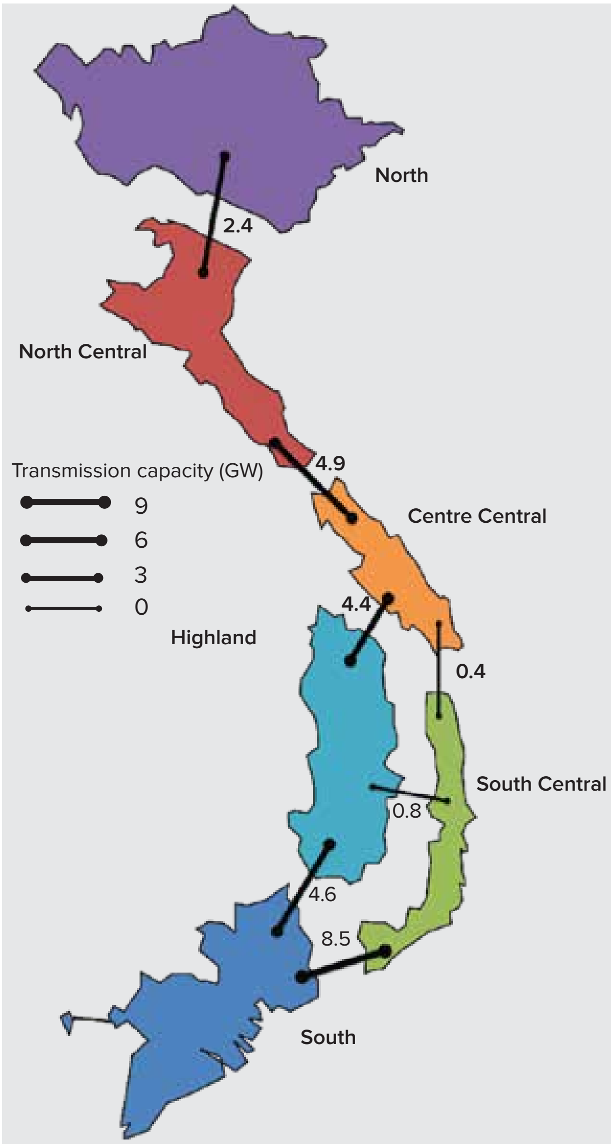

Figure 38: Existing and committed interconnectors in Vietnam, total capacity (GW) in 2020.

The generation investment module

The Balmorel-Vietnam model contains a technology catalogue describing the complete set of new power generation technologies available for future investments, based on the Vietnamese Technology Catalogue (EREA & DEA, 2019f). The technology assumptions develop from now to 2050, i.e. costs and technical characteristics develop according to technology-specific learning curves. The investment module allows to invest in a range of different technologies including coal power, gas power (combined cycle plants), biomass-based power plants, wind power (both onshore and offshore), solar PV and storage options, such as batteries and pumped hydro projects.

The electricity demand

The electricity demand is the main output from the TIMES model and used in Balmorel as input for different scenarios, by soft-linking the two tools. The power demand determined by TIMES includes transmission losses (assumed 2.5%), which are subtracted when inputted into Balmorel, as the latter model's transmission losses per flow on the transmission lines. Starting from the more aggregated demand from TIMES, the division of the national demand over the 6 transmission regions is based on projections from PDP7.

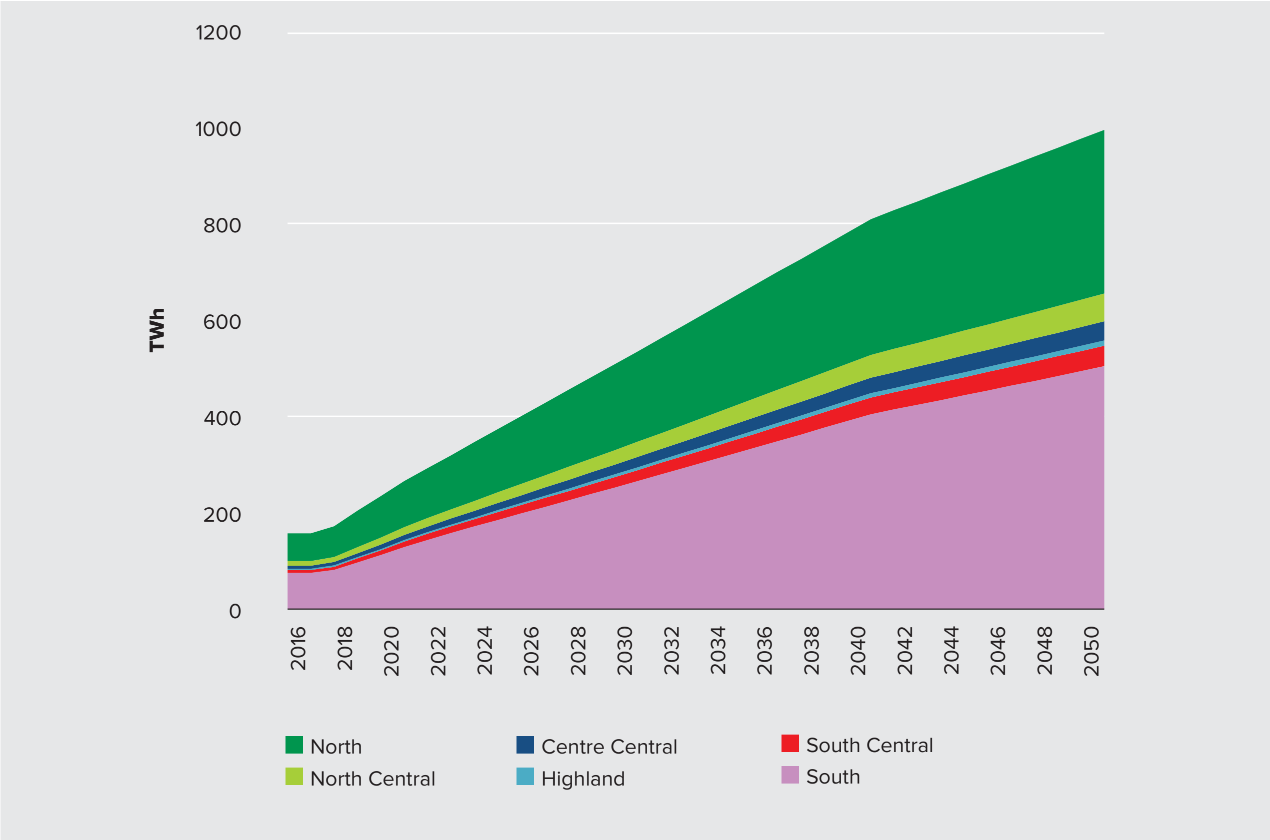

Figure 39: Annual electricity demand per transmission region for the *C1 RE Target scenario*

Future fuel prices

The electricity demand is growing quickly, and a few years ago Vietnam went from being a net exporter of fuel to a net importer. The country is therefore directly exposed to international fuel prices, and projections of future prices are an important input to the least-cost analyses of the Vietnamese energy system. A study on fuel prices and the methodology for projection has been undertaken as part of the EOR19; the results of which are detailed in a separate report (EREA & DEA, 2019e).

Energy potentials for power generation

Further details on the data sources and assumptions for energy potentials can be found in the Technical Report (EREA & DEA, 2019a) and Balmorel Data Report (EREA & DEA, 2019b).

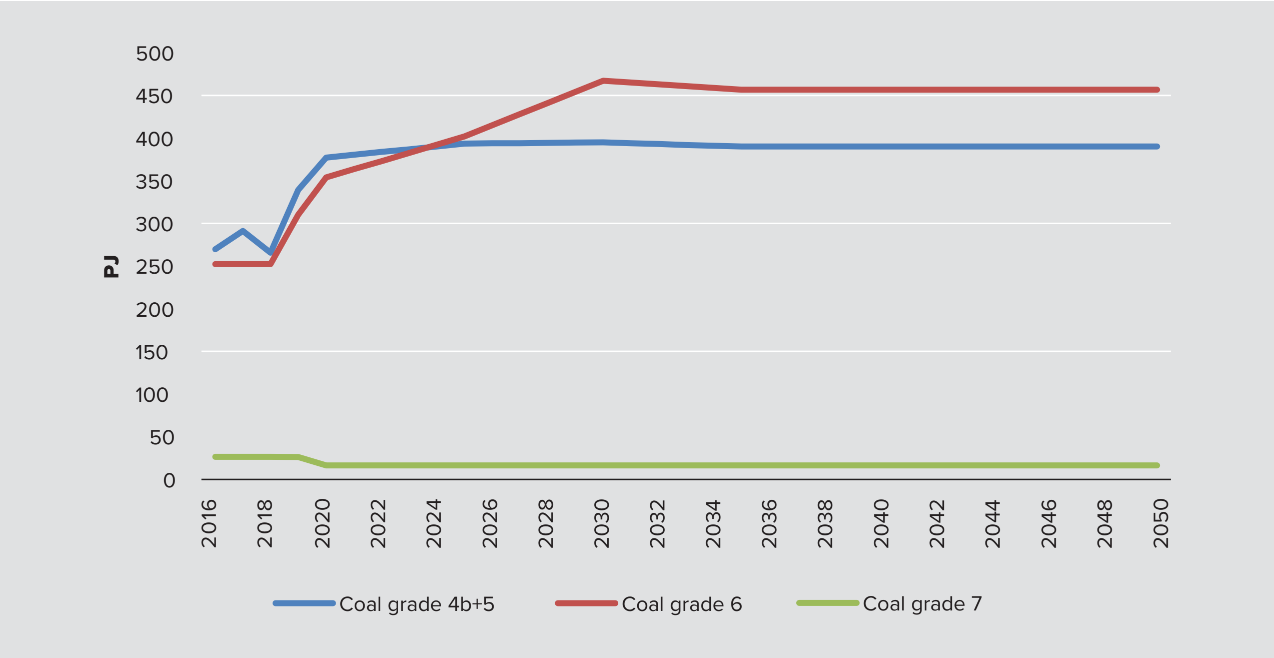

Figure 40: Maximum domestic coal use (PJ)

Figure 41: Maximum domestic natural gas use in the South (East and West NG, PJ)

Restrictions on biomass-fired power generation capacity have been implemented based on an estimate of biomass resources that could be realistically used for power generation applications[45].

In addition to the capacity constraints, the energy potential for bagasse, (all other) biomass and MSW are implemented based on the results from TIMES (Figure 42).

[45] Prime Minister Decision No. 2068/2015/QD-TTg.

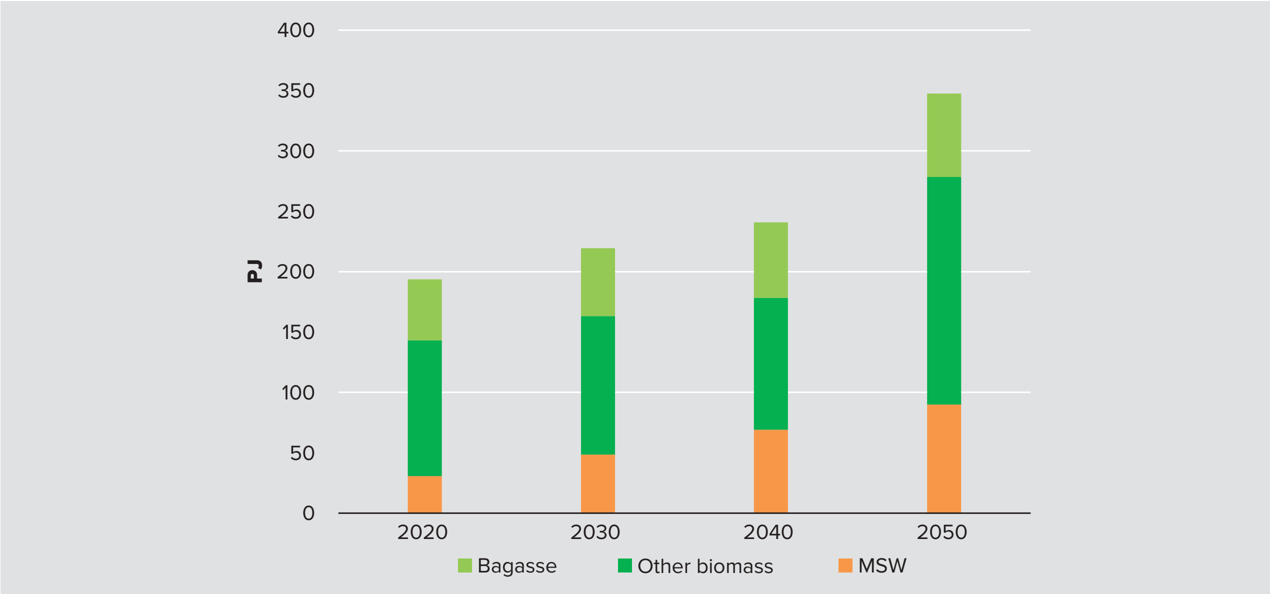

Figure 42: Resource limits on biomass and MSW fuel use implemented in the Balmorel model (PJ) for the *C1 RE target scenario* – based on TIMES results

As Vietnam displays potential for offshore wind power, the offshore wind areas close to Ninh Thuan (South Central region) have been considered in the modelling and included as 6 areas, each with a potential of 1000 MW and an individual wind speed profile based on (Van Quang Doan et. Al, 2019). Other areas for offshore wind, in addition to the Ninh Thuan region, could be further investigated in future studies. The potential for onshore wind power, by region and wind speed, is reported in Figure 43.

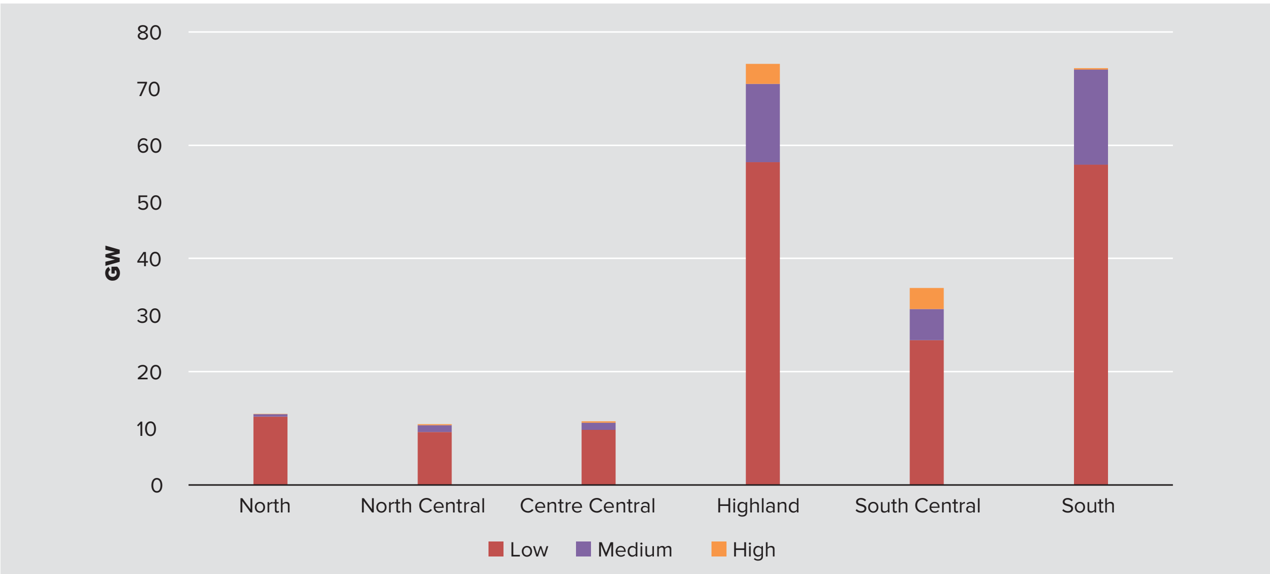

Figure 43: Resource limits for onshore wind generation capacity per region and wind speed class implemented in the Balmorel model. Low: 4.5-5.5 m/s; Medium: 5.5-6 m/s; High: over 6 m/s. All turbines are at 80m height.

The Southern parts of Vietnam are endowed with attractive solar resources, e.g. with full-load hours above 1,600 hours. The solar potentials are based on the draft Vietnam Renewable Energy Development Plan (IE, 2018). A total potential of 380 GW divided in the six transmission regions is used (Figure 44). Using the full potential would occupy 1.6% of the total land area. For the Southern regions, this number is higher (3.4% for the South and 3.7% for the Highlands and South Central). In the Northern regions, less than 0.5% of land has potential for solar generation.

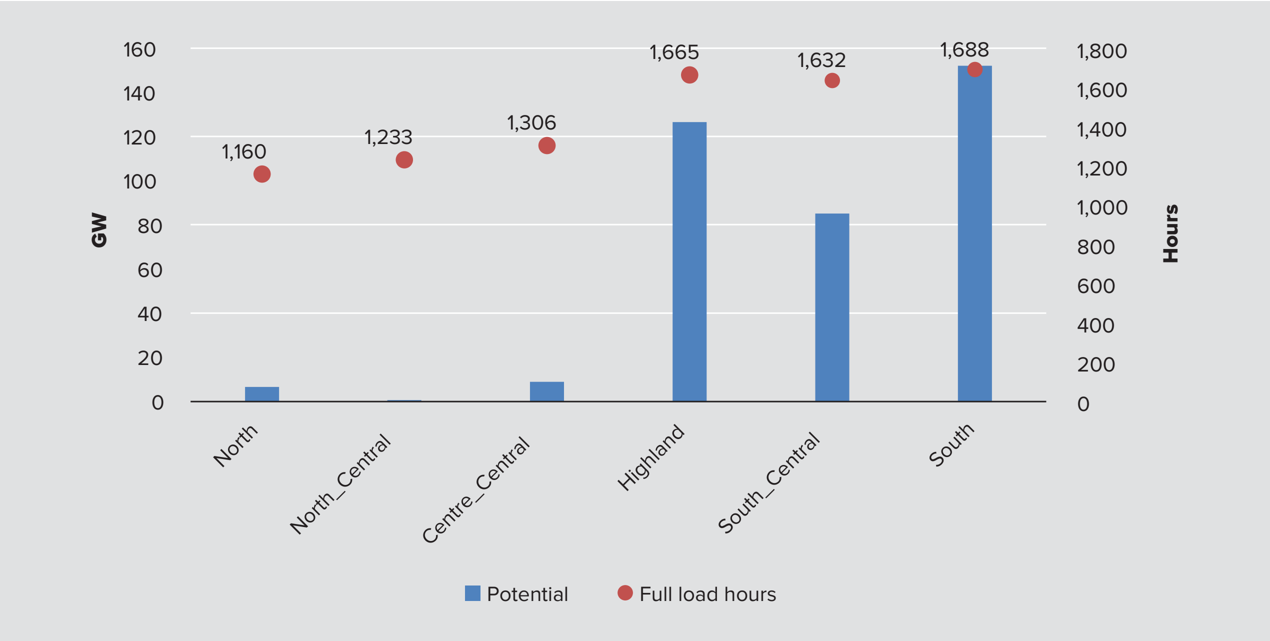

Figure 44: Solar potential and full load hours per region implemented in Balmorel

Vietnam has a quite high potential of pumped hydro storage with 8 investigated sites of total 8900 MW (EVN & JICA, 2004). The potential amounts to 4100 MW, 2400 MW and 2400 MW in the North, Central and the South respectively. Bac Ai PSPP in Ninh Thuan province is included in revised PDP7, with the capacity of 1200 MW and is expected to start operation in 2023 – 2025. This pumped hydro project is characterized by its combination with the downstream lake, the Tan My irrigation lake. This combined electricity-irrigation project will have a significant reduction in investment costs due to investment sharing with the agricultural sector. In the Balmorel model, Bac Ai PSPP has been included as an investment option. However, the plant is not found feasible in the core scenarios.

A.4. PSS/E – Transmission grid model

PSS/E Methodology

Power System Simulator for Engineering (PSS/E) is a power system simulation software herein used to analyze the power development and planning in Vietnam. The model includes several modules in order to assess the system: (i) power flow of grid in static state; (ii) optimal power flow; (iii) study of symmetric and asymmetrical incidents; and (iv) simulation of the process of electromechanical transition and stable analysis of the system.

In the EOR19, the output of the optimization model Balmorel is used as input to the grid modeling in PSS/E. Balmorel optimizes the hourly output power of each power plant in each region and the loading of the transmission lines. The most critical dispatch hours (e.g. highest residual demand or lowest wind and solar generation) are simulated in PSS/E to verify the grid operation (i.e. transmission lines capacity and load) modelled in Balmorel for the years 2020 and 2030.

The critical snapshots considered for the simulation of the load flow in PSS/E are the following:

Highest demand (HD): at 10:00-14:00 or 19:00-21:00 - to check the capability of transmission lines in the heaviest load condition.

Lowest demand (LD): the lowest load condition (usually the first days of the lunar year - New Year holidays), with high voltage in the transmission grid.

Highest residual demand (HRD): at 19:00-21:00, with high load and zero output power from solar PV - to check the possibility of supplying power from traditional power plants.

Lowest residual demand (LRD): maximum output from wind and solar PV power - to check the grid operation when dispatching of traditional sources is lowest.

Highest flow (HF) and Lowest flow (LF): condition with high generation from one region and transmission to other regions over a large transmission distance / minimum level of transmission between regions - to check the responsiveness of transmission grid in two states, including level of transmission losses.

Highest wind and solar (HWS) and Lowest wind and solar (LWS): highest and lowest wind and solar power in the South-Central region – to check the impact of large shares of wind and solar power on the transmission grid.

For each dispatch snapshot provided by Balmorel, PSS/E calculates the load levels and voltage requirements of the main elements of the system, such as transmission lines and substations. The simulation grid (both demand and supply nodes) is built on the basis of the grid represented in revised PDP7, with updates on the newest and approved transmission works. First, the check is performed for normal operation condition (N-0) and afterwards for the N-1 contingency cases. The results are compared to the Grid code standard (ERAV, 2016) to check the responsive level of the grid represented in Balmorel. For congested elements, especially interconnected transmission lines, the result can suggest alternatives, such as upgrades and expansions of the transmission capacity.

The output of PSS/E is therefore valuable for:

- Checking the feasibility of the proposed generation expansion scenario in Balmorel for grid operation according to the approved planning.
- Checking the load level of the transmission lines for some critical generation operation snapshots; and, providing recommendations for upgrading and expanding the interconnected transmission lines.
- Estimating the investment cost for the transmission grid to meet the proposed generation expansion plans.

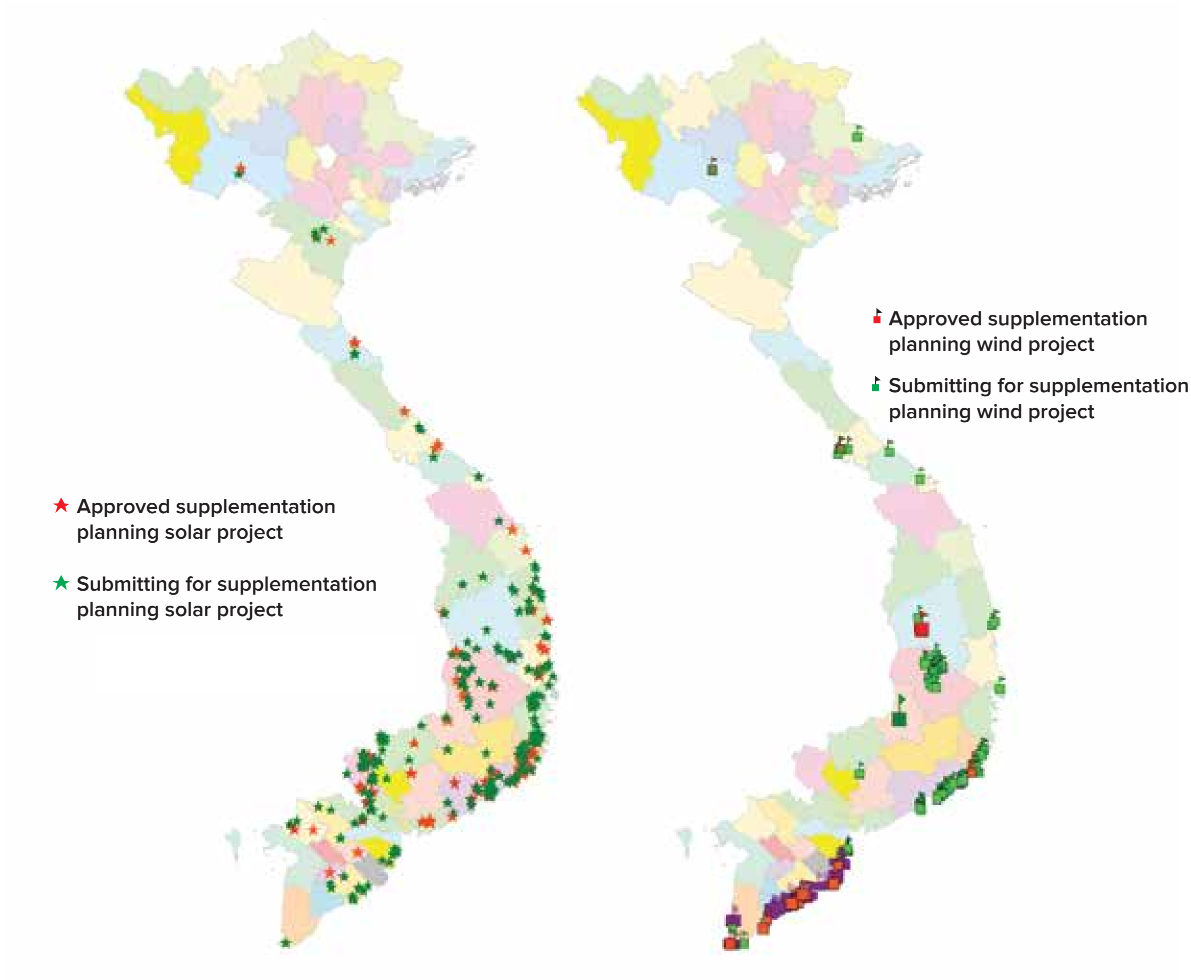

Figure 45: Location of solar PV and wind power plants (2020)

Results from PSS/E

Two power system development scenarios with large shares of RE generation are used to evaluate the grid operation in the Vietnamese power grid in 2030:

- *C1 RE target scenario:* annual RE share of 33% in 2030
- *RE 50% 2030 scenario:* annual RE share of 50% in 2030

Grid recommendations are made based on grid simulations in the PSS/E model, where the generation dispatch of four critical hours (HRD, HF, HWS and LWS) are assessed to test the viability of the generation and grid configuration found by the Balmorel least-cost optimization. For each of these snapshots, load levels and voltage requirements are tested and compared to the Vietnamese grid code (ERAV, 2016). Both normal N-0 operation conditions and N-1 contingency cases are considered.

For the *C1 RE target scenario,* some of the recommendations for safe grid operation include a new 500kV substation in the Highlands and 10 GW transmission capacity investments (three 500kV lines) to be able to transmit renewable power directly to the South-East region. In the internal grid, some additional substations are suggested to help with congestions (such as in Dien Bien, Huong Hoa, Bac Lieu, Hong Liem and Thuan Bac).

In the *RE 50% 2030 scenario,* the strong development of solar generation in the South region increases the needs for grid reinforcements. New solar generation in the Highland region is mostly transmitted to the demand centre in the North region. The grid analysis results indicate that it could be worthwhile to invest in a large HVDC transmission line directly from the Highlands to the North, due to the mountainous area between the two regions. Additional to the internal grid suggestions for the *C1 RE target scenario,* reinforcement of the grid around Hanoi would be needed.

Table 15 shows the recommended grid reinforcements based on the PSS/E analyses additional to the revised PDP7 transmission plan. It can be seen that the *RE 50% 2030 scenario* needs more reinforcements compared to the *C1 RE target scenario*. The table also shows the recommended total transmission capacity on the interfaces between the regions. These are higher than the Balmorel transmission capacities simulated, especially for the *RE 50% 2030 scenario*, where the HVDC line is included in the recommended expansions.

Table 15: Recommended grid reinforcements from PSS/E additional to the revised PDP7 grid expansion plan for 2020-2030 and total transmission capacity on interfaces recommended based on PSS/E compared to Balmorel.

		C1 RE target	RE 50pct
Transformers - 500 kV	*(MVA)*	36,600	38,400
Transmission lines - 500 kV	*(km)*	3,028	5,989
Transformers - 220 kV	*(MVA)*	17,750	24,000
Transmission lines - 220 kV	*(km)*	7,009	8,340
PSS/E transmission lines - interfaces	*(MW)*	29,373	34,360
Balmorel transmission lines - interfaces	*(MW)*	22,037	21,089

The costs related to the grid reinforcements based on the PSS/E analysis are shown in Table 16. The total grid-related costs are 14.5 and 17.6 billion USD in the *C1 RE target scenario* and *RE 50% 2030 scenario*, respectively. As Balmorel only includes the model-optimised transmission capacity on the interfaces, the costs found from the optimization are considerably lower. When including committed expansions to the calculation, about 10.6 to 14.3 billion USD are not included in the Balmorel model. Table 16 shows the total annualized system costs for the two scenarios. The costs not included add between 5% and 6% to the total power system costs, for the *C1 RE target scenario* and the *RE 50% 2030 scenario*. It should be noted that the comparison is not completely consistent, as only model-optimised capital cost for generation is included in the graphs, while both committed and model-optimised capital costs are included for the transmission grid. Figure 46 illustrates that additional power transmission investments represent around 5% of the total power system cost in 2030, according to the transmission grid assessment performed with the PSS/E model.

Table 16: Costs related to the grid expansion recommendations between 2020-2030 compared to costs included in the Balmorel model.

		C1 RE target	RE 50pct
PDP7R internal grid cost	*(Million USD)*	7,843	7,843
PDP7R interfaces cost	*(Million USD)*	1,729	1,729
Additional* internal grid cost	*(Million USD)*	2,875	3,512
Additional* interfaces cost	*(Million USD)*	2,081	4,553
Total internal grid cost	*(Million USD)*	10,718	11,355
Total interfaces cost	*(Million USD)*	3,810	6,282
Total costs	***(Million USD)***	**14,528**	**17,637**
Balmorel endogenous interfaces cost**	*(Million USD)*	3,352	3,291
Balmorel all interfaces cost	*(Million USD)*	3,880	3,819
Internal grid cost not in Balmorel	*(Million USD)*	10,718	11,355
Interfaces cost not in Balmorel	*(Million USD)*	-70	2,991
Total cost not in Balmorel	***(Million USD)***	**10,648**	**14,346**

Additional to PDP7R
*****Model-optimised***

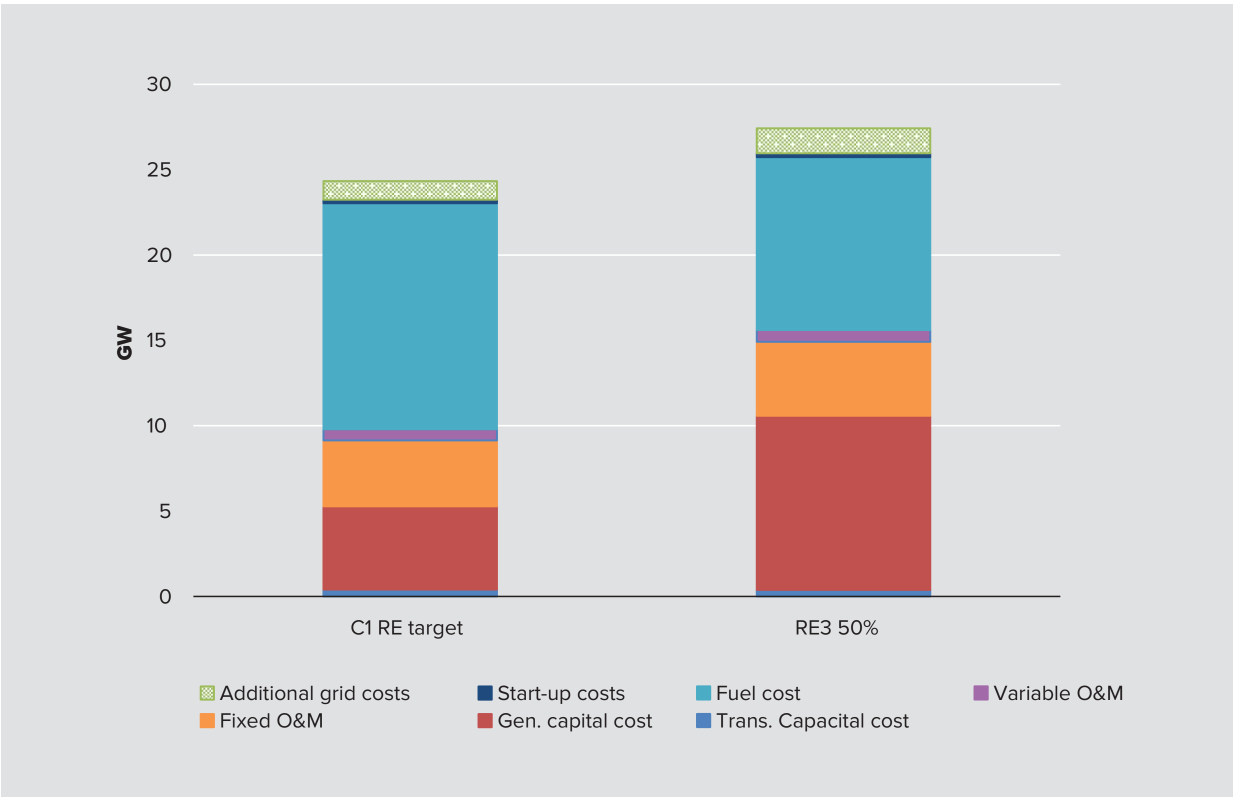

Figure 46: Total power system costs for the *C1 RE target scenario* and the *RE 50% 2030 scenario*, including the additional grid costs based on the PSS/E analysis.

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