GE VERNOVA

FUTURE PATHWAYS FOR VIETNAM'S POWER SECTOR

A Scenario-Based Modelling to support execution of concept to reality

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CONTENTS

1. Executive Summary

Vietnam has emerged as one of Asia's fastest growing economies with a power system undergoing rapid transformation. The country has achieved remarkable development with annual GDP growth exceeding 6% and electricity consumption growth of over 9% over the past three years. Vietnam's National Power Development Plan (PDP8), approved in 2023 and revised in 2025 (Revised PDP8), establishes a roadmap to achieve net-zero emissions by 2050.

As outlined in the Revised PDP8, Vietnam's energy transition is built on accelerating renewable energy deployment; gradually phasing down coal while safeguarding energy security; strengthening grid flexibility through transmission upgrades, storage deployments, and flexible generation; using gas and LNG as transition fuels; improving energy efficiency to curb demand growth; advancing power sector and market reforms to attract investment; and ensuring a just transition that supports industrial competitiveness, workforce reskilling, and social stability.

As Vietnam eyes at least 10% average GDP growth rate by 2030, the urgency of ensuring reliable, future-ready power supply has never been greater to support the growing economy and population's needs.

With focus on supporting the effort in moving the concept to reality, the intent of this paper is to utilize a production cost modelling approach to explore the different pathways for achieving this objective by evaluating multiple future scenarios. Through this modelling approach this paper attempts to provide insights on challenges and the potential mitigation measures that could be considered to prepare the system to support and deliver on the government's vision for the electricity sector.

Comprehensive modelling in GE Vernova's Production Cost Module of the PlanOS software platform examined four distinct scenarios to understand a range of potential outcomes: the Reference case, the Deferred Capacity case, the Low Renewables (RE) case, and the High RE case. The Reference case follows minimum targets of Revised PDP8 as currently defined, while the Deferred Capacity case incorporates construction timelines reflective of the current rate of addition of new generation capacity. The Low RE case models outcomes at 50% of the revised PDP8's renewable capacity target, and the High RE case explores implementing the maximum renewable targets from the revised PDP8 (12% more in 2030 and 10% more by 2050 compared to the Reference case).

While the purpose of the study was not to forecast a specific outcome, or recommend a most likely scenario, the study outcome provides the following strategic recommendations for a more resilient execution of the plan.

1. **Thermal Generation** – Natural gas will play a critical transition role, supported by timely project delivery, sustained investment in the existing fleet, and a clear pathway toward long-term decarbonization

Natural gas will serve as crucial bridging technology, with capacity expanding three-fold by 2030. Vietnam's continued focus on the timely completion of new project with continued investment in maintenance and retrofits for existing fleet for lifespan extension, while planning decarbonization pathways with low-carbon fuels and CCS is important.

2. **Flexibility Solutions** – Prioritize the deployment of fast-response resources, including energy storage, flexible thermal capacity, and advanced grid technologies to enable real-time system management

Consider prioritization in deployment of fast-response technologies including Battery Energy Storage Systems (BESS) and pumped hydro facilities, flexible gas-fired plants ,including aeroderivative turbines, and Advanced grid technologies for real-time management.

3. **Curtailment Management** – Through demand-side flexibility, Power-to-X conversion of surplus generation, and stronger regional interconnections

Renewable energy curtailment can be progressively addressed through a portfolio of strategic measures, including demand-side flexibility such as aligning electric vehicle charging with variable renewable generation, scaling Power-to-X solutions to convert excess energy into green hydrogen, and strengthening regional integration through enhanced interconnections with neighboring countries.

4. **Strengthening Grid Infrastructure** – Continue development of transmission backbone to reliably move power from generation to load centres, while investing in smart grid and forecasting capabilities to manage increasing system complexity

Continue to strengthen transmission backbone (550kV and 220kV systems) to evacuate power from generation sites to load centres, particularly supporting Central Vietnam's role as a transmission corridor. As the grid becomes more complex with higher penetration of Inverter Based Resources (IBR), invest in smart grid technologies and forecasting capabilities for real-time management and optimization over the short to medium term.

5. **Diversified financing** – Leverage diversified funding sources and bankable project structures to optimize financing costs

To support significant investment requirement, consider leveraging diverse funding sources including Export Credit Agencies (ECAs), commercial banks with ECA guarantees, and develop bankable project structures to reduce financing costs.

6. **Workforce transformation** – Power sector workforce is expected to grow significantly, driven largely by wind and solar developments, requiring scaled-up, world-class training programs to build technical and leadership capacity

Power sector workforce to expand by 67% (from 300,000 to 500,000 FTEs by 2035). It is projected that wind and solar technologies will account for over half of the direct labour force by 2030s. Suggest continued focus on comprehensive training programs for capacity building of technicians and managerial staff to meet world standards.

Vietnam's energy transition is a highly ambitious effort to drive country growth, while decarbonizing the power sector, depends on coordinated action across infrastructure, technology, and policy. It requires major transmission upgrades to move renewable power to demand centres, focus on gas as a bridging fuel, expanded energy storage to manage intermittency, stronger regional grid interconnections for flexibility and exports, supportive regulatory frameworks for flexible resources and demand management, and advanced grid management and forecasting technologies to maintain system reliability.

Through this integrated approach combining financial innovation, technological advancement, and strategic workforce development, enhanced by regional cooperation, Vietnam can demonstrate how such an energy transition could work as a model for other countries in the world pursuing rapid country growth, while achieving their net-zero goals.

2. Introduction

Vietnam's economy has transformed into one of Asia's most trade-reliant economies, with exports, and hence external demand, becoming the biggest drivers of economic growth. Vietnam's power demand growth has been among the strongest in the world as the country shifted from an agriculture-based economy toward rapid industrialization and urbanization. Vietnam is one of the fastest growing economies in the world, averaging an annual GDP growth rate of more than 6% and annual electricity consumption growth of more than 9% over last three years compared to a global average of 2-2.5%. Power sector demand growth is outstripping the country's GDP growth, hence the criticality of ensuring the supply of durable, reliable and sustainable electricity.

Vietnam Electricity (EVN), the state-owned holding company, owns over 38% of installed generation capacity and the entire transmission and distribution network through its subsidiaries. Independent Power Producers (IPPs) have been allowed to participate in the market since 2000 and represents close to 41% of the grid's power supply today.

A road map for achieving net zero for the country by 2050 was approved and released on May 15, 2023, as the National Power Development Plan (PDP-8)[1]. The main highlights of the PDP-8 were the following:

- Accelerate renewable growth through hydro, solar, wind and biomass.
- No additional coal plants after 2030 with the aim to switch coal to biomass or ammonia in the future.
- Coal to gas transition followed by switching from gas to hydrogen.

The Prime Minister issued Decision 768/QD-TTg on April 15, 2025[2], approving the adjustment of PDP-8 for the 2021 to 2030 period with a vision towards 2050 with the following general objectives:

- To firmly maintain national energy security, meeting requirements of national socio-economic development and industrialization and modernization.
- To successfully carry out just energy transition in association with the modernization of production, building of smart electricity grids, and management of the advanced electricity system following the trend of green transition, emission reduction and science and technology development around the world.
- To form the general energy industry ecosystem based on renewable and new energy sources.

The revised PDP8 also has a clear focus on an aggressive development of renewable energy sources (excluding hydroelectric power) to serve electricity generation, accounting for 28 – 36% of total energy sources by 2030 and 74-75% of total energy sources by 2050.

There will be a significant change in the demand as well as supply side by 2050, with the demand growing from the current levels of 49GW to 90GW by 2030 and 206GW by 2050. The demand is forecasted to grow significantly to meet the aforementioned economic growth.

Coal projects currently under construction through 2030 and specified in the Revised PDP8 to the tune of 12GW will continue to be implemented, followed by switching to biomass and ammonia. Development of onshore, nearshore and offshore wind power, as well as solar power, especially floating solar power, are promoted. Domestic gas and Liquified Natural Gas (LNG) power projects are required for the energy transition, with a projected total capacity addition of 22.4GW of LNG by 2030. Nuclear capacity of 4.0-6.4GW is also projected to be in operation by the 2030-35 period.

A number of Hydro resources have been developed, and additional large, pumped storage and mini hydro projects are planned. Increasing renewables penetration leads to complexity in power and market operation, especially to ensure the stability of the grid. Flexible power sources and Battery Energy Storage System (BESS) are suggested as potential solutions, with storage capacity projected to be 10.0 to 16.3GW by 2030.

[1] https://vepg.vn/wp-content/uploads/2023/05/PDP8_full-with-annexes_EN.pdf
[2] https://vepg.vn/wp-content/uploads/2025/06/768_QD-TTg_658055.pdf

In order to assess potential system challenges in the implementation of the plan, under various potential scenarios, and to proactively mitigate risks, GE Vernova conducted a comprehensive assessment of the Vietnam energy system. Anchored on Revised PDP8, this study intended to:

1. Assess a range of potential scenarios in the future Vietnam power system
2. Identify stress points and periods of operation of the system
3. Explore potential reliability risk mitigation methods

2.1 Modelling Scenarios

For the analysis, the electricity system of Vietnam was modelled in GE Vernova's Production Cost Module of the PlanOS software platform. The Production Cost module simulates the system based on the inputs provided, such as the demand (sub-hourly or hourly), wind and solar profiles, hydro profiles, transmission data and thermal unit data (capacity, operational constraints such as ramping constraints, outages, minimum thermal limits etc.) as seen in Figure 1. The module performs an hourly simulation factoring all inputs and perform a security constrained economic dispatch of the generation fleet to meet the hour-by-hour demand. The simulation will solve to meet the system demand with the most economical combination of the generation fleet available. The output from the simulations is used to analyze the system operations such as the hourly dispatch profile of the generating units, hours online, starts/year, emissions, transmission flows and Locational Marginal Prices (LMPs). Outputs can be summarized to observe the transition of the system over a long-term horizon (till 2050), the change in the generation mix and other parameters as needed.

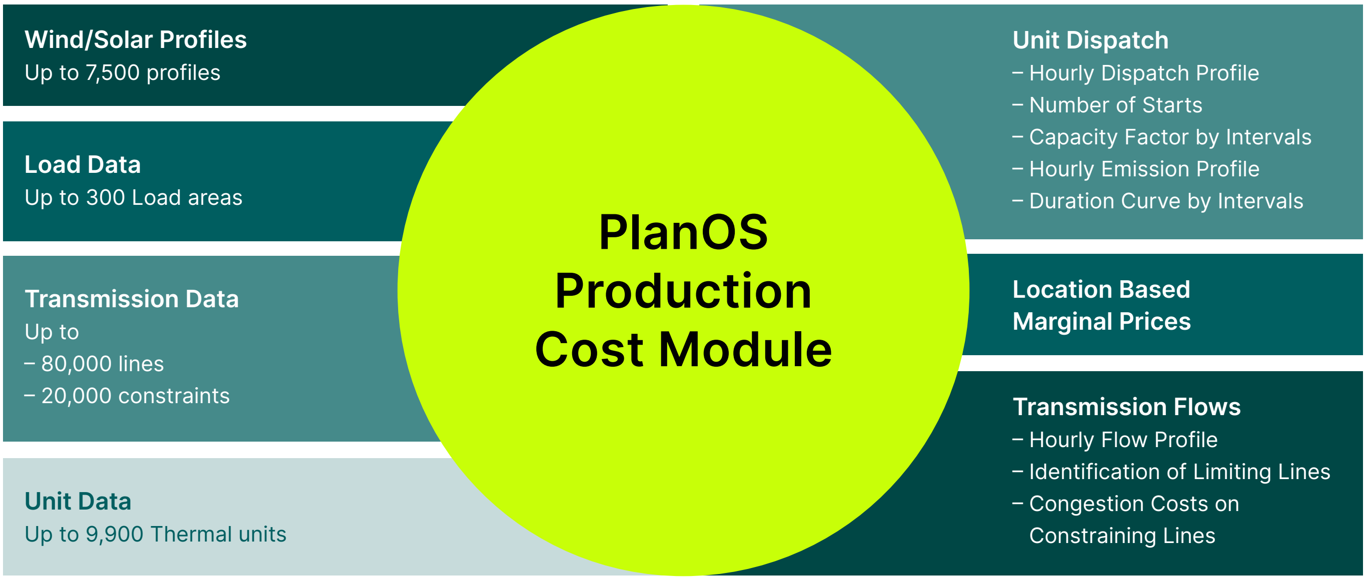


Figure 1: PlanOS Production Cost Module

Four cases were conceptualized, denoting pathways that could help decarbonize the electricity grid. Insights from the production cost simulation with an hourly resolution highlighted the stress points in energy infrastructure development and system operation.

These cases are discussed below with reference to demand, installed capacity variations including thermal (coal, gas), solar, wind (onshore and offshore), storage (BESS and Pumped Storage Hydro (PSH)) and other technologies projected in 2030 and 2050. The demand projection was the same for all cases.

Reference Case – The Reference case model serves as the baseline model for analysis. This model was developed using data as per the Revised PDP8 relating to installed capacities (minimum values) of various technologies for year 2030 and 2050 as highlighted in Table 1 below.

Deferred Capacity Case – This case reflects power plants currently under development or in the planning pipeline. With many projects in various stages of completion from early permitting through active construction-this case estimates potential installed capacity by 2030 assuming current development timelines are maintained, including:

- Gas plants – additional gas capacity of 16.9GW is considered by 2030, which will make the cumulative gas capacity reach 25.6GW by 2030 from 8.7GW as of December 2024. Beyond 2030, the installed capacity will reach the Revised PDP8 target by the year 2050.

- Coal plants – 6.6 GW of coal plants are planned to come online between 2024-2030. As presented in Table 1 for Reference case, the target coal plant addition is 11.7 GW by 2030. The difference in capacity addition of 5.1 GW is projected to be added beyond 2030 in the Deferred Capacity case.
- Nuclear additions pushed to beyond 2030. It is assumed that there will be 2GW of nuclear additions by 2035.
- 1GW of offshore wind capacity expected to come online by 2030.
- Since new variable Renewable Energy (vRE) capacity is currently under construction, the historical pace of vRE additions was considered in this Deferred Capacity case until 2030, which is ramped up in subsequent years to achieve target additions by 2050. Findings of this case would highlight the system operation challenges like the requirement of additional flexibility and renewable energy curtailment.

High RE Case – In this case, the vRE installed capacity is assumed to be higher than the Reference case. The maximum targets in the Revised PDP8 of solar and wind capacity are considered for modelling vRE sources. Storage and thermal installations are considered to be same as the Reference case. vRE installations in this scenario are 12% higher than the Reference case by 2050. This case will provide insight into system operation with high vRE installations and the impact on curtailment.

Low RE Case – This case is simulated to understand the impact of lower Renewable Energy (RE) installations in Vietnam's power system operation in milestone years 2030 and 2050, compared to the Reference case. In this scenario, the demand projections, installed capacities of coal and gas remain identical to the Reference case; vRE installations (solar and wind) assumed to be 50% of the targeted capacity additions. As the vRE capacity addition is lower, this scenario highlights the additional energy supplied by conventional sources (thermal), as thermal capacity will be added to meet the demand if there is any unserved energy.

Table 1: Scenarios of production cost simulation for Vietnam

Scenario Name	As of 31st Dec 2024[3]	Reference Case		Deferred Capacity Case		High RE Case		Low RE Case	
Demand		BAU (Revised PDP8's Min projections)							
Installed Capacity (GW)*	2024	2030	2050	2030	2050	2030	2050	2030	2050
Gas	8.7	44.4***	65.6****	25.6	65.6	44.4	65.6	44.4	73.6*****
Coal	26.8	38.5	25.8**	33.4	25.8	38.5	25.8	38.5	25.8
Solar	16.5	76.9	293.1	40.3	293.1	77.0	301.8	52.1	160.2
Onshore Wind	4.9	26.3	84.1	12.4	84.1	39.4	92.7	14.9	43.8
Offshore Wind	-	6.0	113.5	1.0	113.5	6.0	139.1	3.0	56.8
Hydro	23.6	33.3	40.6	33.3	40.6	33.3	40.6	33.3	40.6
Biomass	0.6	3.2	7.0	3.2	7.0	3.2	7.0	3.2	7.0
Storage (BESS+PSH)	-	12.7	116.6	12	116.6	12.7	116.6	7.7	60.1
Imports	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Nuclear	-	4.0	10.5	0.0	10.5	4.0	10.5	4.0	10.5
Total	**82.4**	**244.8**	**756.6**	**161.3**	**756.6**	**257.8**	**799.8**	**200.5**	**478.3**

Notes:
*Considered based on the Minimum targets as per the Revised PDP8
** Biomass or Ammonia Fueled
*** Includes Domestic Gas, LNG, Flexible Sources
**** Includes Domestic Gas, LNG, Hydrogen Fueled (from Domestic Gas and LNG), LNG with Carbon Capture Storage (CCS), Mixed LNG and Hydrogen and Flexible Sources
Flexible Sources are thermal power using LNG, oil, hydrogen, etc. with high operational flexibility
For Lower RE Case (Column D&E), Solar and Wind (off-shore +onshore) assumed to be 70% of targets achieved (***** – Added units to help meet the required demand in low RE Case in the outer years)
For Higher RE Case (Column F&G), Revised PDP8 Max Capacity targets for vRE (solar, Wind) are considered

[3] EVN Annual report 2024-25

3. Assumptions and System Description

A production cost simulation considers the constraints of operating various generation technologies, as well as the transmission limitations between the modelled utility areas. The production cost model was developed using data from the public domain. Hourly demand was taken from the data published from the National Load Dispatch Centre (NLDC) website as available until 2018. Generator information (MW, Location, Type) was taken from the annual reports published by Vietnam Electricity (EVN), from Energy Outlook reports published by the Ministry of Industry and Trade (MOIT) and the Danish Energy Agency. The Renewable profiles were derived through the use of internal tools which utilize the Solar Direct Normal Irradiance (DNI), Diffused Horizontal Irradiance (DHI) published by the National Renewable Energy Laboratory (NREL) and World Bank (WB) and wind data from Wind Atlas[4] to derive the hourly profiles. Transmission information is highly limited in the public domain and the model developed considered the three regions (North, Central and South) as the division of areas. The study leveraged the limited public data available to generally model the transmission system in all scenarios. While the models may not be detailed given the data limitations, they can be used to confidently derive insights for this level of analysis, revised PDP8 establishes a roadmap to achieve net-zero emissions by 2050.

3.1 Modelling Topology

Figure 2 shows the modelling topology adopted for Vietnam's power system model. This topology is common for all cases. From the production cost model perspective, the country is a 'System' which is further divided into three electrical 'Regions'. Each region is then attributed corresponding demand and generation. Three regions are interconnected with transmission links with finite capacities. As shown in Figure 2, these three regions are North Vietnam, Central Vietnam and South Vietnam.

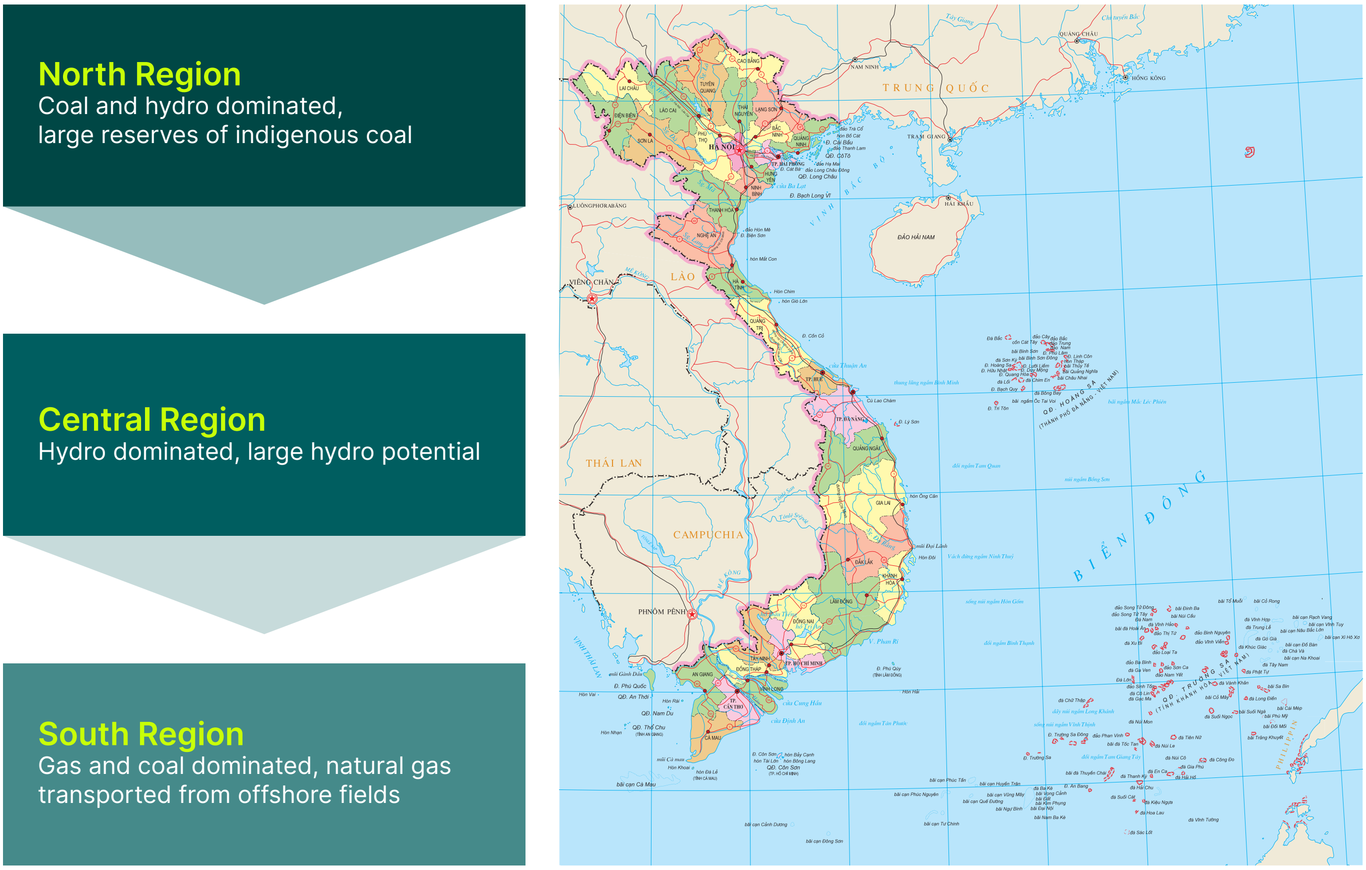


Figure 2: Modelling topology for Vietnam's power system

North Vietnam and South Vietnam account for ~91% of the demand requirements of Vietnam with each absorbing ~45% of power demand. The North, including Hanoi, and the South, including Ho Chi Minh City, have substantial installed capacities to support large urban and industrial power needs. The Central Vietnam region accounts for ~9% of Vietnam's power demand and functions more as a power transmission corridor-playing a crucial role in transmitting power especially from hydro and renewable sources to high-demand centres in North and South Vietnam. The peak and energy demand at regional level is presented in Table 2.

[4] https://globalwindatlas.info/en/

Table 2: Peak and Energy Demand between Vietnams' regions in 2024[5]

Region	Peak Demand (GW)	Energy Demand (TWh)
North Vietnam	25.0	126.0
Central Vietnam	5.2	25.0
South Vietnam	21.4	123.0
Vietnam	49.0	275.0

3.2 Inter-Regional Transmission Capacity

Table 3 shows the Interconnection Limits (MW) considered in the model between the regions. These values are based on the Vietnam Energy Outlook 2024 report published by MOIT[6].

Table 3: Estimated interconnection capacities between regions

Year	North to Central Interconnection (MW)	South to Central Interconnection (MW)
2024	4,000	12,400
2030	5,200	17,900
2035	7,389	20,230
2040	10,354	23,428
2050	26,800	29,200

The Hydro Power Plants are largely concentrated in the North and Central Vietnam regions. Solar power is heavily concentrated in the Central and Southern regions due to better solar irradiation. Wind power is mostly in the southern Central region and the coastal areas of the South region. Amongst the thermal power plants, the gas power plants are largely in South Vietnam, and most of the coal plants are located in the northern and southern regions of Vietnam. In 2024, Vietnam had an installed capacity of 82.4GW with a mix of 35.4GW of thermal capacity, 23.6GW of hydro and 21.4GW of vRE. As per EVN's 2023-24 annual report, Vietnam imports 1222MW of power from Lao PDR and China, which has been considered in the modelling as a hydro power plant. The present model assumes only a 400MW export of power from Vietnam to Cambodia.

3.3 Demand And Supply Projections

The Reference case model of the production cost simulation was developed for years 2030 to 2050 with the data provided in Revised PDP8 which includes the range of projected values (minimum [min] and maximum [max]) for various parameters like peak and energy demand, projected RE penetration, emissions, and installed capacity for 2030 and 2050. Electricity demand is expected to grow in line with the projected GDP growth. Vietnam has experienced high GDP growth in the past decades (5% to 7%), which is expected to continue over the next few years. This is driven through increases in industrial outputs (electronics, steel, textiles, cement, chemicals) and urbanization (residential and commercial). Meanwhile, an increasing penetration of Electric Vehicles (EVs) and growing data centres is leading to power demand growth outstripping the GDP growth rate.

3.3.1 Peak demand and energy

Peak demand and energy are the two very basic yet critical components of any production cost model. Healthy increase in these parameters over the years is an indication of country's economic progress. Key highlights of Vietnam's power system are tabulated for 2030 and 2050 in Table 4 as per Revised PDP8. A peak load of 89.7GW and 205.7GW were considered for year 2030 and 2050 respectively in the model. Similarly, the energy demand for 2030 and 2050 were considered to be 500 TWh and 1238 TWh respectively. The peak and energy demand has been considered uniform across all cases. It is also noted that Revised PDP8 has an ambitious RE energy penetration at 28% and 74% in milestone years 2030 and 2050 respectively.

Table 4: Highlights of Vietnam system in 2030 and 2050 as per revised PDP8

Parameter	Unit	2030 Min	2030 Max	2050 min	2050 Max
Energy Demand	TWh	500	558	1,238	1,375
Production + Import	TWh	560	625	1,360	1,511
Peak Demand	GW	89.7	99.9	205.7	228.6
vRE Penetration (Energy)	%	28	36	74	75
Emission	Million Tonnes	197	199	27	27

Figure 3 shows the projected peak and energy demand for Vietnam from 2022 to 2050 which are adopted from the Business As Usual case from Revised PDP8. For the milestone years of analysis, peak demand for 2030 is 89.7GW while it is 205.7GW for year 2050. Total annual energy stands at 500TWh and 1238TWh for years 2030 and 2050 respectively.

The Revised PDP8 includes new demand drivers like EVs and Data Centres. Given the significant growth of EVs as projected by the World Bank Group in their report[7], it is estimated that the contribution of EVs to Vietnam's peak and energy demand will be approximately 0.5% and 2% respectively by 2030, and approximately 4% and 13% respectively by 2050.

Similarly, from the internal forecast of data centre additions, the contribution of data centre load to peak and energy demand is expected to be approximately 0.8% and 1.3% respectively by 2030, and approximately 2.5% and 3.62% respectively by 2050. The demand contribution by EVs and data centres is presented in Figure 4.

[5] Article "The structure of Vietnam's power sources in 2024" by Cuong Tran Duc (published January 2025)
[6] Viet Nam Energy Outlook Report Pathways to Net-Zero
[7] Recommendations to the National Roadmap and Action Plan for the Electric Mobility Transition

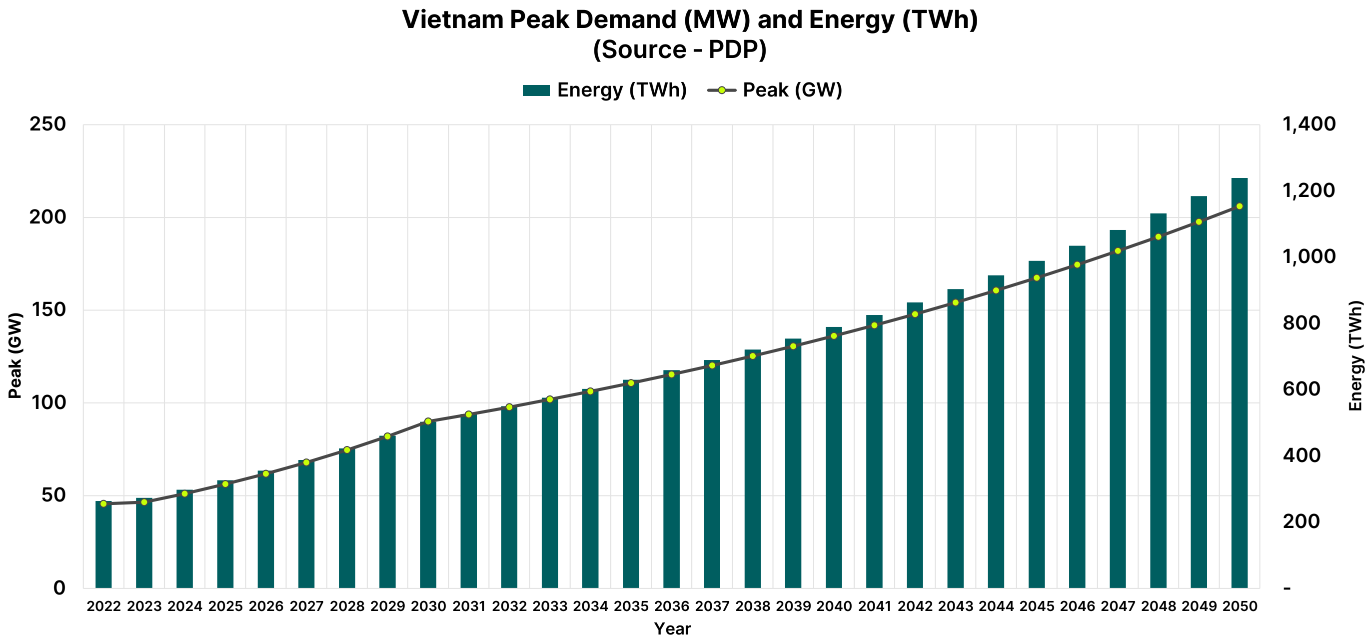


Figure 3: Demand projections

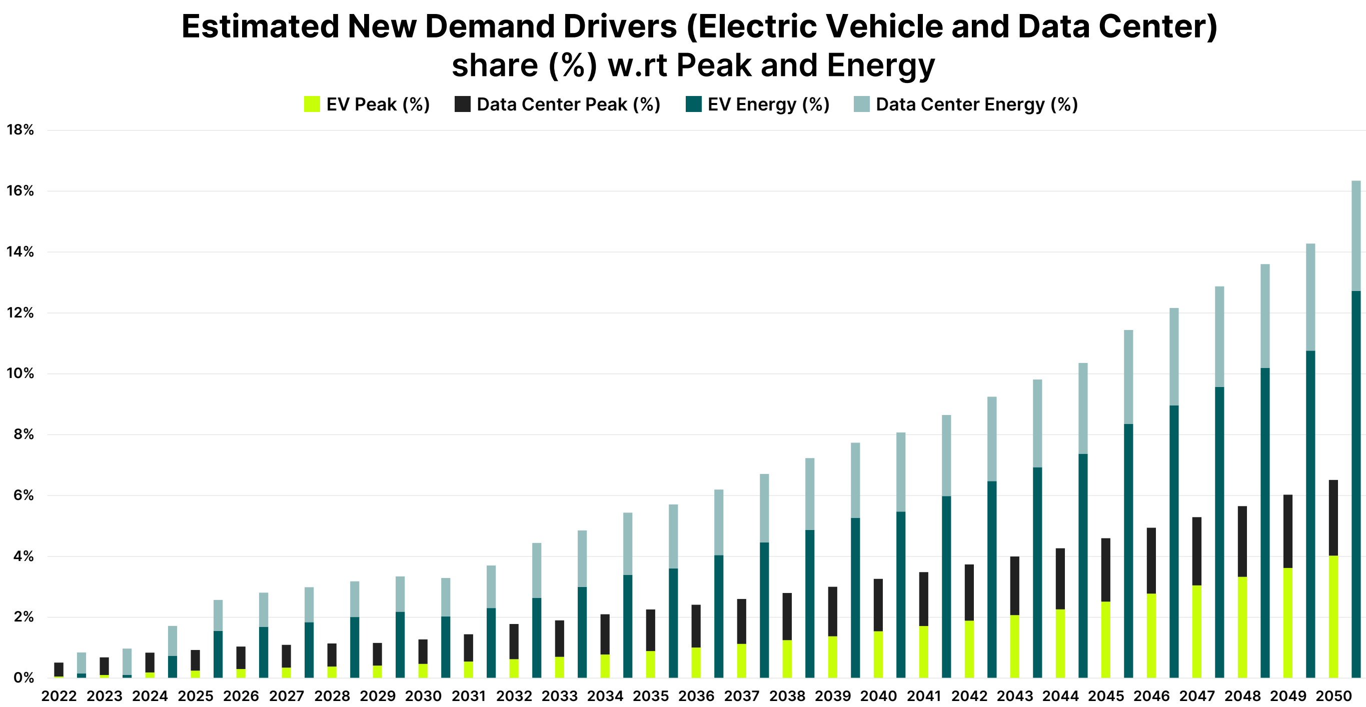


Figure 4: EV and data centre demand as a % of peak demand and energy

3.3.2 Installed Capacity Projections – 2030

The Revised PDP8 indicates the range of projected values of installed capacity of various generation resources through a Min and Max values. These values are presented in Figure 5.

As per the Revised PDP8, there will be implementation of coal projects, which are specified in the master plan and currently under construction through 2030. Coal plants under operation for over 20 years or more will utilize biomass and ammonia, which would be available at reasonable costs. As per the plan, coal plants over 40 years will not operate; if it is critical to continue their operation, they will switch to new fuels. In case of other thermal categories (i.e. gas-based generation), by year 2030 the total gas-based capacity covering both domestic gas and LNG will reach 33-37GW based on min and max targets respectively.

The installed vRE capacity by 2030 as a % of the total installed capacity will reach 38% for 2030 Min and 44% for 2030 Max. Other renewable resources such as biomass, waste to energy, geothermal and hydro will reach 18% for 2030 Min and 15% for 2030 Max with storage technologies in the range of 12.4GW to 22.3GW. This will help in effective absorption of RE in the system thereby offering vRE-shifting and energy arbitrage services.

2030 Min and 2030 Max Revised PDP8 Target Installed Capacity (GW)

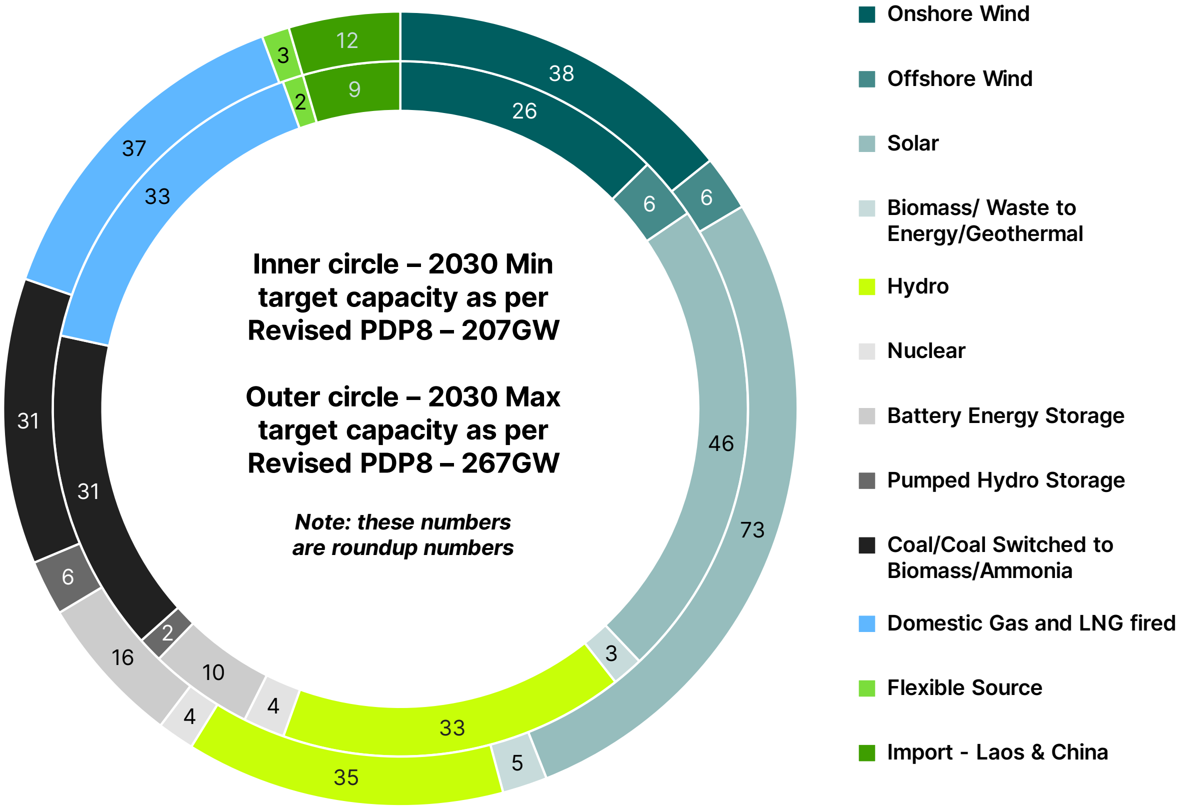


Figure 5: Revised PDP8 Target Installed Capacity (GW) for 2030

2050 Min and 2050 Max Revised PDP8 Target Installed Capacity (GW)

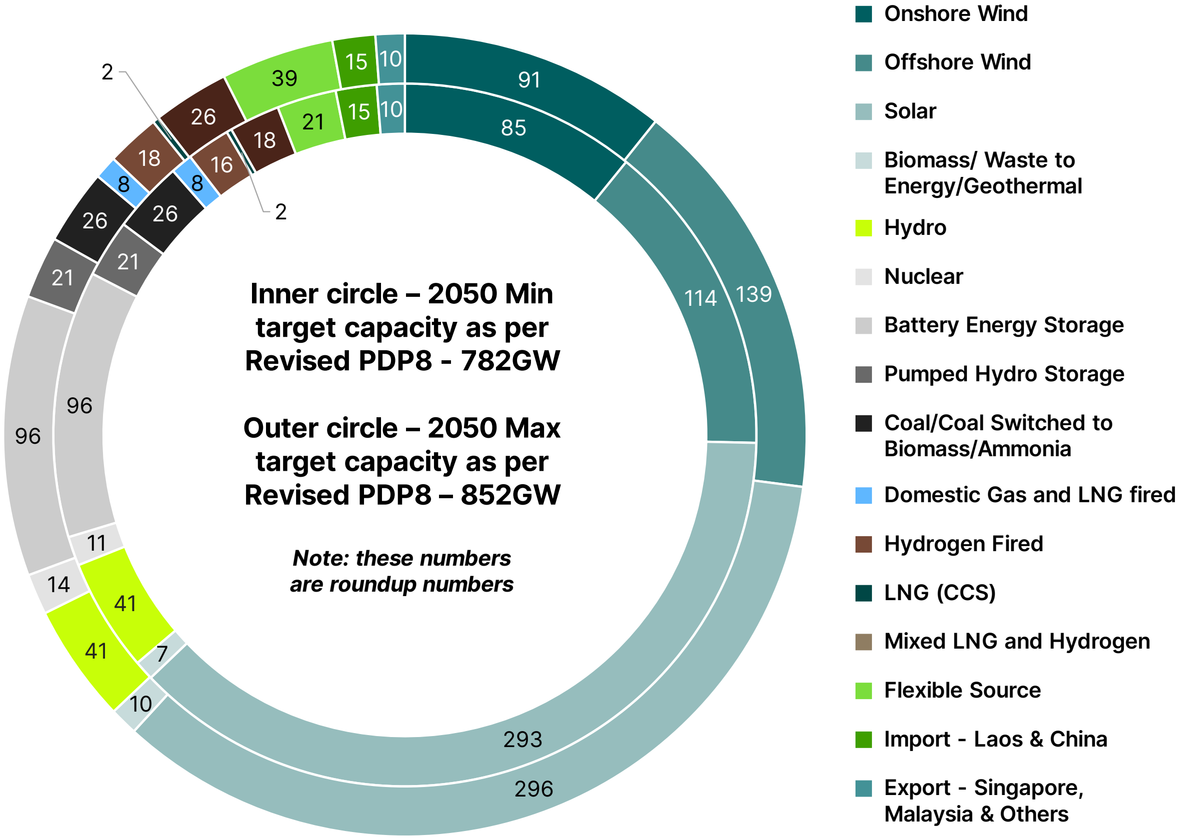


Figure 6: Revised PDP8 Target Installed Capacity (GW) for 2050

3.3.3 Installed Capacity Projections – 2050

Figure 6 indicates the projections for year 2050 as per the Revised PDP8. There is significant increase in the share of RE capacities (all sources) to 70% in overall projected installed capacities. For effective utilization, the storage is also projected to increase to 116.7GW to 117.5GW. The contribution to the installed capacity of vRE is expected to reach ~64% and other RE sources are expected to be around 6%. In addition to storage technologies, flexible power sources (thermal power using LNG, oil, hydrogen, etc. with high operational flexibility) are expected to reach 21.3GW to 38.6GW to support the development of a smart electricity grid capable of safely operating with large-scale RE energy integration.

The Revised PDP8 highlights Vietnam's decarbonization target with plans to operate coal-based power plants on ammonia or biomass. It also highlights, converting domestic gas and LNG-based power plants to run on hydrogen (15.6GW to 18.3GW), with some plants operating with blending of hydrogen and LNG (18.6GW to 26.1GW) and LNG plants with Carbon Capture Storage (2 GW).

By year 2050, it is projected that there will be no utilization of coal for electricity generation with a complete shift from use of coal to biomass and ammonia for the total capacity of 25.8 GW. The installed capacity considerations for the four cases and horizon years 2030 and 2050 are as indicated in Figure 7.

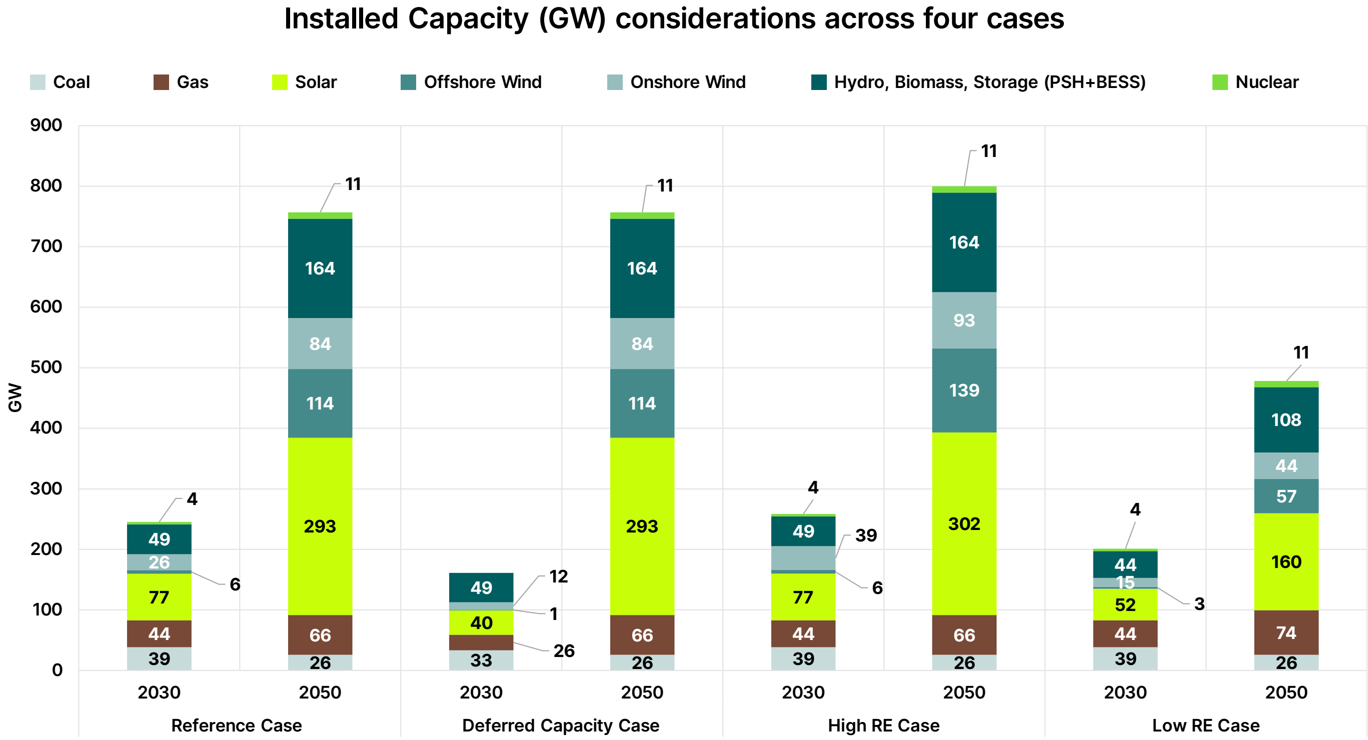


Figure 7: Installed capacity across four cases (2030 and 2050)

4. Analysis of Simulation Cases

Four cases were simulated with production cost model for Vietnam's system. Their results are discussed in this section.

4.1 Installed Base and Generation

Across the four cases, the short-term period (until 2030) has a large mix of thermal capacity mainly comprising coal and gas-based technologies. As the vRE capacity increases, the system will move towards a vRE-dominant system across all cases. In the Reference and High RE cases, the vRE capacity mix ranges from 45% to 47% in 2030 and then increases to 65-67% by 2050. While in the Low RE case and Deferred Capacity case the vRE capacity mix ranges from 33-35% in 2030 and reaches 54-65% by 2050.

This significant portion of intermittent generation in the installed base will need technology and policy support to minimize curtailment and maximize absorption of this generation. In the case of thermal generation, coal and gas-based technologies are similar across the Reference, High RE and Low RE cases. While in the Deferred Capacity case, as it is following current build out of capacities, the thermal capacity additions are lower in 2030. By 2050 the thermal-based generation capacity reaches the planned capacity targets as in the Reference case.

Based on the installation mix, the Reserve Margin (RM) of the system is depicted in Figure 9. The Derate capacity (Capacity available during peak demand) for various technologies that are present in the energy mix are factored into reserve margin calculation. Across the

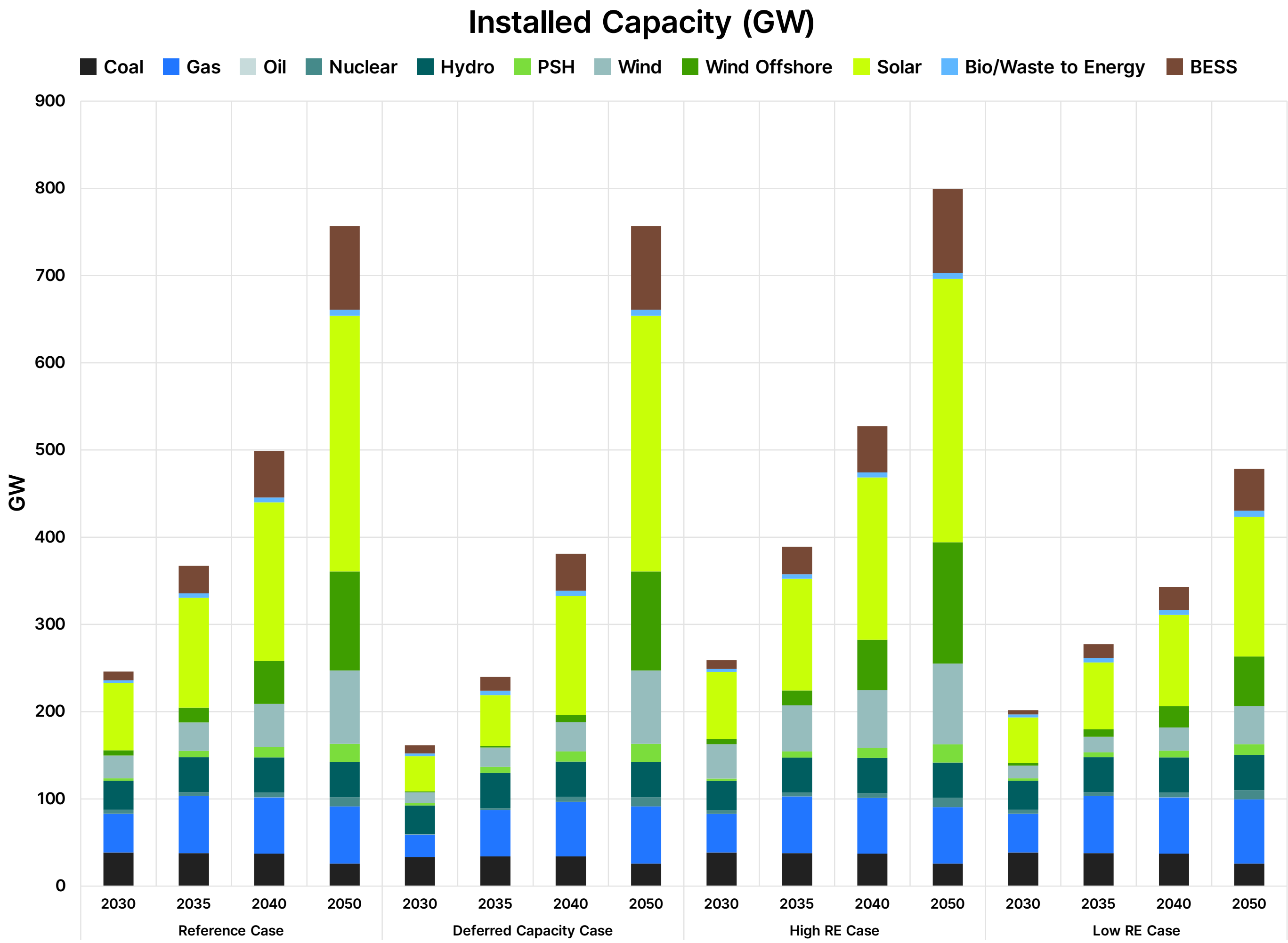


Figure 8: Installed capacity across four simulation cases

cases, the reserve margin is high indicating the availability of significant capacity above the peak demand for the simulation year(s). The high Reserve Margin is driven by the large amount of renewable (derated) and storage capacity in the system, followed by the planned gas-based capacity.

In the Deferred Capacity case, for year 2030, due to the slower pace of additions by 2030 the RM is lower than other horizon years as in this case the buildout of all technologies is slower than the reference case. This is also reflected in the operations as seen in the generation mix mentioned below where existing fleets need to ramp up generation to meet the demand.

Similarly in the Low RE case, since the renewable and storage capacity have been reduced, the RM is observed to drop in the later years reaching close to 18% by 2050. RM is calculated based on the Revised PDP8 minimum demand forecast. If peak demand increases to higher than the current rate, the RM will reduce for the same capacity additions. Similarly lower peak demand growth will show a much higher RM of the system. Based on the technology mix the RM indicates the level of reserves available to maintain grid reliability.

Generation mix from the simulations is based on achieving an optimum mix, while trying to keep the production costs low. This is done while respecting the system constraints modelled i.e. the technological operational constraints (minimum down time, minimum up time, ramping constraints, minimum thermal limits, available generation profiles (hydro, renewables). The operation of the various technologies is based on the capacity mix in each case. Figure 10 compares the energy generation from each technology. When compared to the Reference case, higher energy is provided by coal in 2030 in the Deferred Capacity case as the installed capacity mix is lower and the load to be met is the same, hence there is a need for thermal capacity to generate higher. The overall contribution from the RE in this case is low. In year 2035 and 2040, the contribution of gas plants increases, while by 2050, the energy mixes for both cases are comparable.

In reference to High RE case, despite higher RE installations than the Reference case, the overall contribution of RE in the energy mix across all years is comparable to the Reference case. This, in turn, highlights system limitations in RE absorption.

The case of Low RE when compared to Reference case indicates higher dispatch of gas units and reduced contribution from RE (wind and solar). This is justified as RE installations are reduced in this case, and thus gas plants are supplying the load.

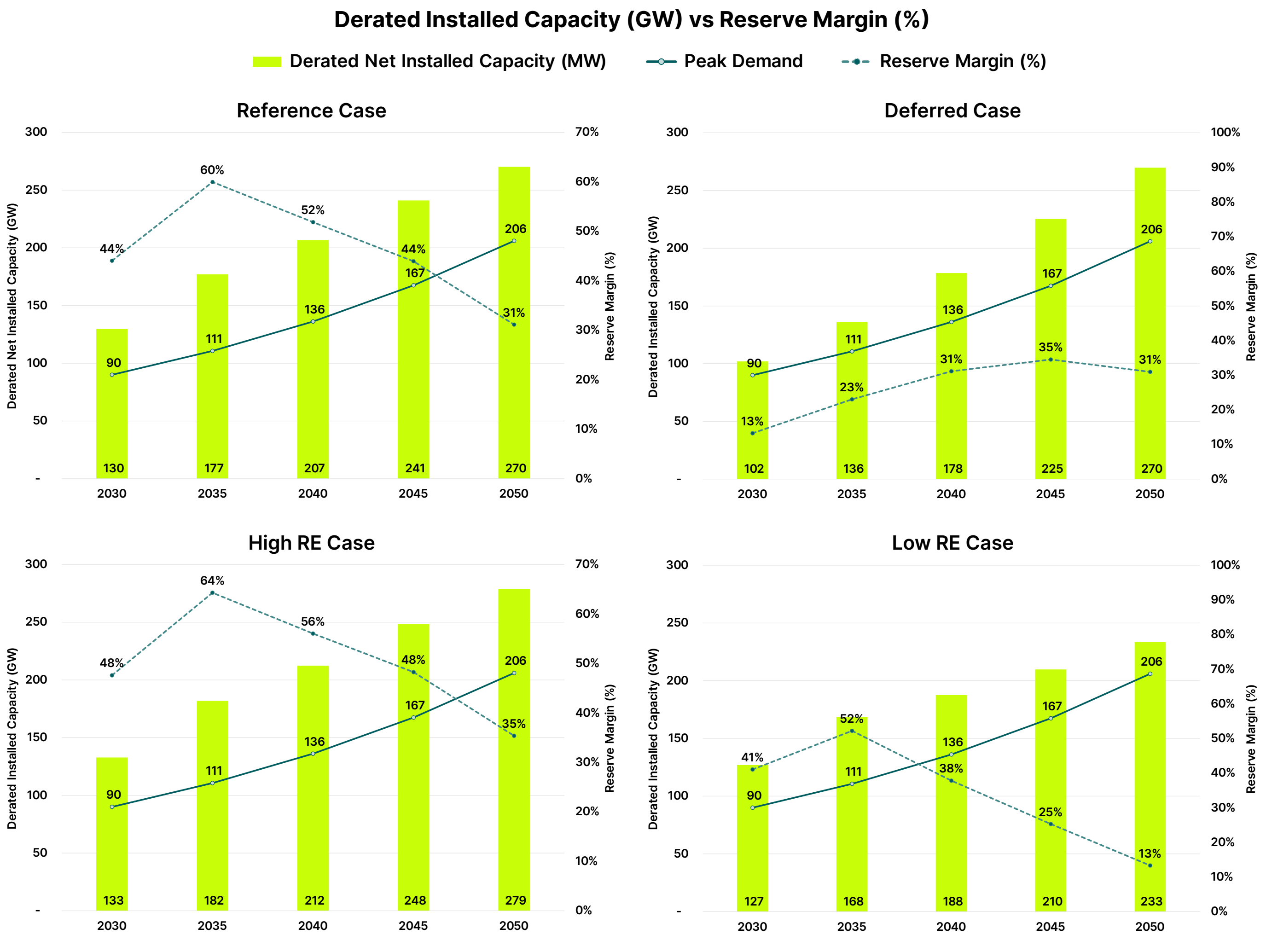


Figure 9: Reserve Margin (%) vs Available Capacity (GW)

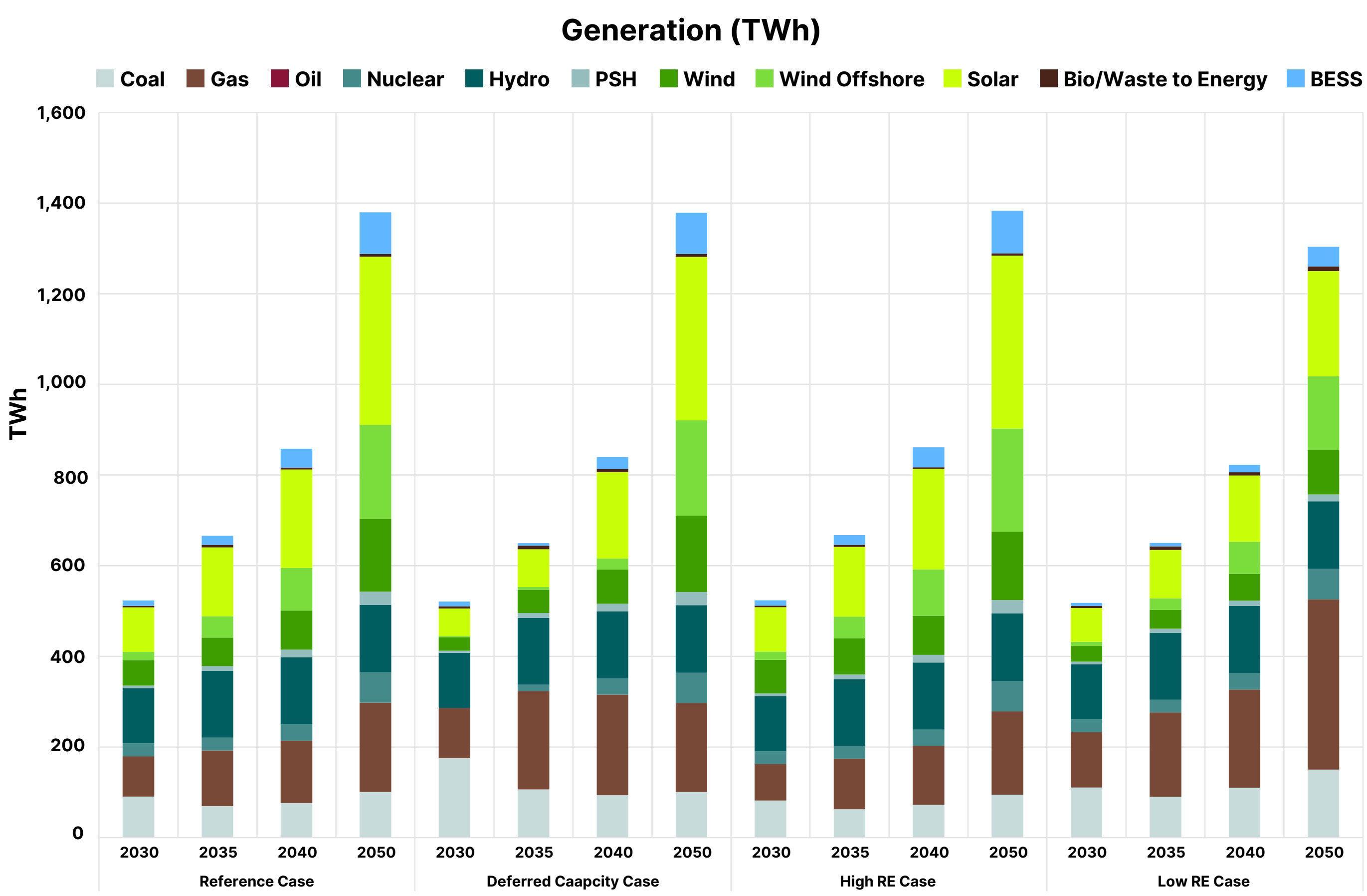


Figure 10: Energy generation from various technologies across four simulation cases

Figure 10 and Figure 11 show the trend of generation mix across four scenarios for long term (2030 to 2050).

In the Reference case, thermal generation (coal and gas) will see a decline in the overall generation mix with higher contribution from renewable sources. Coal and Gas contribution to the generation mix drops from 50% in the near term (2023-2025) to 23% by 2050. Low emission sources (nuclear, hydro, wind, solar) will continue to increase as per target additions increasing from 50% in the near term (2023-2025) to 68% by 2050. Significant complexity in operations of the grid expected in the medium term as the annual vRE penetration increases beyond 30%. This underlines the need for higher flexibility resources and storage capacity for reliable operations.

For the Deferred Capacity case, thermal generation (coal and gas) will see a decline in the overall generation mix 2030 onwards due to the increased penetration RE sources. However, until 2030, The system will be dependent on the thermal capacity to meet demand. Gas contribution is expected to increase from 2030 onwards until 2040 (21% to 33% levels) with its contribution peaking around 2035. Lower-emission sources (nuclear, hydro, wind, solar) will continue to increase with increasing additions but will have slower growth (as additions have been deferred).

In the High RE case, thermal generation (coal and gas) will also see a decline in the overall generation mix with higher contribution from renewable sources. Coal and gas contribution drops from 50% in the near term (2023-2025) to 20% by 2050. Lower-emission sources (nuclear, hydro, wind, solar) will continue to increase as per target additions increasing from 50% in the near term (2023-2025) towards 71% by 2050. Like the Reference case there should be expectations of the need for more flexible generation and other measures in helping absorb the large RE generation.

In the Low RE case, coal and gas contribution to the generation mix drops from 50% in the near term (2023-2025) to 40% by 2050 as RE capacity additions are lower than the Reference case targets. Lower-emission sources (nuclear, hydro, wind, solar) will maintain their contribution with the pace of additions with their contribution remaining at around 50% levels throughout the horizon.

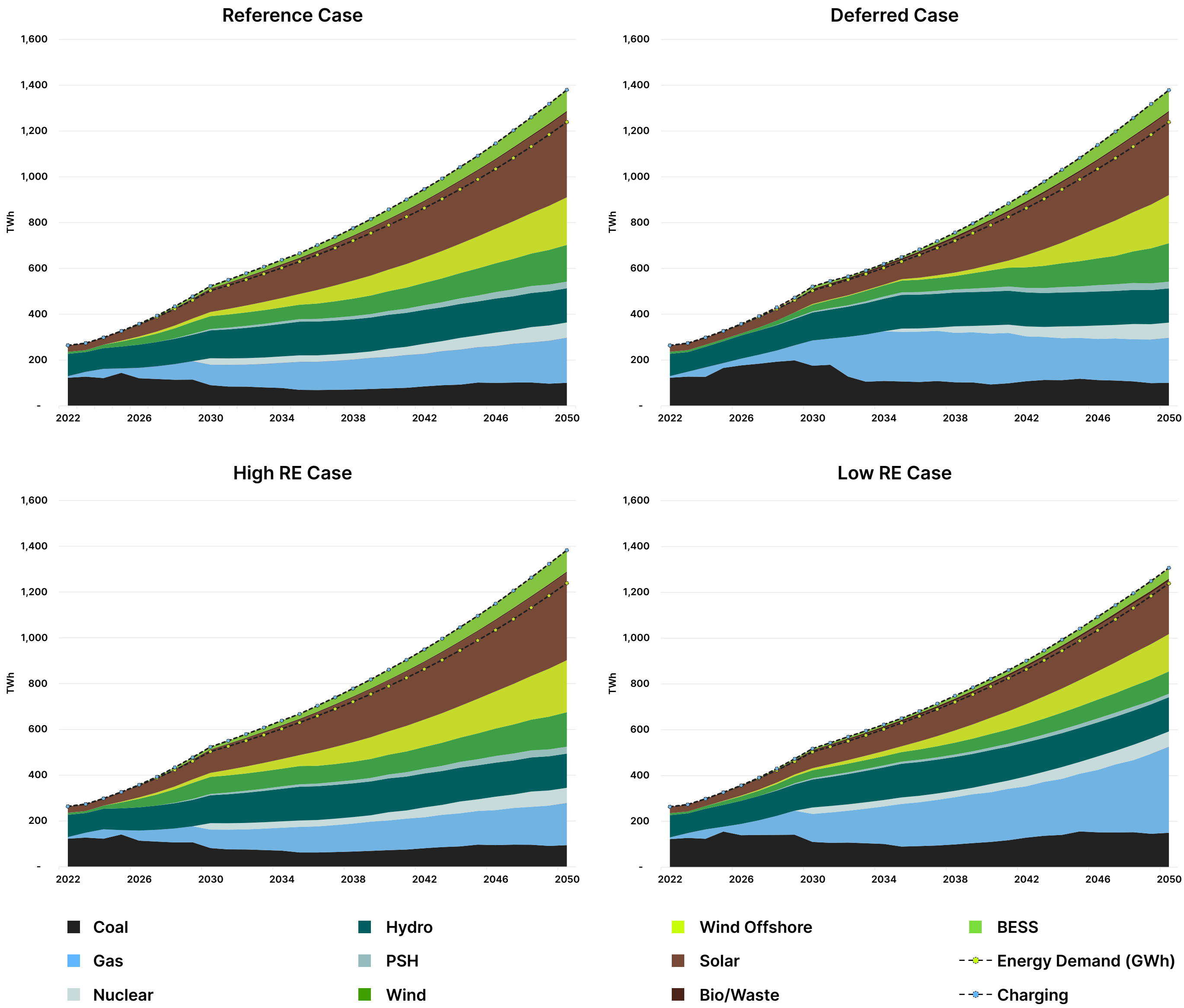


Figure 11: Trend of Generation mix for four cases from 2022 to 2050

The generation mix indicates a need for various technologies to accommodate the large capacity of intermittent resources planned, which includes the need for flexible generation sources like gas, BESS, storage and hydro. As the system becomes RE dominant, there will be a need for generation planning to factor the impacts of weather anomalies (in the case of vRE), as well as hydro availability to meet the growing demand over the long term.

The generation also includes the requirement for charging of storage-based technologies such as Pumped Storage Hydro and BESS, this is indicated as the charging line beyond the energy demand. These technologies help the system to increase vRE penetration levels in the outer years. Additionally, fast response flexible resources would help in meeting the ramping requirements of the system and help smooth out operations of other resources such as nuclear and coal-based capacity. New technologies such as Small Modular Reactors (SMRs) could be explored to help address ramping requirements. In the simulations, the nuclear technologies considered was based on traditional technologies, excluding SMRs from modelling considerations. Another aspect that could provide flexibility is the change in thermal minimum operations of coal-based plants. Lowering of the thermal minimum would potentially help in absorbing more renewable generation. Countries with large coal fleets are exploring such options as these systems incorporate more renewables in their grid with support of fast response technologies such as gas based flexible generators and storage technologies.

The generation mix determines the average cost of generation as seen in the Location Marginal Price (LMP)[8] trends in Figure 12. With increasing penetration of vRE generation (at almost zero marginal cost), there is a decrease in LMPs. Increasing vRE generation and lower thermal generation in the system brings down LMP. The lowest LMP is observed in the High RE case as compared to the Reference case and the highest in the Low RE case where the system demand is mainly catered to by costlier thermal generation. The Deferred Capacity case in the short term (2030 to 2035) sees a higher LMP due to higher contribution from the thermal generation meeting demand and as renewable penetration increases, there is a decrease in the LMPs. By 2050, apart from the Low RE case all other cases align with the Reference case.

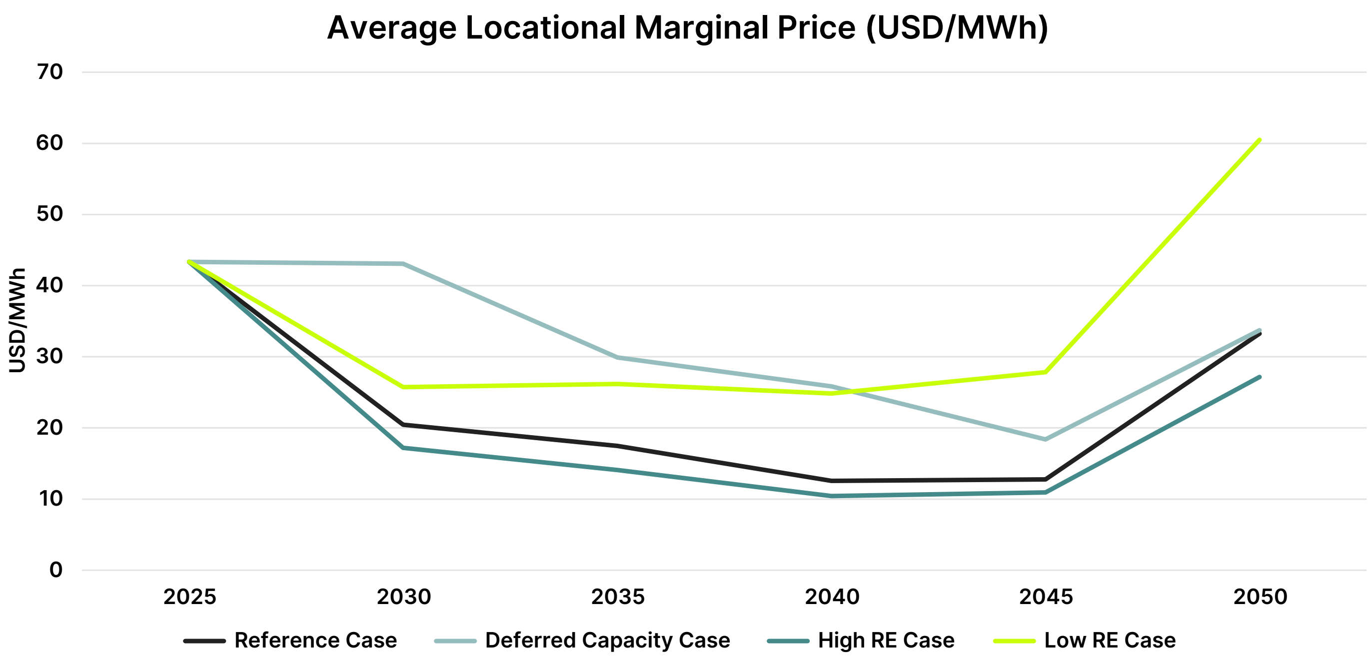


Figure 12: Average Locational Marginal Price in USD/MWh

[8] Locational Marginal Price (LMP) is the cost of supplying one additional megawatt-hour (MWh) of electricity at a specific location on the power grid at a specific time.

4.2 Renewable Energy (RE) Curtailment

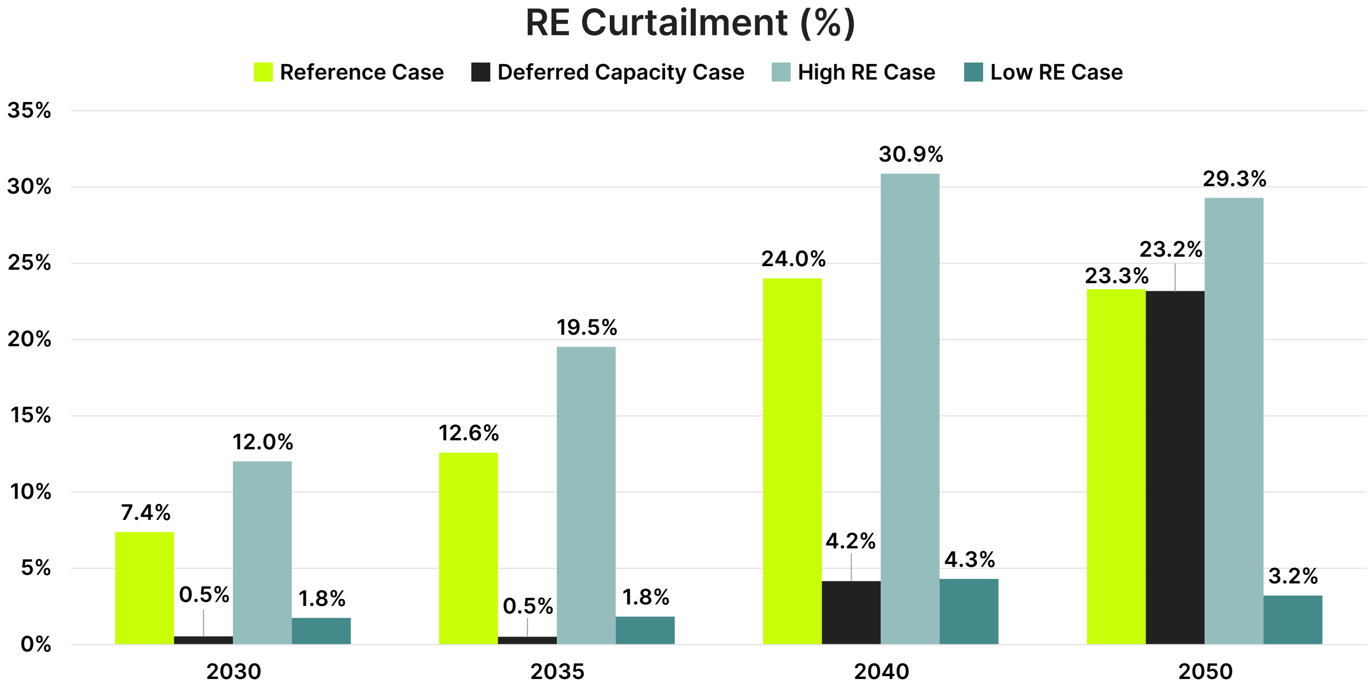


Figure 13: RE curtailment (Solar and Wind) for all cases

The RE curtailment values shown in Figure 13 for all cases across milestone years is inclusive of all variable renewable technologies (vRE – onshore wind, wind offshore and Solar). The Deferred Capacity case observes the lowest vRE curtailment as target installations have been deferred but as the full target capacity is reached by 2050, curtailment levels are similar to the Reference case. As curtailments levels increase based on target capacity additions in the Reference case as per the Revised PDP8, there is an indication of excess generation available from renewable sources.

The RE curtailment values in Deferred Capacity case and Low RE case are comparable except for 2050 (due to lower installations). In High RE case, with the aggressive installation target, the system is seen to have a high amount of curtailment of vRE generation. vRE curtailment is observed in all systems with high vRE penetration. It is inevitable due to the inherent nature of vRE (intermittent and variable) and its lower correlation with the demand pattern. However, higher values of curtailment indicate the requirement of additional balancing flexible resources in the system and storage performing renewable shifting service. In any system, vRE curtailment should be mitigated as it results in economic loss. The curtailed energy could be alternatively used for Power to X applications like Green Hydrogen production.

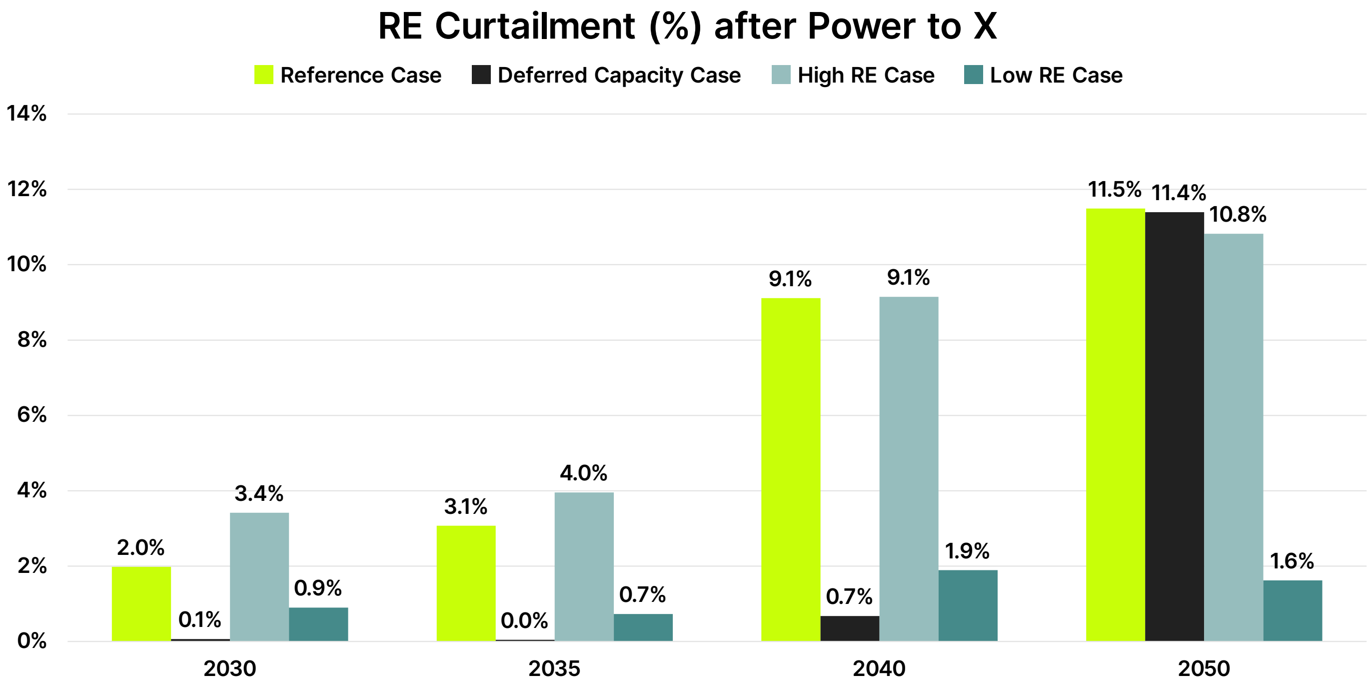


Figure 14: RE Curtailment after Power to X for Hydrogen Production

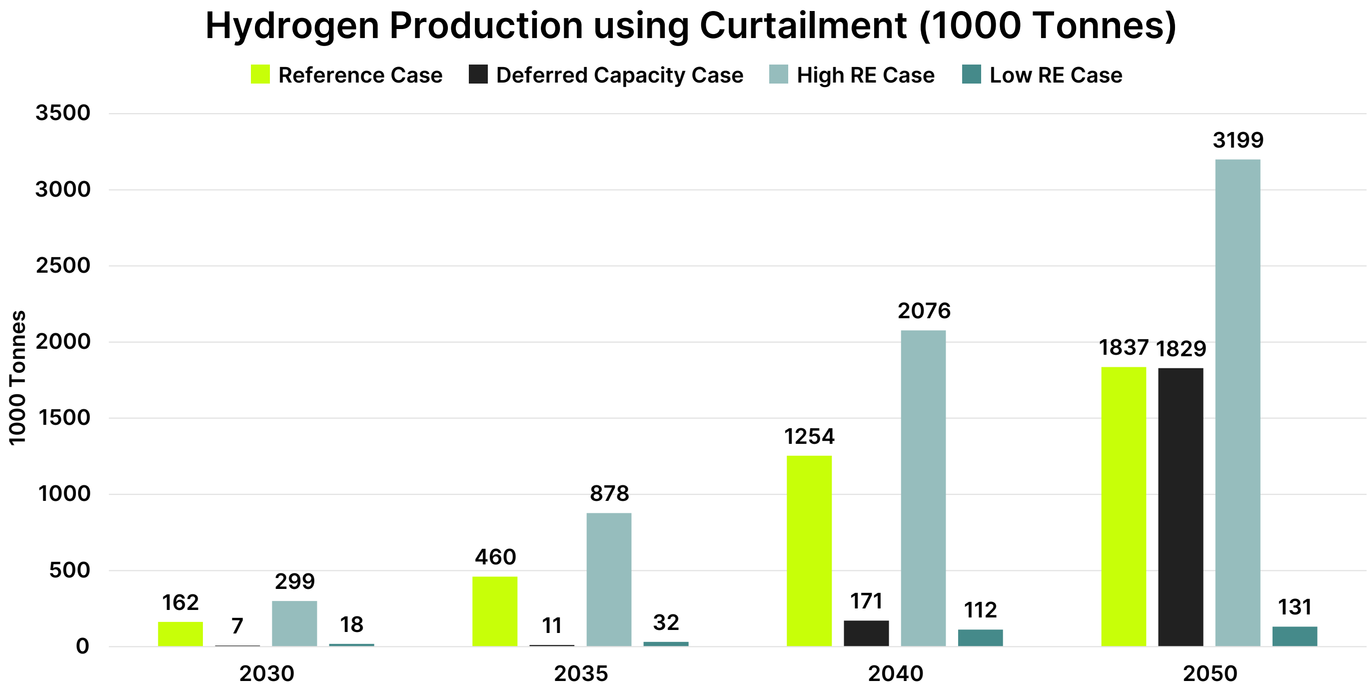


Figure 15: Hydrogen Production in '000 Tonnes

Further analysis was done to explore the use of curtailed energy from Solar, Wind and Offshore Wind in Figure 13 to Power to X (P2X) model, to produce Hydrogen through electrolysers. The renewable curtailment post P2X are presented in Figure 14. Hydrogen production using the curtailed energy is presented in Figure 15. Based on the available curtailed energy across cases, the P2X conversion (to Hydrogen) has significantly brought down curtailment levels close to 11% by 2050.

Based on the curtailed energy absorbed, hydrogen production is highest in the Reference and the High RE case. Due to lower available curtailed energy in the Deferred Capacity and Low RE case the amount of hydrogen production is lower. As per the Revised PDP8 there is a significant capacity build out to look at meeting Hydrogen target productions. The above graph is indicative of the potential hydrogen production from the curtailed energy from the electricity sector.

The simulation model has considered storage capacity as per Revised PDP8 targets. Additional storage capacity could help reduce curtailment levels. In addition, as per the Revised PDP8, interconnections to the wider ASEAN system are also mentioned, such as new interconnections planned with Malaysia and Singapore. Since the quantum and timeline of these interconnections will be needed to be analysed under a more detailed feasibility study keeping in check the reliability and stability aspects, the current simulations have considered the Vietnam system as standalone with only the interconnection with Cambodia. Thus, interconnections and export of the surplus vRE generation to neighbouring grids is a key aspect that needs to be considered in the planning process to avoid curtailment and enable optimum utilization of resources.

Along with exports, another avenue of absorption would be demand-side measures including changing EV load patterns to be in sync with the vRE generation through policy incentives. Curtailment reduction can also be achieved by looking into more flexible generation namely Aeroderivative gas turbines with excellent load following characteristics and low start-up times as well as operational changes in traditional baseload generators such as coal (lowering thermal minimum limits). Evacuation of power from these vRE resources will also need significant investments in transmission infrastructure. These are highlighted in the Revised PDP8 which emphasizes the need for strengthening the transmission backbone of the Vietnam Electricity Grid.

4.3 Transmission (Interconnection) Flows

The simulation model considers a high-level transmission interconnecting three regions, North, Central and South. The North and Southern regions will remain the largest demand centres over the long term. The Central region will be a crucial transmission interconnection to help transfer flows between the North and the South. The Central region is a lower demand centre with a very high installed base of largely hydro, solar and potential offshore wind plants.

This is evident from the net transmission flows on the Central to North interconnection (Figure 16) and Central to South interconnection (Figure 17). There is a consistent trend of export of energy from Central to North across all scenarios in the simulation horizon. Imports into Central from Northern are minimal and primarily seen in the long term (post 2045) as demand across all regions increases.

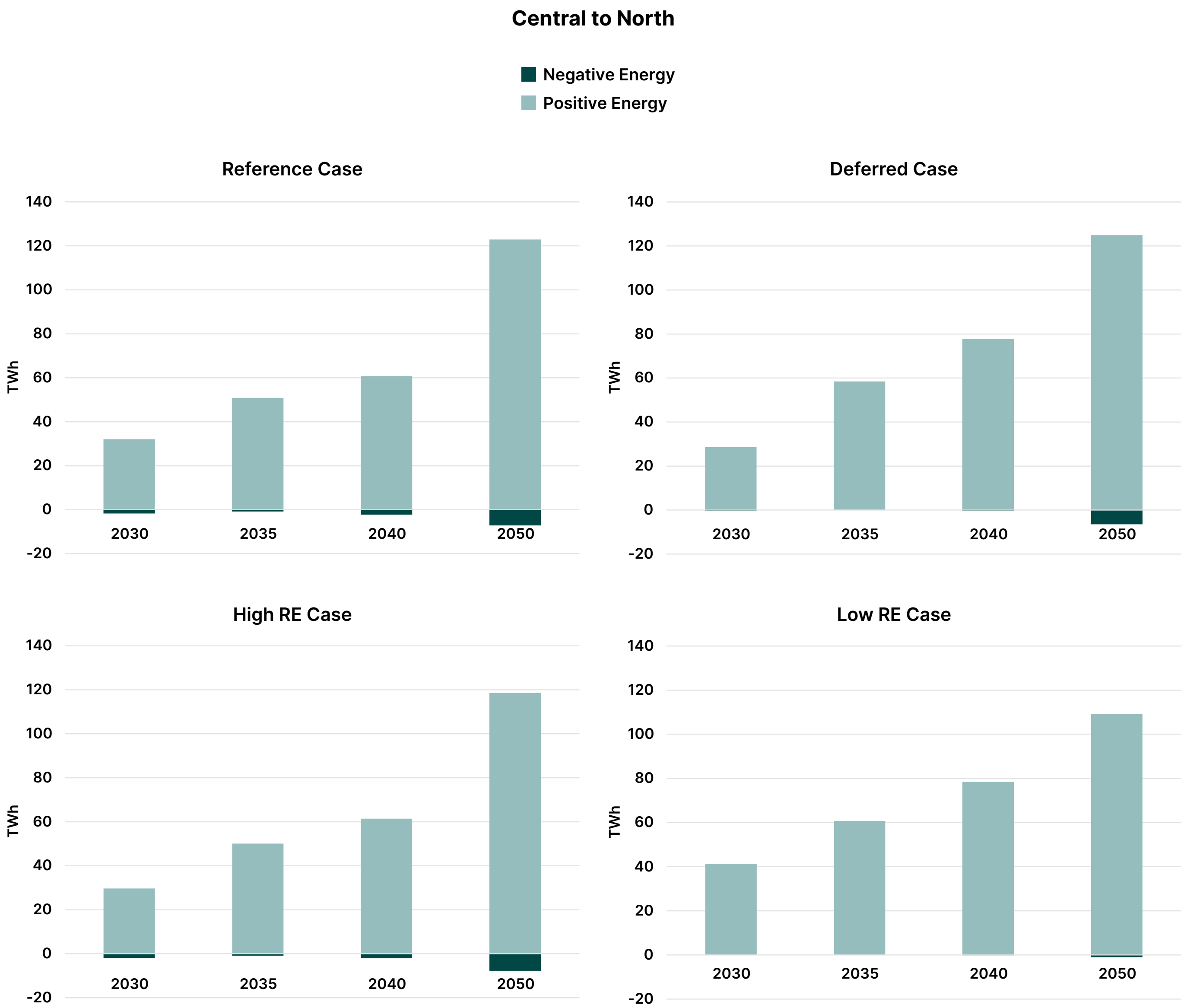


Figure 16: Net Transmission flows between Central to North regions across all cases

In the case of the Central to Southern interconnection, flows are predominantly from Central to Southern, but there is a small quantum of reverse flow in all cases from 2035 to 2040; This trend increases till the end of the horizon year (2050) especially in the Low RE case as renewable capacity additions have been lowered and their effect mostly impacts the central region.

As transmission infrastructure is integral to the evacuation of electricity from the generation sources to the demand centres, there has been a significant push by the government in investment and upgrade to the transmission sector. Multiple government documents, in particular the Revised PDP8, highlight the need to modernize and synchronize the grid through investment in digitization, aligning grid expansion with generation growth and regional needs, transmission upgrades of the backbone system (500kV, 220kV), reduction in system losses, and adoption of HVDC, ultra-high voltage and advanced grid technologies (SVC, SVG, FACTS, BESS and DLR)[9].

[9] SVC – Static VAR Compensator
SVG – Static VAR Generators
FACTS – Flexible Alternating Current Transmission Systems
BESS – Battery Energy Storage Systems
DLR – Dynamic Line Rating

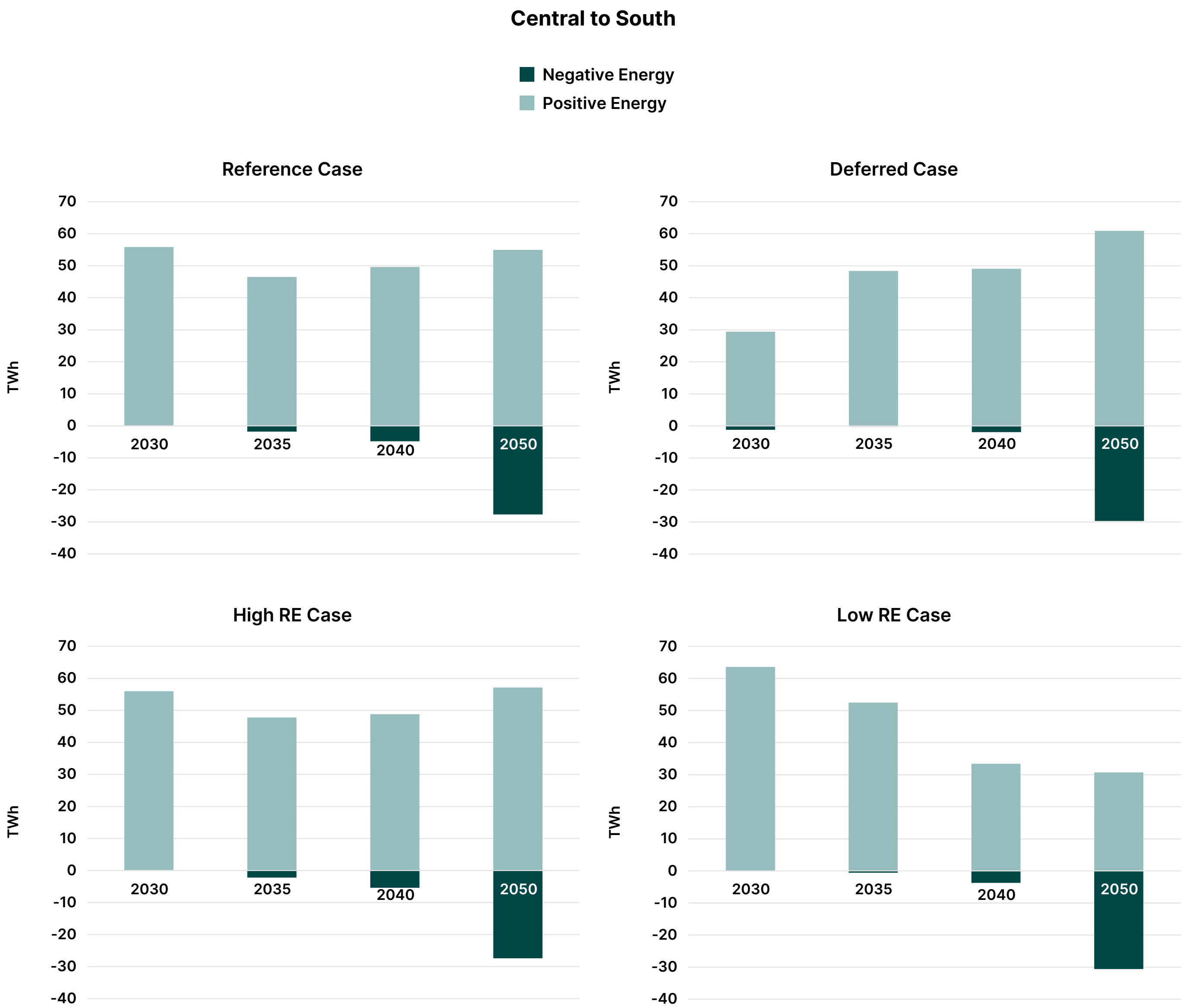


Figure 17: Net Transmission flows between Central to South regions across all cases

4.4 System Performance

Across cases, operational aspects on an annual basis for coal and gas are shown through average hours online as per Figure 18. Similar levels of operation are observed with the highest impact coming from the quantum of RE generation in the system respective to the installed capacity for the case. When RE generation is lower (short-term) higher operations are observed for coal and gas plants. With increasing penetration there is a decrease in the coal and gas contribution (as seen in the lower operating hours) in the mid-term and as demand increases in the long-term, there is a need for thermal generation to increase their contribution to address the growing system demand.

The need for flexible resources is indicated through showing the average starts of gas and storage technologies in Figure 19. As the penetration of renewables increase over the mid-term there is an increasing need for storage capacity to provide this flexibility. Gas-based technologies also contribute to the ramping requirements in the system. It is also observed through the higher operational numbers from Pumped Storage Hydro which indicate the potential for long duration storage in the system (dependent on the load pattern).

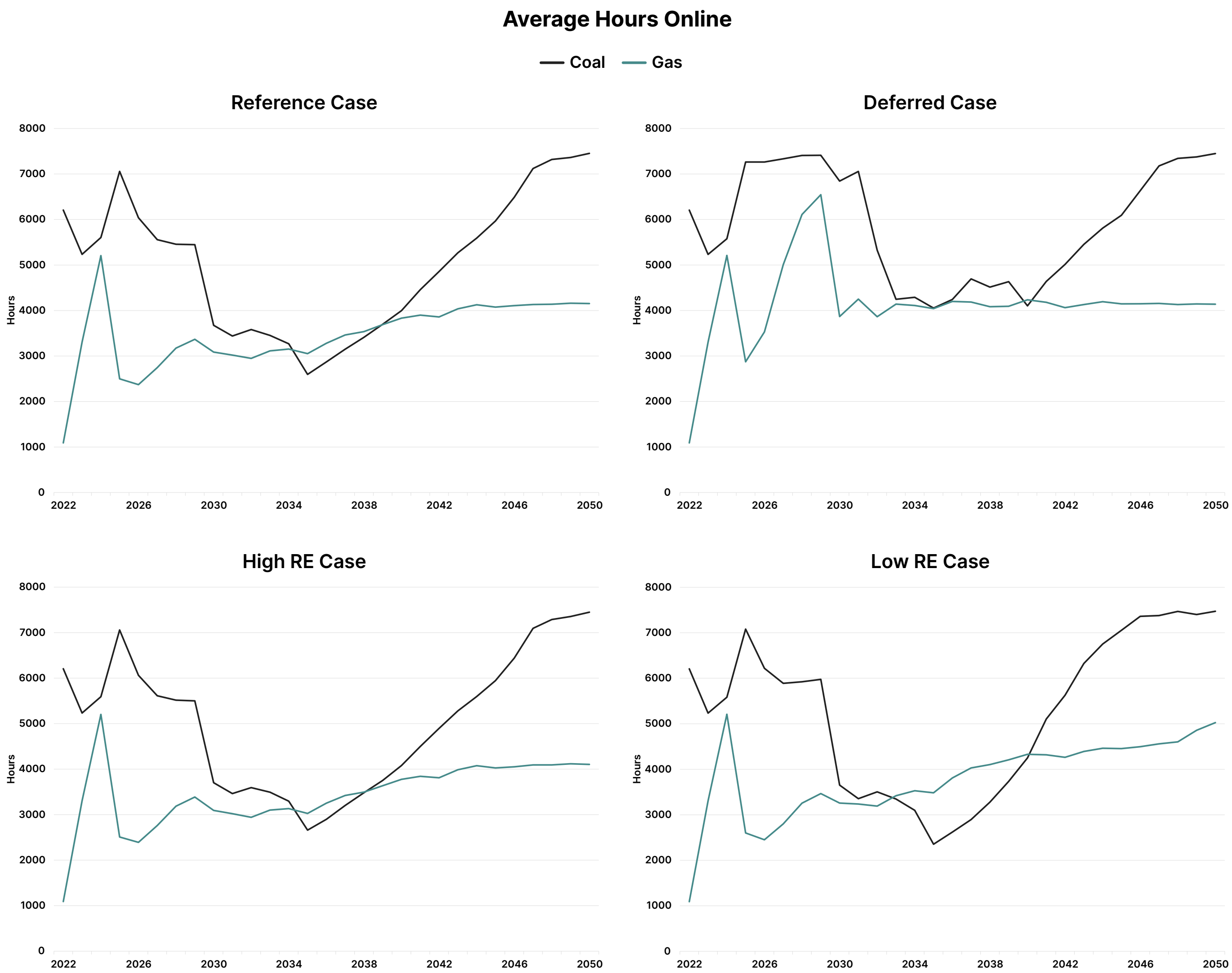
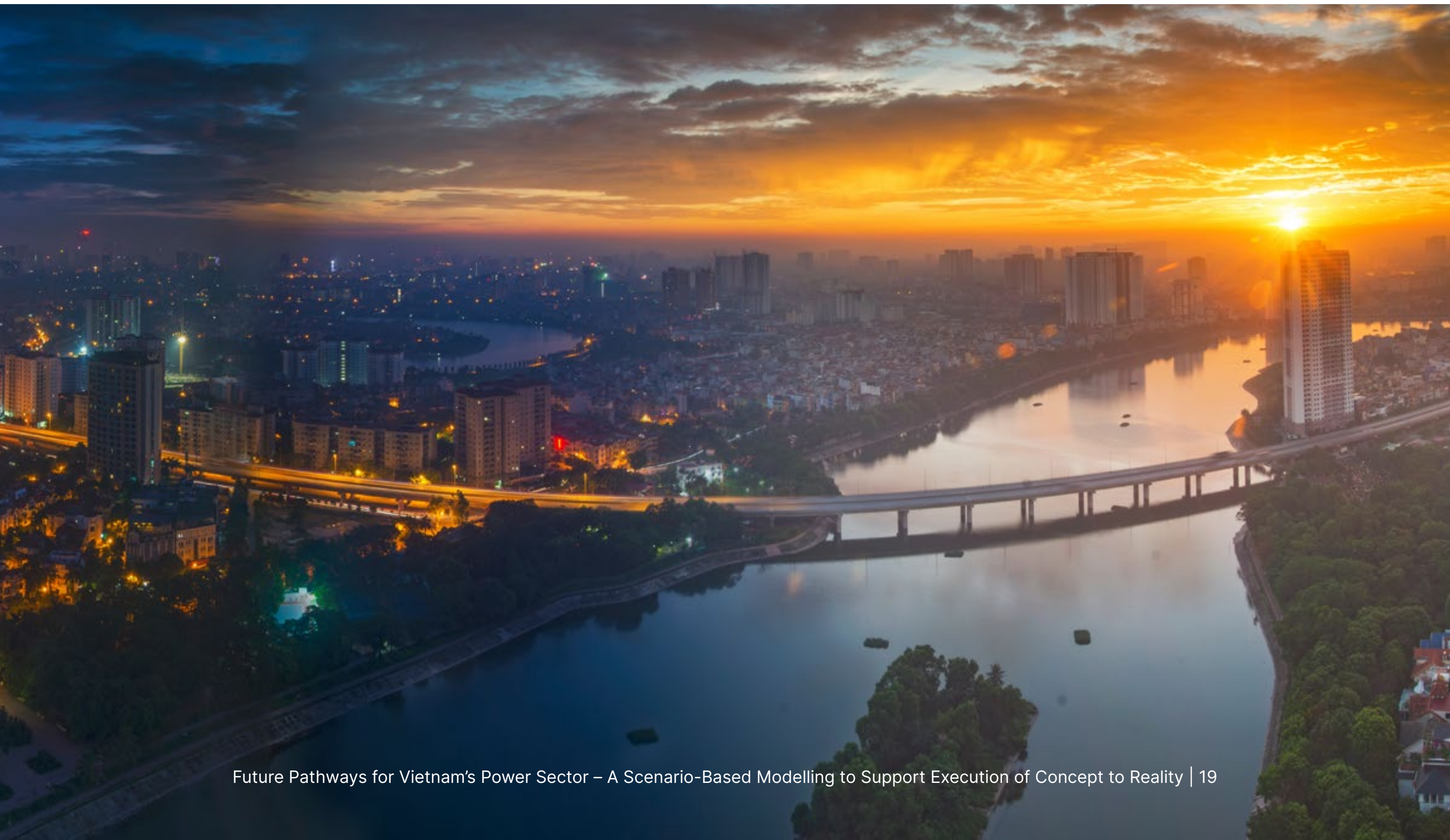


Figure 18: Average Hours Online (Coal and Gas)



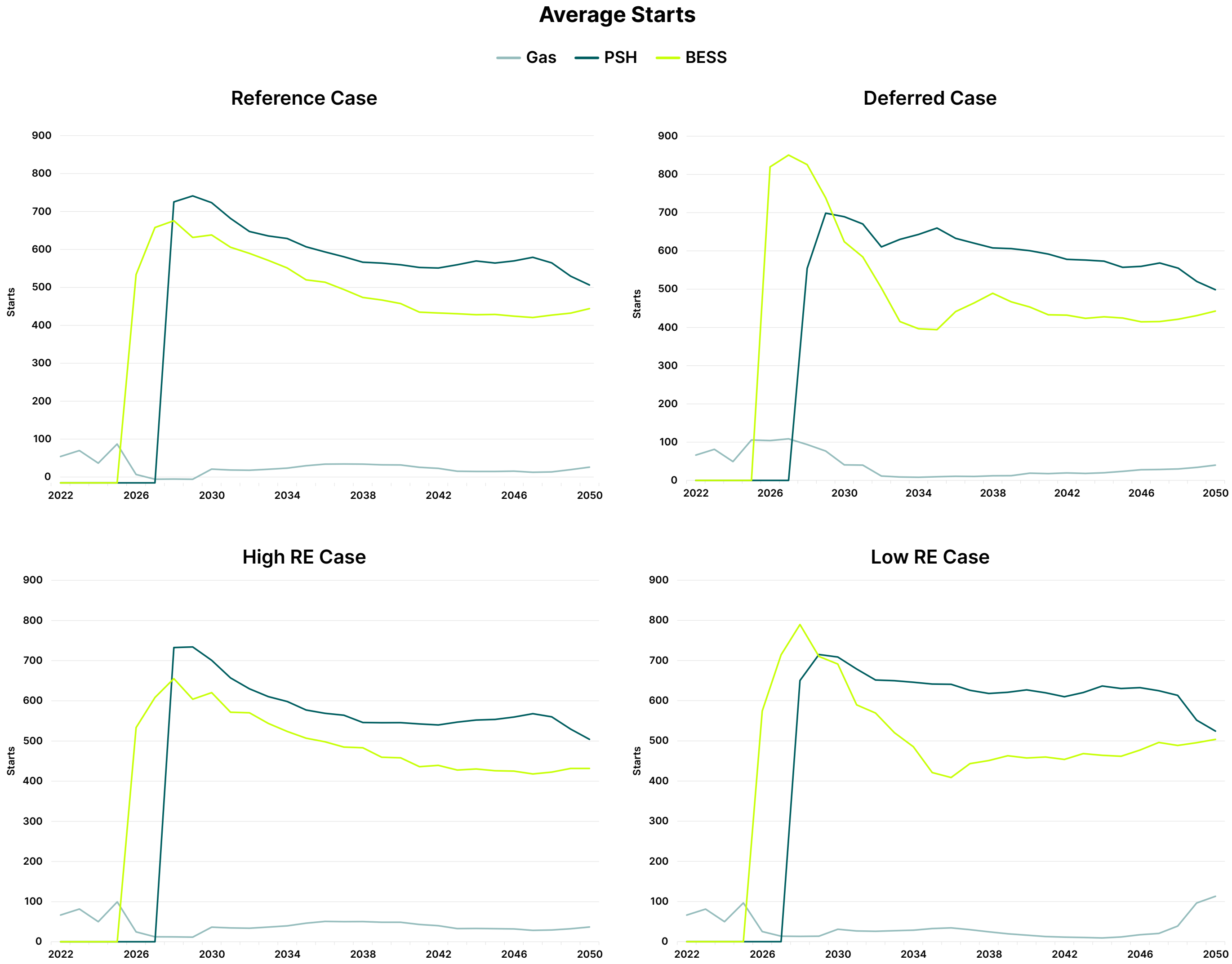


Figure 19: Average number of starts (Gas and Storage)

An hourly snapshot of the system in the Deferred Capacity case where capacity additions are synced with the current pace of buildout is shown in Figure 20. Two periods are highlighted for the year 2030 which include a high vRE generation period and a high demand period for the Deferred Capacity case. In the case of high demand, the thermal capacity along with hydro generation cater to the demand requirements along with vRE generation (no curtailment is observed). The ramping requirement in this period is mostly catered to by hydro and storage technologies and thermal based technologies (gas and coal) would need to ramp down during periods of high solar generation. In the High RE generation periods the gas-based generation fleets along with hydro will need to be available to meet the variability in the system. During the high demand period most of the thermal generation (Coal and Gas) would be operating to meet demand requirements and variation in RE generation is mostly handled with the help of Hydro and some amount of storage generation.

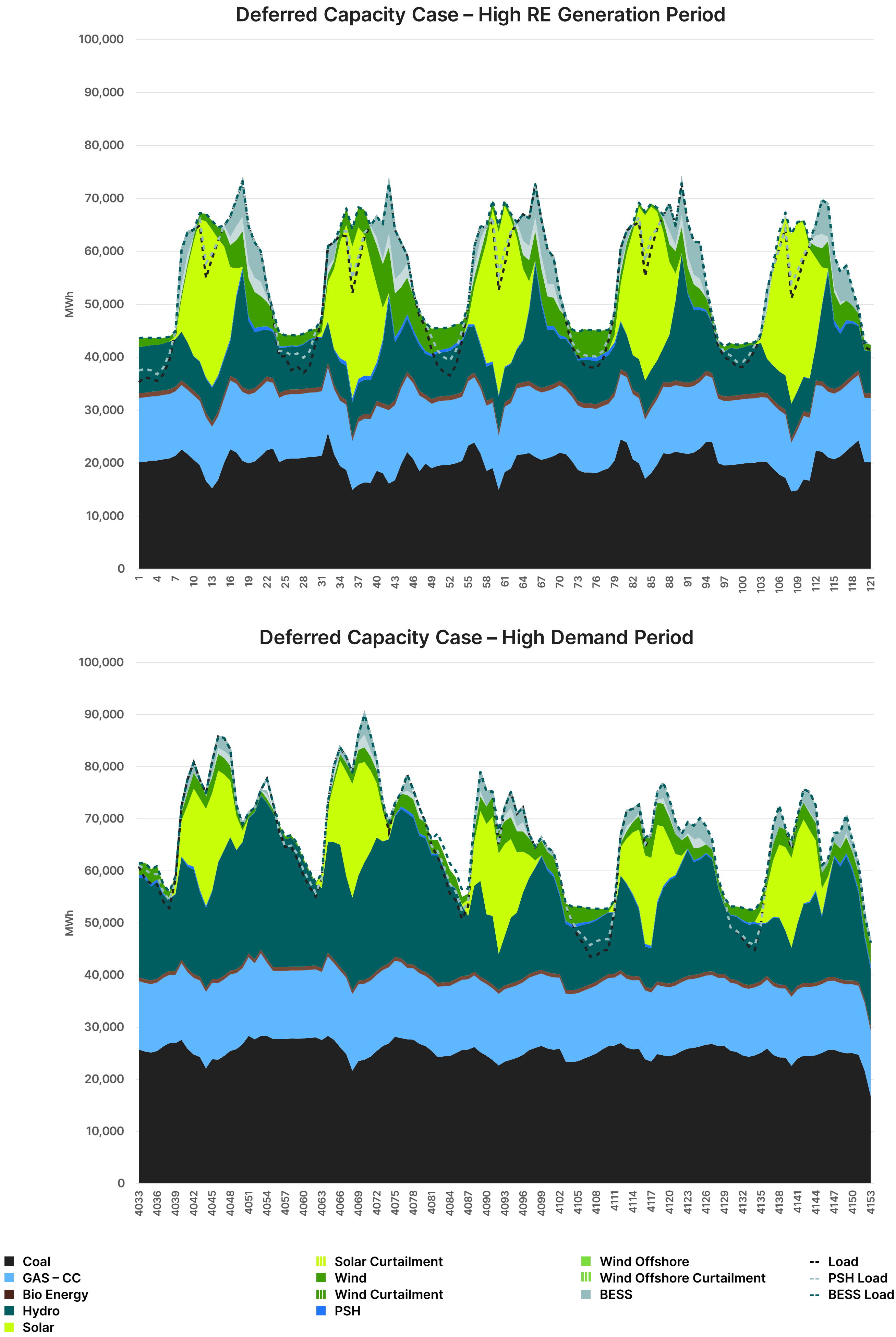


Figure 20: 2030 Dispatch Stack for Deferred Capacity Case

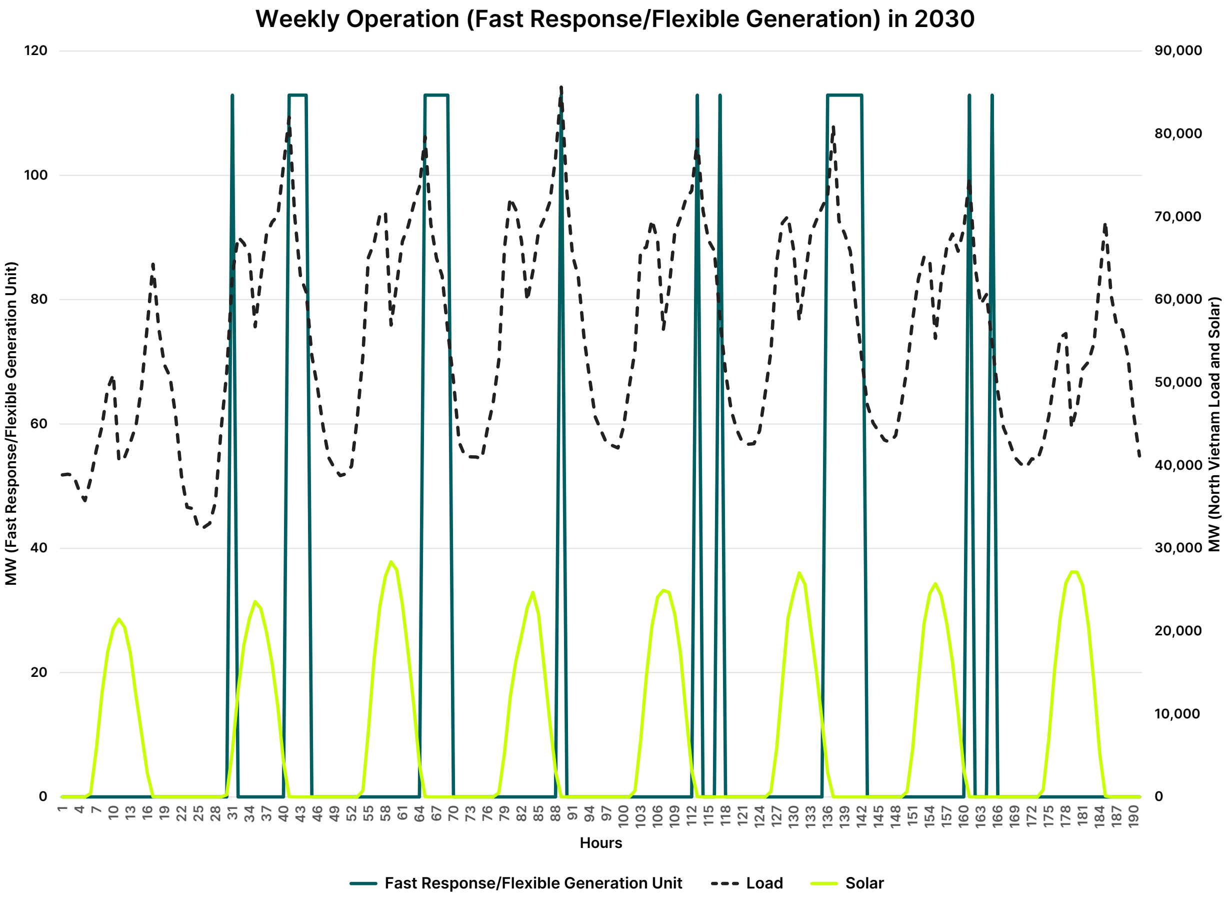


Figure 21: Fast Response/Flexible Generation Unit hourly operation snapshot

Flexible generation with fast response capability (gas fired units) will help meet the need for responding to both demand and renewable generation variations. Figure 21 depicts an hourly snapshot of operations of a fast response flexible generation unit during a high demand period in the Northern region in 2030. As seen during periods where solar generation ramps down and system load peaks the flexible generating unit ramps up to cater to this variation. These units have excellent load following characteristics and have the capability to come online within a short period (<10 mins or faster) to meet tertiary reserve requirements and help planners and system operators to smoothen operations. Larger thermal units would be slower to respond to these variations and will involve significant planning and a high level of forecasting accuracy to cater to these sudden variations.

Increasing penetration of renewables have distinct complexities for grid adequacy, operational reliability, and system stability. It is not sufficient to show that annual energy and peak capacity are adequate; the system must also maintain frequency, voltage, and secure power flows in real time, and be resilient to recover from disturbances and extreme events. As inverter-based resources displace synchronous generation, traditional sources of inertia, fault current, and reactive power decline, changing how the system behaves following contingencies and tightening operational margins.

System flexibility becomes a central requirement. Variability and uncertainty in wind and solar output increase the need for fast-acting resources across multiple timescales: from sub-second frequency response to intra-day ramping and even seasonal balancing. A portfolio of flexible assets- more flexible operation of thermal units, hydro and pumped storage hydro, batteries, demand-side flexibility (including industrial load shifting and managed EV charging), and grid-enhancing technologies such as dynamic line ratings, topology optimization, and HVDC must be planned and operated as an integrated flexibility stack.

Traditional reliability criteria (such as N-1 and N-1-1) remain important, but planners also need to consider a broader set of "credible extreme events" given the changing resource mix. Black start and system restoration strategies must adapt as well, with greater reliance on grid-forming inverters, storage, and distributed resources to re-energize the grid in a controlled manner. At the same time, the infrastructure required to interconnect large volumes of renewables introduces new points of vulnerability, and correlated weather risks (wind lulls, heat waves, wildfires, smoke events) must be explicitly considered, making resource diversity, geographic dispersion, and targeted hardening and redundancy key design principles for resilience. Addressing these issues requires explicit performance requirements for renewable and storage plants, additional reactive compensation (such as STATCOMs, SVCs, and synchronous condensers), advanced volt/VAR control, and updated approaches to contingency planning, black start, and system restoration in a more decentralized, weather-dependent grid.

4.5 Emissions

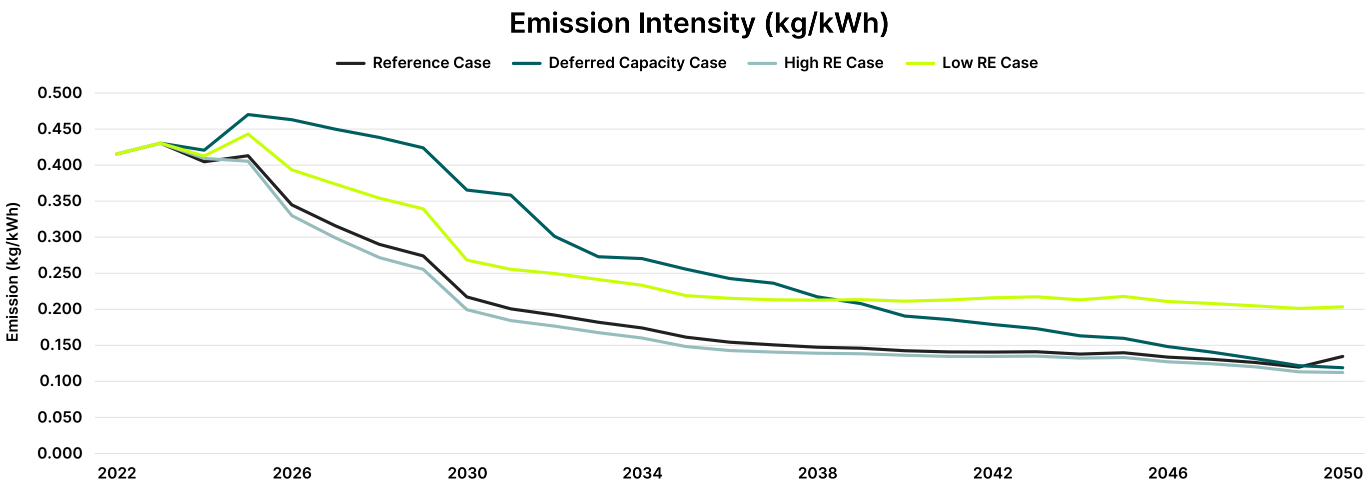


Figure 22: Emission Intensity Comparison between Cases

The increasing contribution of renewables in the overall generation mix will reduce CO2 emission intensity over the years as illustrated in Figure 22

The Reference case illustrates a gradual but consistent reduction in CO2 emission intensity over the years. Starting at 0.415 kg/kWh in 2022, the emission intensity reduces to 0.135 kg/kWh by 2050. The most significant drop in emission intensity occurs between 2026 and 2030, where it decreases from 0.344 kg/kWh to 0.217 kg/kWh due to the large RE installations during this period.

In contrast, the Deferred Capacity case shows an initial increase in CO2 emission density until 2027, peaking at 0.470 kg/kWh before beginning to decline. This is largely due to the deferred renewable capacity installations.

These scenarios collectively emphasize the critical role of renewable energy in decarbonization of the electrical system. The Reference case shows a steady reduction with significant improvements between 2026-2030. The Deferred Capacity case highlights the consequences of delayed implementation, resulting in higher short-term emissions but eventual alignment with long-term goals. The High RE case underscores the benefits of early and substantial renewable energy integration, leading to rapid emission reductions. Conversely, the Low RE case illustrates the challenges and slower progress associated with minimal renewable energy adoption, which could be addressed through utilization of Hydrogen to achieve emission targets. Overall, these insights reinforce the importance of timely and significant renewable energy deployment in achieving lower CO2 emission intensity.

5. Factors Beyond the Plan

To enable the execution, from concept to reality, according to the plan, there are other elements which need to be considered. These include financing and capacity building requirements.

5.1 Installed Base and Generation

To reach the expected ~200GW Reference case installed generation capacity under Revised PDP8 by 2030, ~US$136 billion[10] of investment capital is required between 2026-2030, and an additional ~US$700 Billion[10] of investment is required from 2031-2050 to reach the 2050 Reference case capacity of ~760GW.

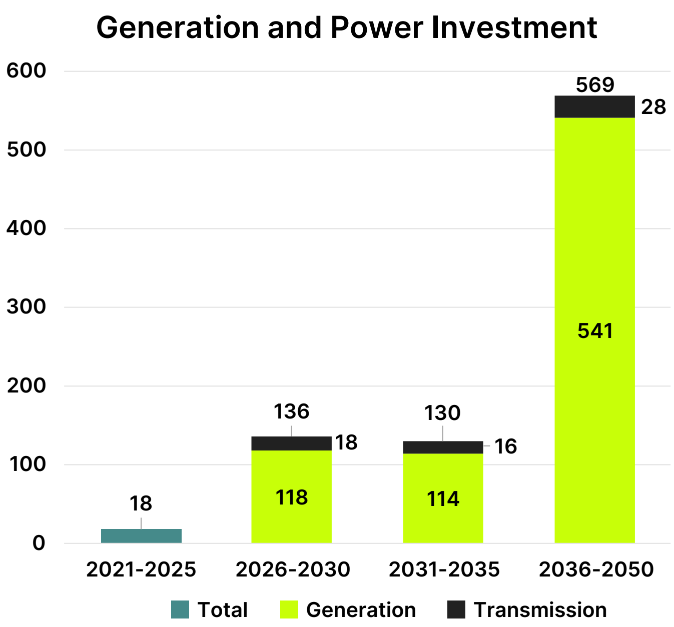


Figure 23: Generation and Power Investment required under Revised PDP8 (2026-2050, USD billion)[11]

[10] https://www.pecc3.com.vn/en/pdp8-revision-a-strategic-direction-for-sustainable-energy-transition-in-vietnam/
[11] Note that these figures are based on the planned investment in the power sector for 2021-2025 under Decision No.345/QD-TTg; No breakdown of required investment available

Gas Financing

No Gas Financing

		Project Limit	Vietnam Country Limit
	USEXIM	Based on US content	✓
	DFC	Up to US$18	✓
	SACE	Case by case basis Based on content	✓
	Saudi EXIM	Case by case basis Based on KSA content	✓
	KUKE	Case by case basis Based on PL content	✓
	HEXIM	Case by case basis Based on HU content	✓
	SERV	~US$650M Private ~US$650M Sovereign	Up to $2B
	BPI	Based on FR content	✓
	ECI	Case by case basis Based on UAE content	✓
	EDC	~US$700M	✓
	UKEF	Based on UK content	At least £5B
	Euler Hermes	Based on DE content	✓

✓ No country limit
✓ Smaller ECAs with limited balance sheet

Figure 24: ECA funding limits for Vietnam[12]

ECAs can play a crucial role in financing Vietnam's power projects, particularly for large-scale energy transition initiatives like LNG to Power projects. ECAs involvement is necessary to provide guarantees and risk mitigation, attracting commercial banks and enabling the long-term loan tenors required for such capital-intensive investment.

A collaboration between commercial banks and ECAs provides key benefits which includes loan guarantees by ECAs, preferential interest rate support to buyers, co-financing and syndication for large projects and political risk insurance where ECAs provide insurance to a lender against non-payment due to political event.

Vietnam is rapidly developing its LNG to power capacity as a key part of its revised PDP8 to reduce reliance on coal. The landmark Nhon Trach 3 and 4 projects were financed using a hybrid corporate model that included tied and untied ECA facilities, setting a precedent for future projects without government guarantee.

5.2 Capacity Building (Skills & People)

Vietnam's energy transition requires a fundamental transformation in how the country develops and deploys its human capital in the electricity sector. The nation must cultivate high-quality human resources across all critical areas-from electricity generation and transmission to load dispatch, market operations, and smart grid management recognizing that technological advancement must be supported by skilled professionals capable of operating, maintaining, and innovating within complex systems. At the heart of this effort is building a contingent of highly skilled experts and scientists who will form specialized units and centres of excellence, driving innovation and elevating Vietnam's position in the regional energy landscape. To achieve these goals, comprehensive training and retraining programs must be implemented for technicians and managers, designed to meet world-class standards with modernised curricula that combine theoretical knowledge with practical, hands-on experience directly connected to production realities. Vietnam's strategy is further strengthened through international cooperation, particularly initiatives like the Just Energy Transition Partnership (JETP) as well as other initiatives by domestic, international and private organizations which provides access to workforce training, technology transfer, and governance expertise from various partners and initiatives. This dedicated focus on human capital development, formalized through the government's priority "Scheme/project on training and improving the quality of human resources," in the Revised PDP8 will ensure that Vietnam's workforce is equipped to lead the country's electricity sector confidently through 2050 and beyond.

Vietnam's electricity sector is poised for significant workforce expansion as the country transitions toward renewable energy under its Power Development Plan 8 (PDP8). The sector's direct labour requirements are projected to increase by approximately 67% over the next decade, growing from around 300,000 full-time employees (FTEs) today to approximately 500,000 FTEs by 2035. It is also projected that by the 2030s, wind and solar technologies are estimated to account for more than half of the direct labour force in the power sector i.e. around 300,000 FTEs[13].

[12] GE Vernova Financial Services analysis
[13] Projection of Labour Force for Viet Nam's Energy Transition by New Climate Institute and GiZ

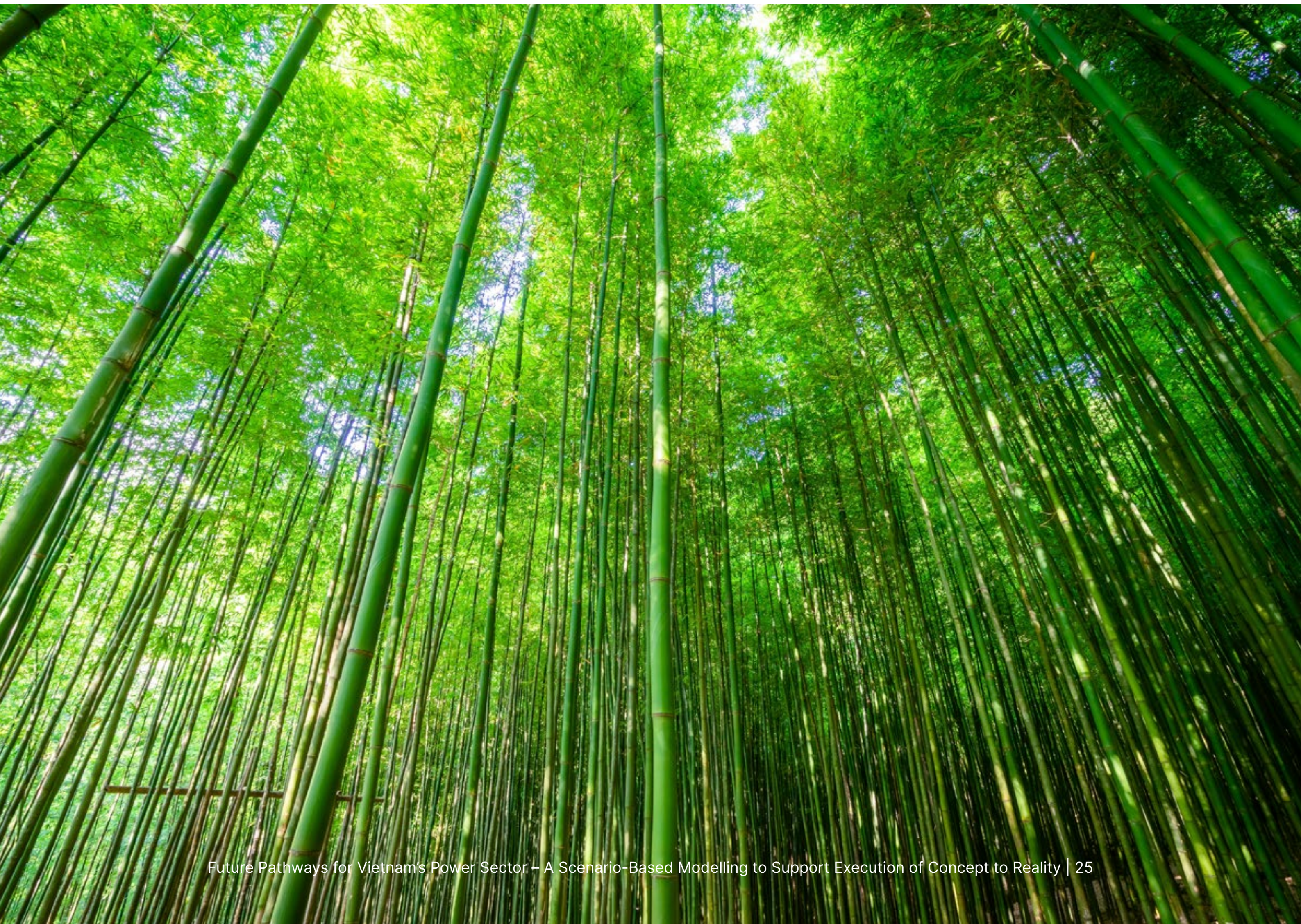
A few areas which could be considered for capacity building include:

- RENEW Skills Development Program for energy transition.
- Power generation technology training (gas turbines, combined cycle plants).
- Renewable energy workforce development (wind energy, offshore wind).
- Grid modernization and digitalization skills.
- Energy storage and grid solutions training.
- Digital power plant technologies and Asset Performance Management.
- Partnerships with technical universities and vocational institutions.
- Operations and maintenance certification programs.
- Women in energy STEM education initiatives.

Capacity building programs are an important step in helping bolster the economic growth and development towards a cleaner, inclusive, secure and sustainable electricity grid.

5.3 System and Market Coordination

Generation, transmission, and market reforms should move in a coordinated manner, as the timing and sequencing of each strongly influence system costs, reliability, and investor confidence. Accelerated deployment of renewable energy and new thermal capacity requires sufficient transmission infrastructure to evacuate power from high resource regions to demand centres. Delays in grid expansion can strand new generation assets, increase curtailment, and undermine both cost and emissions outcomes. As highlighted in the revised PDP8, there is a strong emphasis on co developing generation and transmission, incorporating provincial needs and strengthening key system corridors-underscoring the importance of a carefully planned, phased build out. In this context, continued efforts to enhance transparency, progress toward more cost reflective tariffs, and the use of increasingly bankable contracting frameworks can support both generation and grid investment. Over time, and consistent with the evolution of the power sector, these measures can be complemented by further development of spot markets, adequacy mechanisms, and congestion management tools that help align operational and investment decisions with system needs.



Experience from power systems with high renewable penetration underscores the role of timely market evolution in managing curtailment risk, stranded assets, private investment incentives, and reliability. Australia's National Electricity Market (NEM) and the Electric Reliability Council of Texas (ERCOT) in the United States have introduced more granular pricing-through five-minute settlement and regional pricing with constraint-based dispatch in the NEM, and full nodal locational marginal pricing in ERCOT alongside competitive ancillary service markets to reward flexibility and reduce curtailment. Germany and the United Kingdom have relied on combinations of priority dispatch (historically within the EU framework), long term support contracts with curtailment compensation, and well-developed balancing and ancillary service markets; in the UK's case, these are complemented by a formal capacity market to maintain reliability and protect investors as renewable penetration increases. Chile illustrates the value of coordinated transmission planning, nodal pricing, and long-term auctions in reducing the risk of stranded generation and curtailment.

5.4 Regional Cooperation

Vietnam is currently interconnected with China, Lao PDR, and Cambodia, mainly through 110–220 kV lines, with some 500 kV interconnections either in operation or at advanced planning and development stages. These interties support bilateral power trade, with cross border flows governed by long term PPAs and associated operational and technical protocols rather than a fully integrated regional power market.

Looking forward, Vietnam's plans under the revised PDP8 are closely aligned with the ASEAN Power Grid (APG) vision. Vietnam is pursuing expanded 220/500 kV interconnections with Lao PDR to import hydropower and reinforcing ties with Cambodia that could, over time, support limited wheeling arrangements across the Mekong sub region. At the wider ASEAN level, Vietnam participates in APG related initiatives aimed at developing multi country power trade corridors, where power from Lao PDR and potentially Vietnam, subject to future agreements could be wheeled through Thailand and Malaysia to Singapore, building on pilot projects such as the Lao-Thailand-Malaysia-Singapore (LTMS) arrangement. The expected benefits include lower overall system costs through access to diverse regional resources (notably Lao PDR hydropower), improved integration of Vietnam's growing wind and solar generation through regional balancing, and enhanced security via shared reserves and emergency support. Realizing these benefits will require continued efforts to harmonize grid codes, technical standards, commercial frameworks, and regulatory arrangements, alongside joint transmission planning, regional system studies, and clearer rules for cross border trading and wheeling under both ASEAN level frameworks and bilateral or multilateral agreements.

6. Observations

The analysis above which is based on hypothetical cases uncovered several insightful observations.
The key findings of the simulations are:

1. **Operational challenge emerges with high vRE penetration coupled with demand growth:** Energy penetration from vRE in the Reference case is ~33% in 2030. The high penetration from vRE resources is supported with the help of Hydro, Pumped Storage, BESS and fast response flexible generation (gas-based). To meet the high demand growth, natural gas-based generation will serve as a crucial bridging technology and is projected to increase at least three-fold (from 8.7GW to 25.6GW capacity by 2030) even under the Deferred Capacity case to provide both baseload and flexibility requirements.
2. **Delayed execution could lead to resource adequacy concerns:** Reserve Margins in the system will remain high in the Reference case driven by the large additions of storage and high vRE based technologies. However, the Deferred Capacity case, where the pace of capacity additions has been slowed down, the Reserve Margin (~13%) in the system by 2030, emphasizes the need for timely capacity additions to meet the growing demand.
3. **Flexibility needs for meeting operational complexities:** With high levels of vRE penetration there is a need for flexible generation such as BESS, Pumped Storage as well as fast response units to help in meeting the changes in vRE generation. From the simulation results, even for year 2030 in the Reference case the ramping requirements exceed 1000MW/hour for about 10% time. These ramping requirements in the system would be primarily catered to by these technologies, improving vRE absorption.
4. **Curtailment management in outer years:** With large vRE penetration curtailment is observed in the simulation for all cases, with the lowest seen in the Low RE case. In the Deferred Capacity case the curtailment levels are manageable till 2040 and as it reaches the 2050 target of the Revised PDP8 the curtailment levels are close to the Reference case simulations. As the vRE generation is catering to meet demand of the electricity sector, the curtailed energy could be used for producing additional green Hydrogen (Power to X) in the range of 1.8-3.0 million tonnes per annum by 2050.
5. **Increasing penetration of vRE** puts downward pressure on Locational Marginal Prices (LMPs) but with demand growth, 2050 LMPs will be predominantly set by costlier generating plants: As cheaper resources supply electricity there will be a drop in average system LMPs of about 53% from 2025 levels by 2030. As penetration of vRE and low-cost resources increases the system will see a gradual fall in LMPs till 2045, and by 2050 a slight increase as the demand will need costlier generators to meet the load.

6. **Central Vietnam will function as a critical transmission corridor:** North and South Vietnam account for ~91% of demand, requiring substantial interconnection capacity. Strengthening of the 550kV and 220kV backbone transmission system hence becomes critical to evacuate power from generation sites to load centres. It is observed from the flows that the Central region is a major backbone of the transmission network.

7. Conclusion

Based on the findings, under various cases, there are several areas for consideration to mitigate the risks, and ensure secure, affordable and sustainable power in Vietnam:

- **Requirement of thermal power plants:** As demand growth continues with the economy expanding, resource adequacy plays a key role, with the thermal fleet, through a focus on gas-based technologies, playing a key role (20-30% of generation mix) in meeting this demand over the medium and long-term horizon. Existing fleets with continued investments in maintenance and retrofits for extending their lifespans would help reduce the burden of expediting new generation buildouts to meet increasing demand. With expected continued utilization, decarbonization of thermal fleets will need to be addressed to meet emission targets.
- **Key role of flexibility:** Flexibility in the power system is a key requirement with high vRE penetration. To address this, as well as accelerating the deployment of battery energy storage systems (BESS) and pumped hydro facilities, Vietnam could consider developing flexible gas-fired power plants. These are capable of rapid ramping and have the ability to provide capacity at short notice, with technologies like the aeroderivative gas turbines with excellent load following characteristics, to improve renewable absorption.
- **Curtailment Management:** To manage curtailment levels, Vietnam can consider developing further the Power-to-X capabilities for green hydrogen production in addition to the current targets. The analysis shows significant hydrogen production potential from curtailed energy (reducing curtailment to ~11% by 2050). Other measures that could be considered include demand side management measures, which include smart EV charging aligned with renewable generation, load shifting and regional integration to monetize excess renewable generation by developing further interconnections with neighboring countries beyond the existing ones.
- **T&D backbone buildout:** With central Vietnam expected to function as a critical transmission corridor between North and South regions, it requires substantial interconnection capacity. Strengthening of the 550kV and 220kV backbone transmission system hence becomes critical to evacuate power from generation sites to load centres. As the grid becomes more complex with higher penetration of Inverter Based Resources (IBR), it would be important to invest in smart grid technologies and forecasting capabilities for real-time management and optimization over the short to medium term.
- **Financing:** As per the revised PDP8 the total investments required in generation and T&D would be ~US $118 billion till year 2030, with an additional ~US$700 billion from 2031 to 2050. Vietnam should consider leveraging Export Credit Agencies (ECAs) for large-scale project financing and develop diverse funding sources including commercial banks working with ECA guarantees. Project PPAs with bankable characteristics could also contribute to lower the cost of financing and increase the chance of financing as well.
- **Capacity Building:** The power sector is projected to create about 200,000 additional jobs by year 2035[14]. There is expected to be a fundamental workforce transformation across all electricity sector areas with a key imperative to develop comprehensive training programs for technicians and managers to world-class standards.
- **Market structure reforms:** Vietnam is in the process of setting up of a wholesale power market in year 2026. With higher RE penetration and flexible supporting power requirement, it is important to consider establishing supportive regulatory frameworks including an ancillary services market that incentivizes flexible resources and ensures fair cost recovery mechanisms for all stakeholders.

Vietnam's energy transition represents one of the world's most ambitious decarbonization efforts, requiring coordination across multiple sectors and technologies. Transmission infrastructure requires major upgrades to evacuate renewable power from generation sites to load centres. Deployment of storage and fast response flexible gas-based generation is essential for managing intermittent renewable generation and maintaining grid stability during weather-dependent generation variations. Regional integration through ASEAN interconnections will provide outlets for surplus energy export while enhancing overall system flexibility. Policy support must establish regulatory frameworks that incentivize flexible resources and demand management while ensuring fair cost recovery. Technology innovation in advanced grid management and forecasting capabilities will enable operators to predict and respond to system conditions with unprecedented precision. A balanced approach that combines the above will ensure Vietnam meets its vision for the energy sector, while providing prosperity to its people.

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