The need for flexible internal combustion engine (ICE) power plants and their applications in Vietnam's future power system

ACKNOWLEDGEMENT

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Foreword

During more than 45 years of friendship, Vietnam is always one of Finland's main development cooperation partner countries. Under a number of bilateral programmes, Finland has supported Vietnam in the development of key sectors, such as water and sanitation, forestry, and innovation. The Embassy of Finland in Hanoi has enjoyed a successful cooperation with Vietnam's Institute of Energy. Together, we have carried out a comprehensive study mapping the potential for biomass as a source of renewable energy in Vietnam. Many specialists and researchers from the Institute have had in-depth and frequent exchanges with Finnish experts in the field of energy, and this study is another great example of the continuing collaboration between the two countries.

As Vietnam is currently preparing its new plan to optimize the future energy mix, Finland is committed to supporting Vietnam in the energy transition towards a sustainable and reliable power system. A flexible source of power is one of the key factors for Vietnam to ensure national energy security for socio-economic growth, while prioritizing the development of renewable energy and gas to power generation, as aligned with Resolution 55 of the Vietnam's Politburo on the orientation of the National Energy Development Strategy until 2030, with a vision to 2045.

Kari Kahiluoto
Ambassador of Finland to Vietnam

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Executive summary

The global energy landscape is in transition towards more flexible and sustainable energy systems. As the cost of renewables continues to decline, the number of new investments into coal-fired plants and other inflexible baseload technologies is decreasing. Vietnam has emerged as the hotspot for clean energy investment within Southeast Asia, driven by solar developments with cumulative installations expected to reach more than 5 GW in 2020. Power demand grew at an average rate of 10% annually from 2016 to 2020 on the back of a growing manufacturing industry and it is expected to grow at an average rate of 8% for the period of 2021-2030.

Currently, Vietnam's power system is facing various challenges, including the lack of an adequate supply of electricity to meet growing demand, environmental pollution, and delays in large thermal power plant projects. EVN and MOIT have been working towards finding quick solutions to reduce the risk of annual electricity shortages. Recently, a number of wind and solar power, and CCGT (LNG) power plant projects have been added to the Power Development Plan No.7 (Revised) to address the issue. As the share of renewable energy ("RE") will continue to increase, Vietnam's power system will face new challenges not only in maintaining system reliability and resilience, but also in balancing net load demand to ensure system stability. Without adequate and detailed planning, the overall cost of generation may increase, despite the addition of lower cost RE.

This study introduces a sustainable, reliable, and affordable type of power generation technology, the Internal Combustion Engine (ICE). ICE-based power plants can be built quickly and operate flexibly as an enabler for power systems with a high proportion of solar and wind power. Without flexible ICE-based power plants it will be difficult to balance the system and to provide critical power. Furthermore, significant RE penetration cannot realistically be achieved, and the savings by low cost RE will not be realized without ICE. An ICE can reach 100% capacity within just 2 minutes, can quickly be ramped up and down, and can be shut down and restarted without any operational penalties. This ability saves fuel, wear-and-tear as well as emissions, since running the engines idle is not necessary.

ICE-based power plants are different than conventional thermal power plants using Steam & Gas Turbines. These contemporary combustion engine plants provide ultimate flexibility with high efficiency, harnessing gaseous, liquid or biofuels. These plants can operate on baseload, provide peaking power, and also provide grid stability services. ICE power plants comprise standardized modular units, allowing for fast construction time (within 1 year only) and easy expansions. It is necessary to determine the optimal investment in new generation assets in Vietnam, and to study the role of ICE power plants using LNG in the grid from 2020 to 2050. Flexible ICE power plants are the key to ensuring demand is met in the short term while enabling the smooth integration of renewables into the grid.

The analysis in the study is carried out using powerful modelling tools, such as BALMOREL, PDPAT and PLEXOS. The study has focused on the role of flexible power generation and the use of ICEs in Vietnam's future power system. The objective of the study is to optimize the future power system in Vietnam with the lowest total system cost, while maintaining system stability and reducing emissions.

The study has considered different scenarios in different planning horizons: long-term (2020-2050), medium-term (2020-2030) and short-term (2020-2025) for the future power development plan of Vietnam's power system. These alternative scenarios reflect different situations such as; delays in committed power plant projects until 2025, lower renewable prices with increasing competition, and capacity optimization until 2050 using BALMOREL modelling software.

This Vietnam power system study carried out by the Institute of Energy (IE) under the Ministry of Trade and Industry (MOIT) recommends adding internal combustion engine (ICE) power plants from 2022 onwards into Vietnam's power system. The ICE power plants need to be built in the South with a total capacity of 650MW during 2022-2023. These ICE power plants will support the high energy demand by 2025, especially as Vietnam is expected to experience delays in the delivery of some coal and CCGT power projects in the South. Additionally, drought conditions could create a risk of power shortage in the country. In the long term, the needed capacity of flexible ICE power plants to provide reserve capacity, supply peak demand, and balance the renewable generation in the grid will be 2.5GW in 2030, 10.6GW in 2040 and 13.4GW in 2050. With ICEs in the system, total system cost will be reduced by 180 million USD/year in 2030, and similar savings can be achieved in the future years by building more ICE power plants.

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total installed capacity of ICE (MW)	400	650	650	650	650	650	1250	1850	2450
North (MW)							300	600	900
South (MW)	400	650	650	650	650	650	950	1250	1550

With all the benefits provided by ICE power plants to the power system of Vietnam, as showed in the modelling study, IE strongly recommends that the planning and policy authorities include ICE power plant projects in the Power Development Plan No. 8 (PDP8) starting from 2022-2023 with a capacity of 650 MW in the Southern power system. To ensure the financial viability of the ICE power plant project, this study proposes to develop a mechanism for reserve capacity payments for flexible power plants, and develop an ancillary services market for the Vietnam grid.

Chapter 1. Overview of the Energy and Power System of Vietnam

1.1. Overview of Vietnam's power system

Vietnam's economic growth during the period of 2011–2019 has been relatively high compared to the rest of the world, reaching an annual average of 6.3% for the last 10 years.

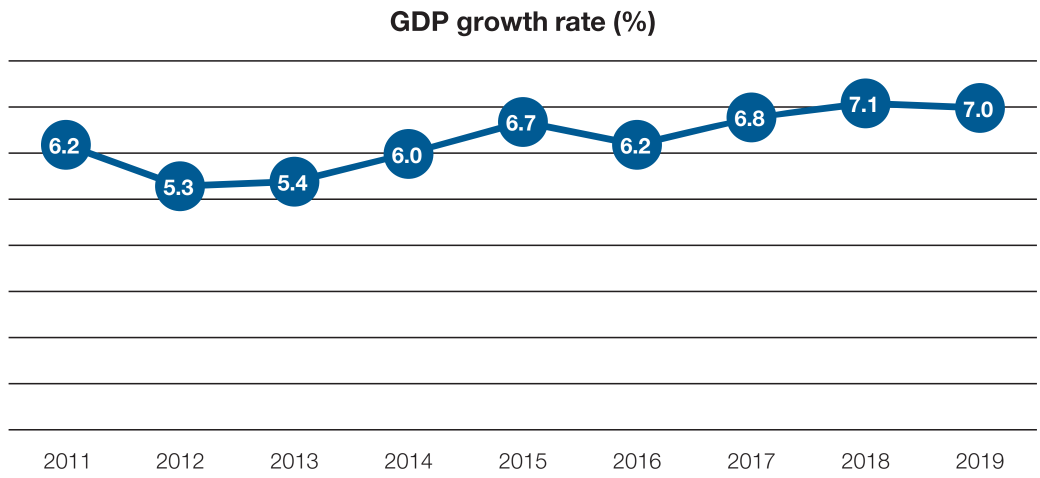


Figure 1-1: GDP growth rate for the whole country during period 2011–2019
Source: Institute of Energy's statistics

Vietnam's energy economy has changed rapidly in the past few decades with its transition from an agricultural economy based on traditional biomass fuels, to a modern mixed economy. Vietnam has many types of domestic energy sources, such as crude oil, coal, natural gas and hydropower, which have played an important role in the country's economic development over the last two decades.

1.1.1. National electricity consumption

Vietnam's electricity load has continued to grow at a 'double-digit' rate for many years, which is typical of a developing country. In the past 5 years, from 2014 to 2019, Vietnam's commercial electricity growth was at 10.4% / year, from 128 TWh in 2014 to 210 TWh in 2019.

In the 5-year period 2014–2019, the average growth rate average of Pmax was 11.5%. Although the system's peak demand growth slowed in 2019, it nevertheless still increased by 8.9% from 35.1 GW in 2018 to 38.2 GW in 2019. It is forecasted that the high growth trend of electricity load will be maintained until 2025.

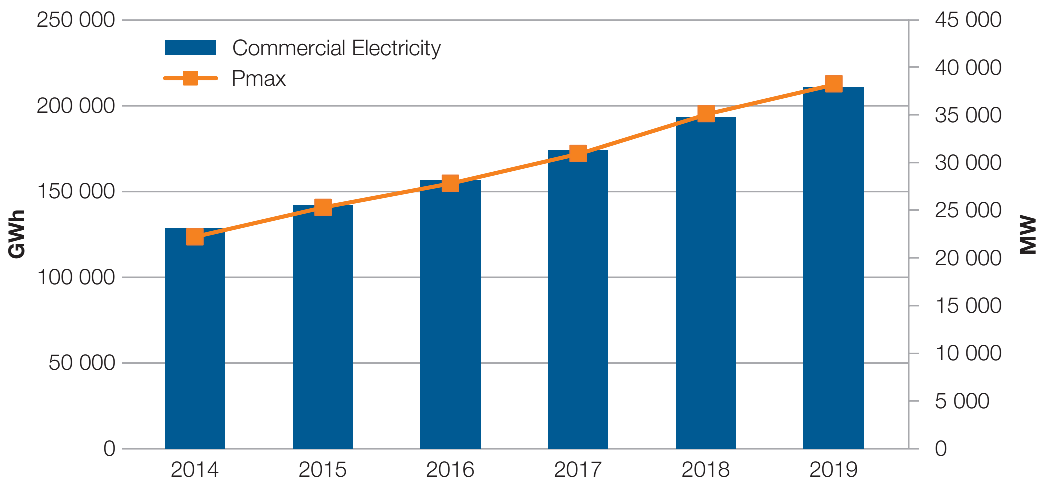


Figure 1-2: Electricity consumption and Pmax during the last 5 years

Industrial electricity accounts for the highest proportion with a rate of over 50%, followed by management - residential consumption, which is over 30%.

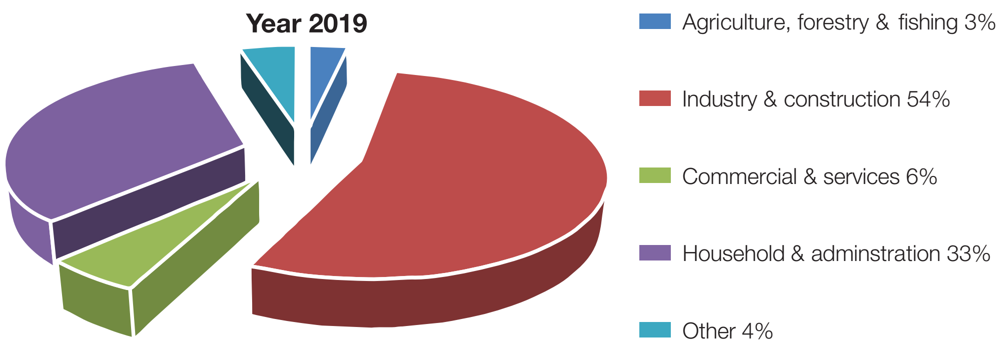


Figure 1-3: Demand distribution in the last 5 years

1.1.2. Power generation

In 2019, the total installed capacity of the national power system reached 55,939 MW, an increase of 13.2% compared to 2018. Generation development in recent years is shown in the following chart:

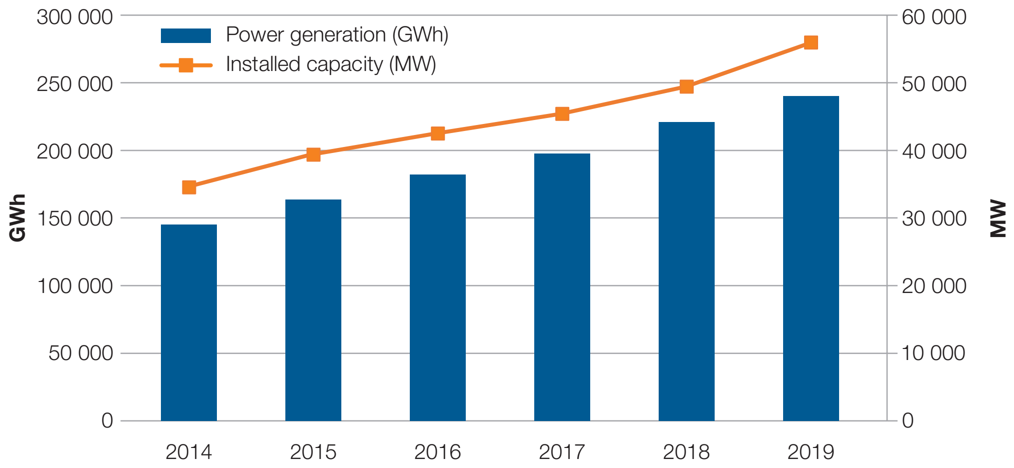


Figure 1-4: Installed capacity of the entire power system in the last 5 years

Regarding the power generation mix, during the period 2014–2019, there was a reduction of hydro power as the potential for large hydro power plants have been fully exploited. The share of gas turbine power generation was also reduced, since no new plants were built during this period. Conversely, coal fire power and renewable energy increased, the most impressive growth being in solar power, the capacity of which increased from 86 MW in 2018 (2 plants) to 4696 MW (90 plants) in 2019.

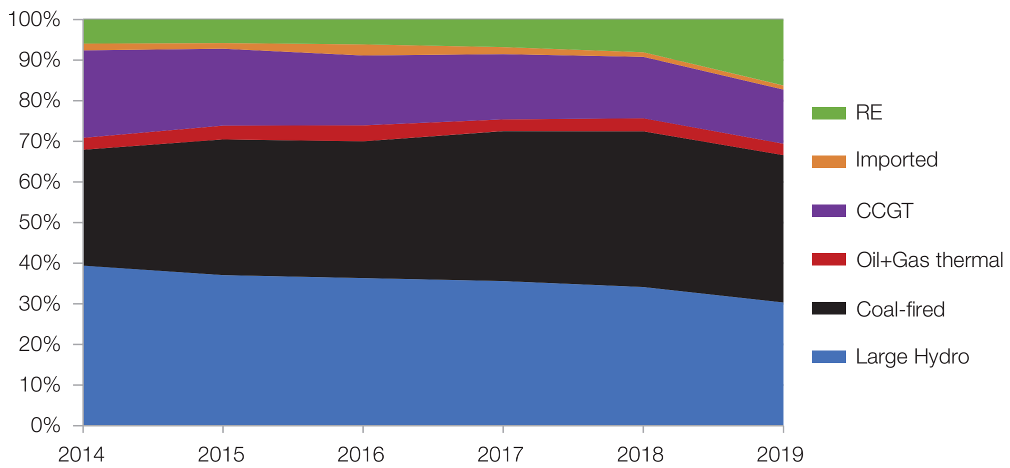


Figure 1-5: Power structure changes during the last 5 years

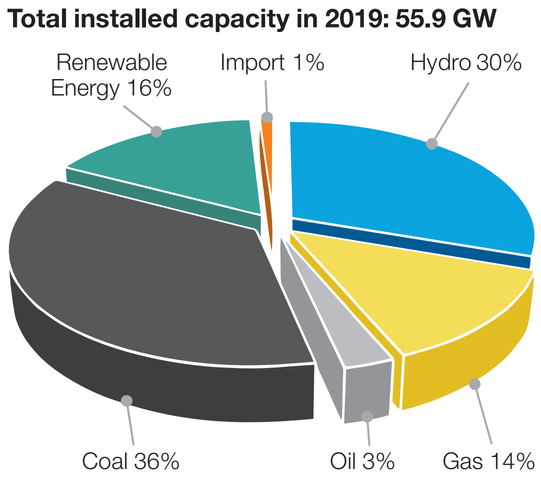


Figure 1-6: Installed capacity by technologies in 2019

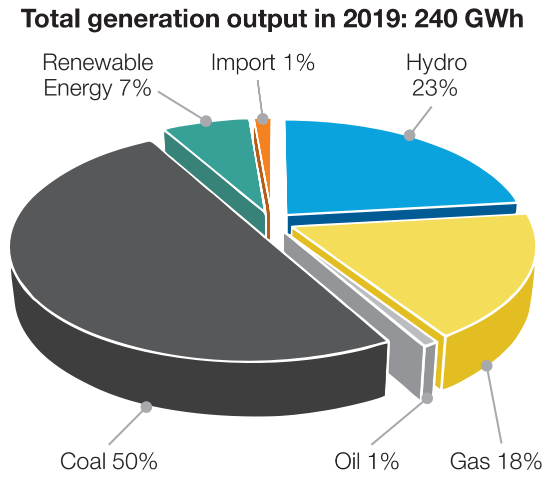


Figure 1-7: Generation output by technologies in 2019

1.2. The challenges in power development planning

1.2.1. High electricity demand growth rate

As a developing country, Vietnam's demand for electricity consumption is always very high. In fact, it has recorded growth in the rate of electricity load during the last 5 years (2014-2019), reaching 10.4%/year, from 128 TWh in 2014 to 210 TWh in 2019. The elasticity of electricity demand in GDP is also high, from 1.6-1.8 (while the world average is about 1), which indicates that energy usage is inefficient, especially in some industrial manufacturing sectors.

According to the load forecast in the base case of the PDP 8 (draft), the growth rate of commercial electricity in the periods 2021-2025 and 2026-2030 will be equivalent to 8.7% & 7.4%.

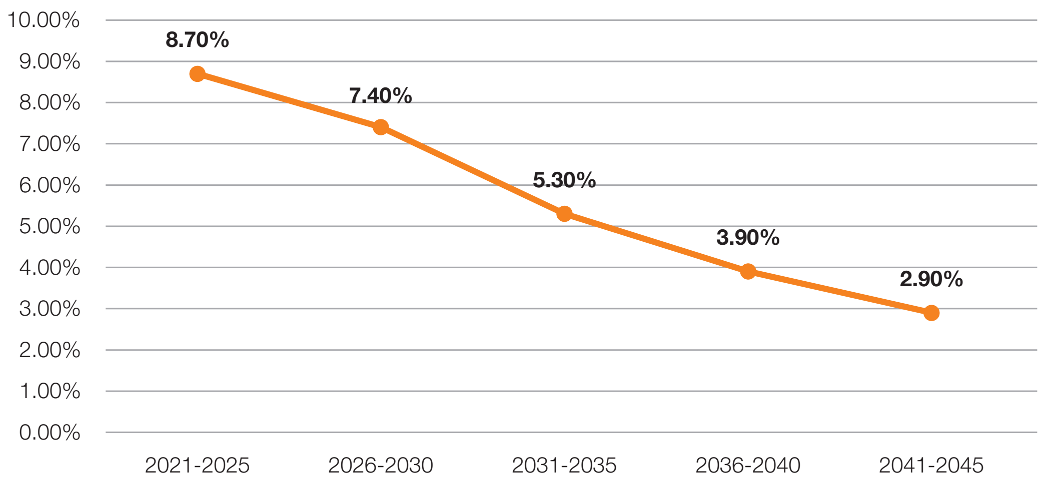


Figure 1-8: Growth rate of forecast demand in the draft PDP 8

These are very high rates of growth compared to the world average, which for many years (1974–2017) has been 3.3%[1]. The growth is especially in the period from now to 2030, when Vietnam's electricity demand is expected to increase by 7.4%–8.7%.

1) IEA, Electricity Information: Overview (2019 edition), 2019

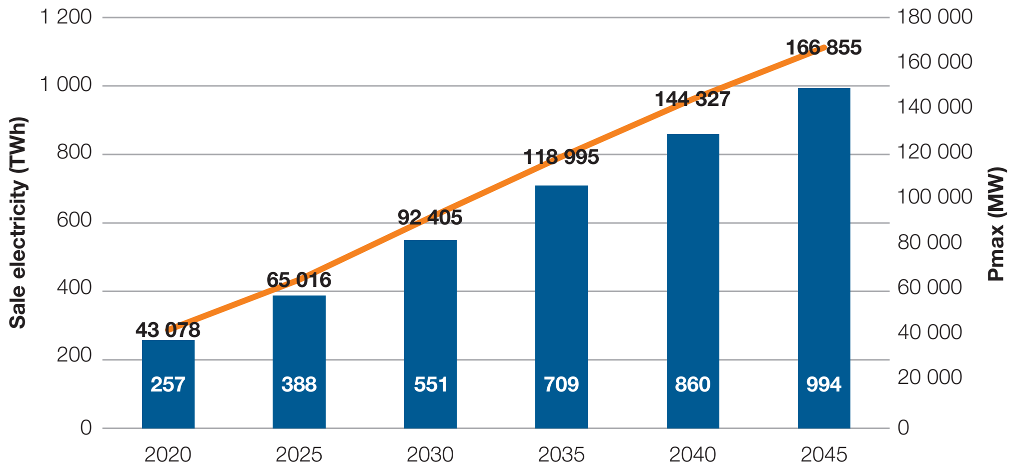


Figure 1-9: Forecast of sale electricity in 2020–2045 – draft PDP 8

1.2.2. Power shortages due to delay in development of power plants

Implementation of the power development program of the PDP7R in the period up to 2020, continues to progress slowly in the traditional power sources (coal, gas, hydropower – mainly coal plants). In the period 2016-2020, the volume of construction of traditional power sources only reached about 60% of the planned volume. The majority of behind-schedule power plant projects is in the years 2019-2020, both in the North and the South. The total capacity of traditional power plants behind schedule is more than 7000 MW, compared to the capacity planned in the PDP7R.

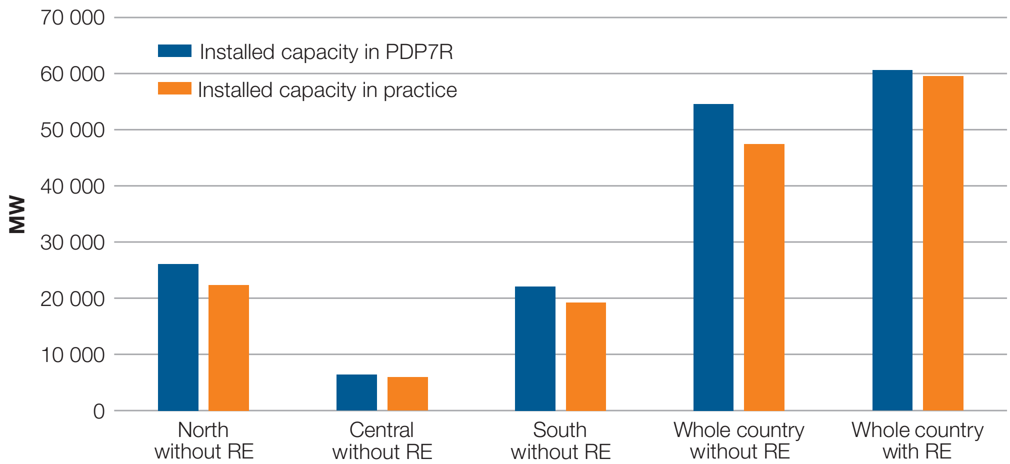


Figure 1-10: Assessing the implementation of PDP7R up to 2030

A specific list of power projects that were planned for the period 2016-2020 but which have not yet been put into operation are shown in the table below:

Table 1-1: Behind-schedule power plants in period 2016-2020

Project	Capacity (MW)	Investor	Fuel	Operating year per PDP7R	Reason
North					
TPP Na Duong 2	110	TKV	Coal	2019	Problem in tariff negotiation
TPP Cam Pha 3	2x220	TKV	Coal	2020	No identified location yet
TPP Hai Duong	2x600	BOT	Coal	2020-2021	Delay in construction progress
TPP Thai Binh 2	2x600	PVN	Coal	2017-2018	Problem in capital arrangement
TPP Cong Thanh	1x600	IPP	Coal	2019	Difficulties in land clearance and capital mobilization
Central					
HPP Yaly extend	360	EVN	Hydro	2020	Have not been invested yet
South					
TPP Long Phu 1	2x600	PVN	Coal	2018-2019	Problems in capital arrangement
TPP Song Hau 1	2x600	PVN	Coal	2019	Delay in construction progress & contractor's capabilities
CCGT O Mon 3	750	EVN	Natural gas	2020	PreFS has not been approved yet

According to the statistics, the slow progress of power generation sources is mainly in coal thermal power plants. The main reasons for this include a lack of capital; difficulty in arranging capital (due to the ceiling of public debt, the capital arrangement for power projects is no longer guaranteed by the Government, power projects are not on the list of ODA loans and foreign concessional capital); delays in equipment delivery; difficulties in compensation and resettlement; length of time needed to complete the loan procedures; difficulties in construction; lengthy procedures to prepare investment projects of BOT power sources; limited capacity and experience of investors, etc.

According to the latest progress update, the series of power plants expected to become operational during the period 2021-2025 will be delayed until the end of the period or after 2025. These thermal power plants include Cong Thanh, Nam Dinh I, Quang Trach I, Quynh Lap I, Vung Ang II, Quang Tri, Long Phu I & Long Phu II, Song Hau II, Van Phong I, and Vinh Tan III. For those power plants planned for 2026-2030, implementation has stopped or remained with undetermined progress. These plants include Cam Pha III, Hai Phong III, Vung Ang III, Tan Phuoc and Long An (fuel change to LNG submitted) and Son My I, Kien Giang CCGT.

In the context that the national electricity demand is forecasted to continue growing at the high rate of 7.4-8.7% (draft of PDP VIII), such delay in the power generation schedule will lead to the risk of power shortages in the coming years, especially in the South during 2021-2023.

1.2.3. Renewable energy development and integration

In line with the global trend towards the development of RE resources, wind and solar power in particular is being developed strongly in Vietnam, thanks to the preferential mechanisms of the Government.

With solar power, it was Decision No. 11/2017 / QD-TTg dated 11/4/2017 with FiT of 9.35 UScents/kWh (effective until June 2019) and Decision No.13/2020/QD-TTg April 6, 2020 at FiT 7.09 UScents / kWh (valid until December 2020). As a result, by the end of July 2020, 36 GW of solar PV had been registered for additional planning (equivalent to 44 GWp), of which 10.5 GW were approved and 5.1 GW went into operation.

Wind sources have an incentive mechanism under Decision No. 39/2018/QD-TTg with FiT of 8.5 UScents/kWh for onshore wind power, and 9.8 UScents/kWh for offshore wind power. By the end of July 2020, more than 34 GW has been registered for power plan implementation, of which 11.8 GW of power has been approved and about 455 MW put into operation.

In the long term planning, the integration rate of renewable energy sources is shown in the Resolution No. 55-NQ/TW of February 11, 2020 regarding the "Orientation of the National energy development strategy of Vietnam until 2030, with a vision to 2045" for the entire energy sector, and "Vietnam's Renewable Energy Development Strategy to 2030, with a vision to 2050" under Decision No. 2068 / QD-TTg dated November 25, 2015 for the power sector specifically.

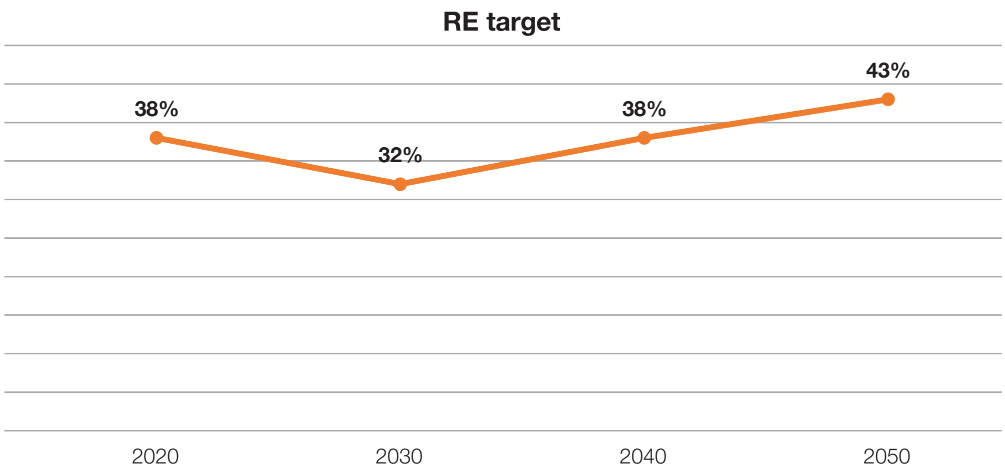


Figure 1-11: Share of Renewable Energy in the Power sector following the RE development strategy

According to the RE development strategy, electricity production from RE sources (including hydropower sources) will account for 38% of the entire system's electricity production in 2020. In 2030, this rate will decrease to 32% due to the fact that hydroelectricity has been fully exploited. In the period 2030–2050, it is expected that solar and wind power resources will develop strongly, with the penetration rate of renewable energy gradually increasing towards the target of 43% (by production) in 2050.

However, along with the increase in the penetration rate of RE sources, especially variable sources (wind and solar power), the power system will face new difficulties and challenges due to the variable and the uncertainty nature of wind speed and solar radiation. The main challenges encountered are as follows:

1. **Non-controllable variability:** Wind speed and sun radiation vary from time to time, hence the power output from these sources also varies constantly.

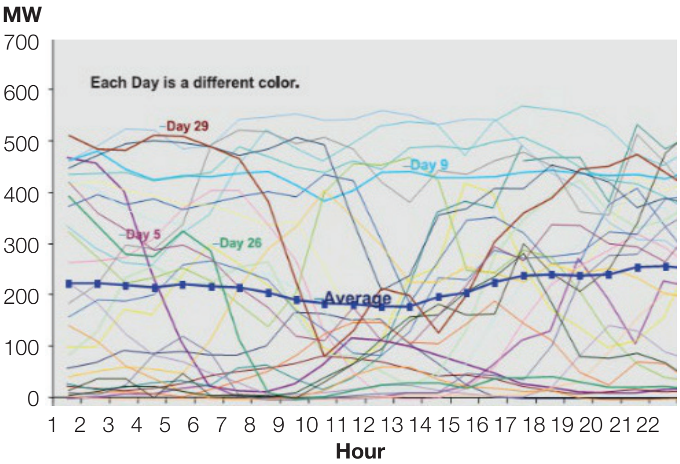


Figure 1-12: Wind variability

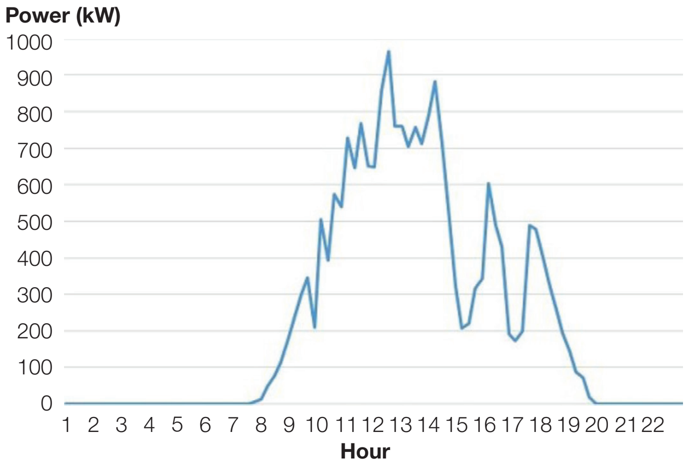


Figure 1-13: Solar variability

2. **Uncertainty and unpredictability:** The output of renewable energy sources is variable depending on the weather and is difficult to forecast accurately, especially in the day ahead period, so there must always be sufficient backup capacity or flexible sources.

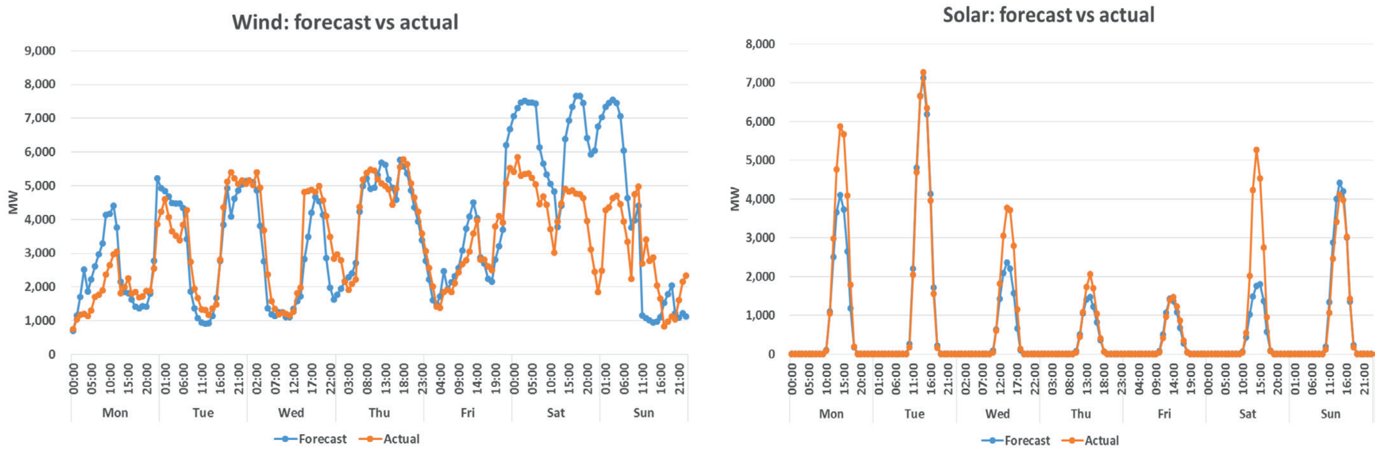


Figure 1-14: Wind & solar output forecast and actual output

3. **Location dependence:** Areas with good wind and solar potential are often located far from the load center. In Vietnam, the potential of wind and solar sources is concentrated in the Central Highland, South Central and South West regions, far from the Southeast and North load centers.

4. **Reductions in the inertial constant of the power system:** In general, wind and solar PV power plants cannot provide inertial support to the system when faults occur due to the absence of rotating components. In order to perform this function, it is necessary to install more energy storage and control components, resulting in a significant increase in investment costs.

5. **Low capacity factor:** According to the evaluation of the projects in operation, the power factor of solar and wind power sources in Vietnam are at 20% and 30% respectively (for comparison, coal-fired power plants usually operate from 70%–75%), so the cost per kWh is still high. In addition, solar power plants only generate high power at noon and do not contribute capacity during night peak hours, so there will be need of backup or flexible sources in the system.

With the short term challenge of power shortages over the next few years, there is a strong need for fast-track power generation solutions which can be deployed within a short period. At the same time, the requirement of flexible capacity to support the integration of intermittent renewables is critical to ensure a reliable power system for Vietnam.

Chapter 2. Overview of the internal combustion engine

2.1. Operating principle

Internal combustion engines (ICE) represent a well-established technology used in automobiles, trucks, construction equipment, marine propulsion, and backup power applications. In ICEs, the expansion of hot gases pushes a piston within a cylinder, converting the linear movement of the piston into the rotating movement of a crankshaft to generate power. ICEs are characterized by the type of combustion, i.e. spark-ignited (SG) or compression-ignited, also known as diesel. The SG engine is based on the Otto cycle, and uses a spark plug to ignite an air-fuel mixture injected at the top of a cylinder. In the Otto cycle, the fuel mixture does not get hot enough to burn without a spark, which differentiates it from the Diesel cycle. In diesel engines, air is compressed until the temperature rises to the autoignition temperature of the fuel. As the fuel is injected into the cylinder, it immediately combusts with the hot compressed air and the expanding combustion gases push the piston to the bottom of the cylinder.

Each movement of the piston within a cylinder is called a stroke. For power generation, four-stroke engines (intake stroke, compression stroke, power stroke and exhaust stroke) are predominately used. The four-stroke process is represented in the figure below:

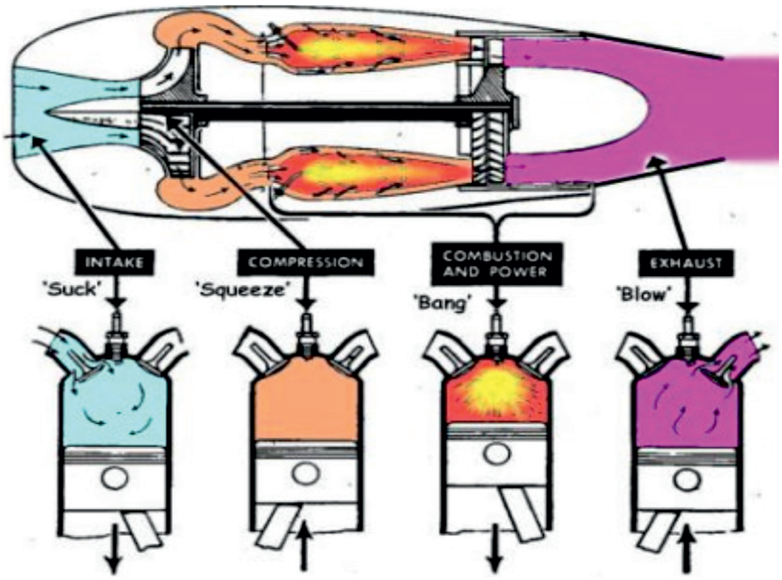


Figure 2-1: Four-stroke engines

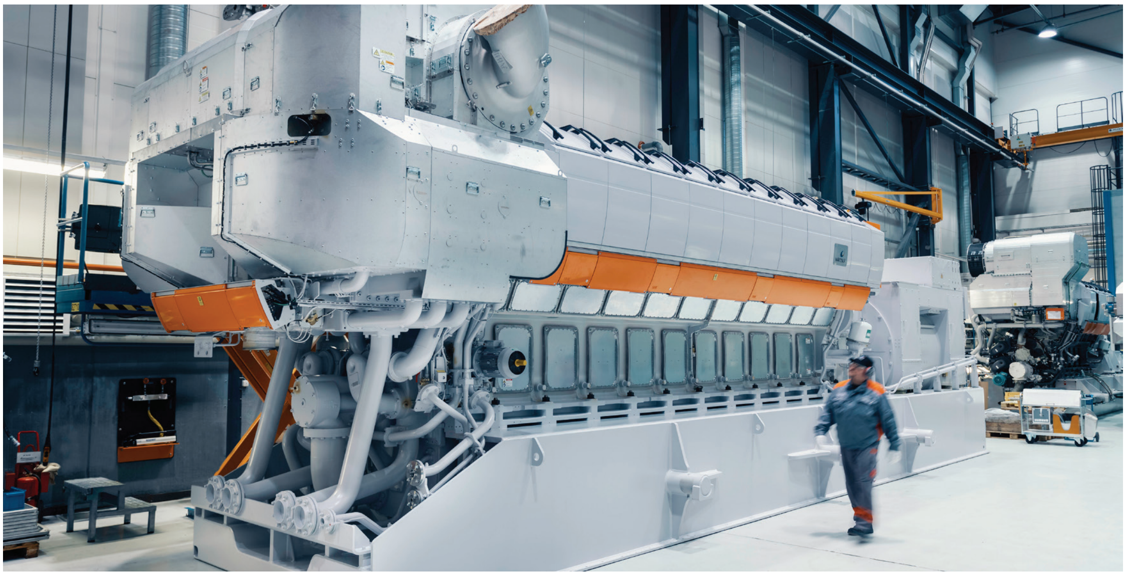


Figure 2-2: An internal combustion engine

2.2. Different types of internal combustion engine

Wärtsilä is a global leader in the research, manufacture, and delivery of ICEs for flexible power plants. Wärtsilä ICEs provide power plant solutions with flexibility in both fuel and operation, and which feature high energy efficiency (at about 46-52%).

Wärtsilä's multi-fuel power plants enable the continuous choice of the most feasible fuel, including solutions for liquid and gaseous fuels as well as synthetic and traditional biofuels. The fuel flexibility of the engine improves energy security and increases resilience against unpredictable interruptions to the fuel supply.

	Gas									Liquid
	Natural gas (/LNG)	Biogas	Ethane	LPG	Associated gas	Crude	LFO/diesel	Liquid biofuel	HFO	Fuel-water emulsion
Viscosity (CsT)	N/A	N/A	N/A	N/A	N/A	2-70@50°C	~ 2-11@40°C	~ 26@50°C	100-700@50°C	350-450@50°C
Wärtsilä 31SG	●	●								
Wärtsilä 34SG	●	●	●	●						
Wärtsilä 50SG	●	●								
Wärtsilä 34DF	●	●					●	●	●	
Wärtsilä 50DF	●	●					●	●	●	
Wärtsilä 32/32TS						●	●	●	●	●
Wärtsilä 32-LPT							●			
Wärtsilä 34						●	●	●	●	●
Wärtsilä 50						●	●	●	●	●

Figure 2-3: Different types of fuel which can be used in ICEs from Wärtsilä

Wärtsilä gas power plants use natural gas, the cleanest fossil fuel available, in the most economical way, thanks to their high efficiency at any load. Wärtsilä gas power plants can run on natural piped gas, liquefied natural gas, liquefied petroleum gas, and selected biogases.

Liquid fuel power plants make electricity available anywhere, anytime. Proven long term reliability makes these plants suitable for land-based/floating baseload, and for stand-by applications. Wärtsilä liquid fuel power plants can run on HFO, LFO, crude oil, emulsified fuels, or liquid biofuels.

Multi-fuel power plants increase the reliability of power generation by being able to adapt to any situation that may occur regarding fuel availability or affordability. They can even switch fuels while running, for example changing to liquid fuel mode if the gas supply is suddenly interrupted. This capability provides 24/7 security of supply, a hedge against fuel price increases, and the preparation for future fuel infrastructure developments.

2.3. Main characteristics of an ICE flexible power plant

To maintain system stability, power grid operators continuously dispatch a fleet of generation assets to match momentary variations in regional electricity demand. Consequently, power plant flexibility has always been an important operational consideration to ensure the continuous, reliable delivery of electricity. An ICE with certain technical characteristics mentioned above is the key factor in ensuring a flexible power plant.

2.3.1. Modularity and standardization

Figure 2-3 illustrates the structure of a typical flexible power plant. Like other gas-fired thermal power plants, it includes a gas supply system, engine, generator, cooling system, and electrical components. To create flexibility for the power plant, the ICE is used to generate power rather than gas turbines.

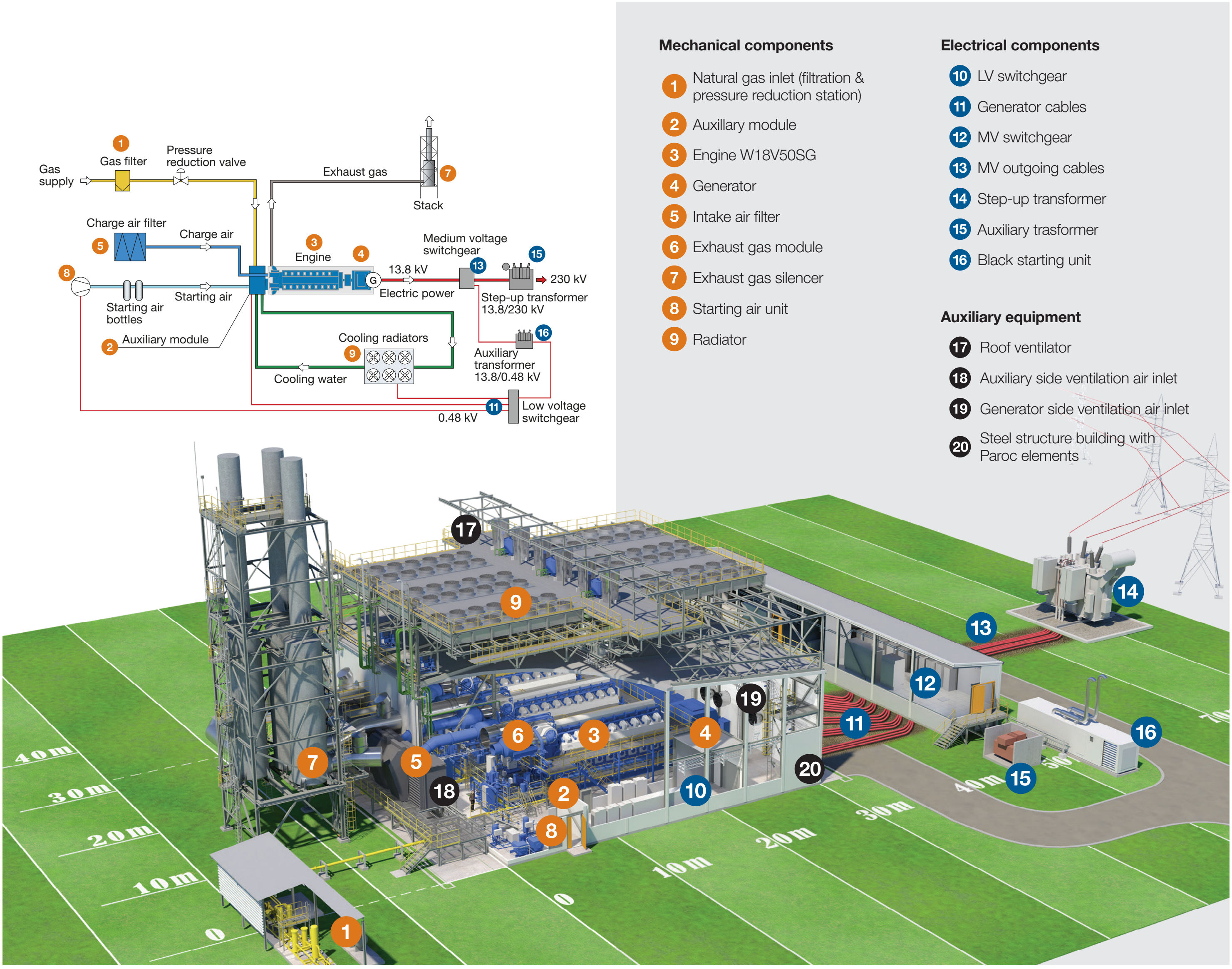


Figure 2-4: A typical ICE flexible power plant

The words modular and standardized are central to Wärtsilä engine power plant solutions. The engines are manufactured and tested in controlled factory conditions before shipment, whereas the entire power plant is pre-designed according to Wärtsilä's standards. Some of the benefits are:

- As energy demand grows, the high modularity makes it easy to expand/extend a power plant to meet increasing future demand
- If there is an urgent need for power, fast-track deliveries (within 12 months) enable capacity deficits to be rapidly overcome
- The standardized design, regardless of the number of engines, enables a minimal plant footprint and reliable, easy & fast onsite construction, installation and commissioning
- Easy integration with renewable assets and energy storage systems

2.3.2. Operating modes

An ICE power plant is capable of operating in multiple modes, from fast start, base load, load following, low load, or fast stop, and can change the output instantly in response to the power system's dispatcher's request.

1. FAST START

An ICE power plant can generate megawatts to the grid in less than 30 seconds from start-up and can reach full load in less than two minutes. This operating mode is especially beneficial in compensating for the sudden drop off in wind or solar output due to changes in weather conditions.

2. BASE LOAD

An ICE is capable of providing baseload as with a conventional thermal power plant, thanks to its stable generation output and high efficiency. At ISO conditions, an internal combustion engine would be able to achieve an electrical efficiency more than 50%.

3. LOAD FOLLOWING

One of the biggest advantages of ICE power plants is their ability to increase and decrease capacity quickly (fast ramp rate), thereby contributing to close load following. Once running and at nominal operating temperature, an ICE power plant can ramp up from 10% to 100% load (or down) in just 42 seconds. At the same time, ICEs can maintain stable efficiency at different loads by turning on/off individual units, thanks to the modular design.

4. LOW LOAD OPERATION

Thanks to their characteristics, such as 1 min shutdown, no minimum down time, zero fuel cost, and zero emissions, ICEs can flexibly operate at low load. This allows the plant to provide power very quickly, if demanded from the grid, and it reduces the start-up costs. With ICEs, "low load" can mean "no load".

5. FAST STOP

In some cases, when there is a sudden drop in power demand or the price in electricity market is lowered, an ICE can provide a fast stop within 1 minute.

1 FAST START	2 BASELOAD	3 LOAD FOLLOWING	4 LOW-LOAD OPERATION	5 FAST STOP
VALUE • Grid stability support • Ancillary Service market	**VALUE** • Competitive lifecycle generation cost • Any output, same generation cost	**VALUE** • Wind and solar balancing • Ancillary Service market	**VALUE** • "Low load" = No load • Not running when no revenue	**VALUE** • Not running when no revenue • PV enabler
FEATURES • Power to grid in 30 sec • 2-5 min to full power • Start-up efficiency	**FEATURES** • Highest simple cycle efficiency • Multi unit → high firm capacity • Flexicycle™	**FEATURES** • Part load efficiency unaffected • No equivalent operating hours (EOH) for cycling	**FEATURES** • 1 min shutdown • No minimum down time • Zero fuel cost • Zero emissions	**FEATURES** • 1 min shutdown • No minimum up time • No EOH calculation

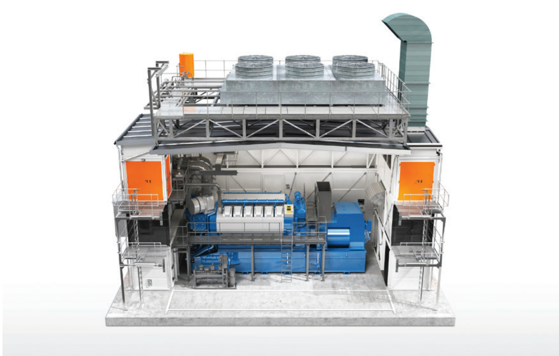
Figure 2-5: Operating modes of an ICE

2.3.3. Applications

1. WÄRTSILÄ MODULAR BLOCK

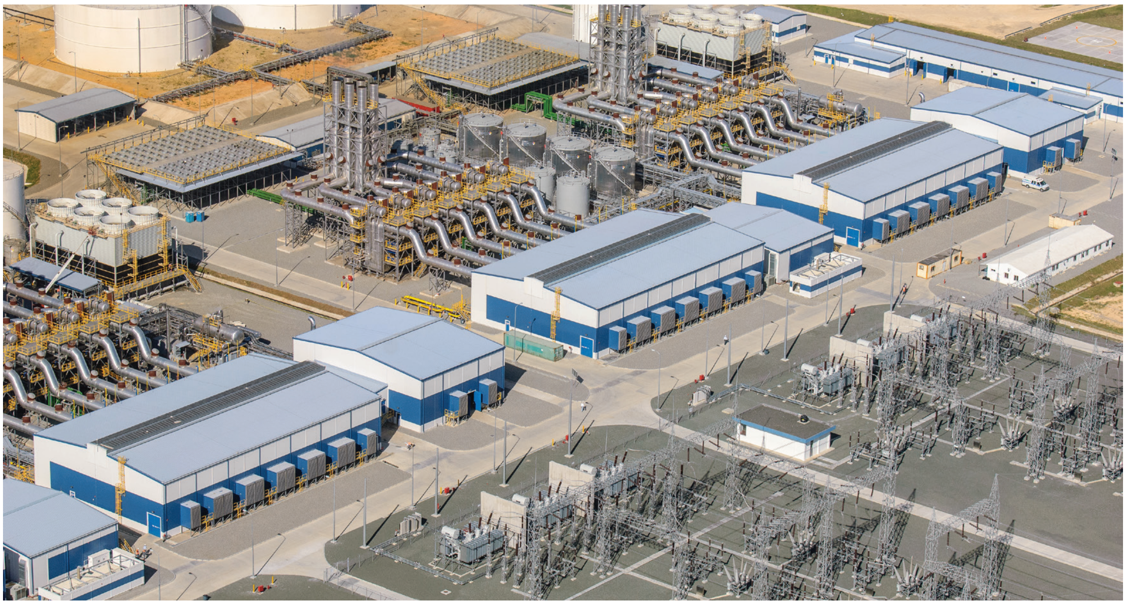
The Wärtsilä Modular Block is a pre-fabricated, modular, configurable, and expandable enclosure for power generation. The key benefits include:

- Short installation time for new power generation assets, from many months to just a few weeks.
- A scalable solution that needs only a minimal upfront investment.
- Re-deployable to move to new sites and offer new business models, such as power-as-a-service or rentals.
- Quick and easy to install with a streamlined delivery process and detailed installation instructions.
- Easy integration with renewable energy and storage systems provides grid stability and balancing.



2. WÄRTSILÄ FLEXICYCLE™

Flexicycle™ combines the excellent dynamic capabilities of internal combustion engines with the superb efficiency offered by combined cycle solutions. By adding a waste heat recovery system to the plant, consisting of a heat recovery steam generator for each engine and a common steam turbine and condenser for the plant, the total efficiency can be improved significantly by 3-4 percent units. The plant can switch between single or combined cycle modes upon request. Flexicycle represents the ultimate solution for flexible baseload plants, in either its gas-fired or multi-fuel configuration. Thanks to the closed-loop cooling system, water consumption is close to zero.



3. FLOATING POWER PLANTS

Wärtsilä's engine solutions can be delivered both as land-based power plants and as floating power plants (power barges). Power barges integrate Wärtsilä's expertise in marine technology with the many benefits of flexible, decentralized power generation. Power barges can be delivered within 12 months, thus providing a rapid answer to increases in power demand in advance of new, land-based plants.

Wärtsilä has delivered 27 power barges with a total output of more than 1,600 MW.

4. POWER CUBES

Wärtsilä's Gas Cube, Multi-fuel Cube, and Oil Cube power generation solutions are compact, ready-to-use pre-engineered packages designed for fast delivery time with minimal site work. The solution consists of a self-contained design with one or several modules, each housing one Wärtsilä genset, plus all the auxiliaries needed. These are easy-to-install and pre-designed solutions for power needs of 5 to 30 MW.

As of now, Wärtsilä has delivered more than 72,000 MW of ICE power plants to 180 countries around the world, of which nearly 10 GW is within the South East Asia region.

2.4. Comparison of ICE with other thermal power generation technologies

1. Efficiency at different ambient temperatures and loads

Depending on the site conditions, a power plant's actual electrical output, efficiency, and fuel consumption can be quite different than its performance at design conditions. Figure 2-5 shown the comparison of net efficiency at different ambient temperatures between Wärtsilä ICEs and gas turbines.

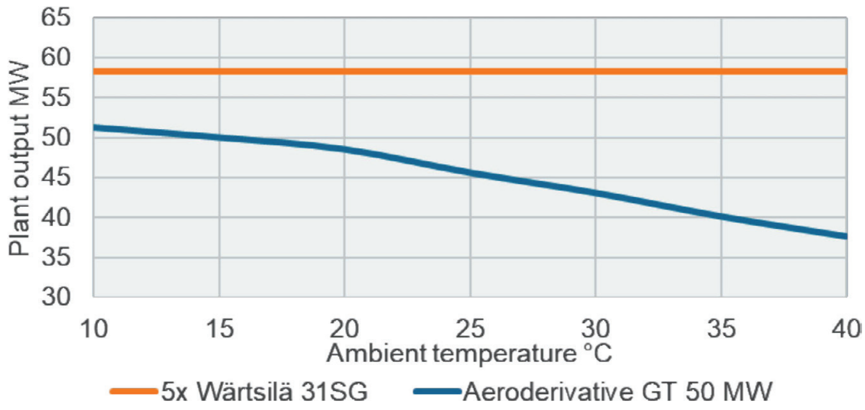


Figure 2-6: Net efficiency at different ambient temperatures

Regarding the net efficiency at different loads, Figure 2-6 illustrates a comparison between Wärtsilä ICEs and gas turbines. Technical limitations cause the efficiency of gas turbines to increase gradually from 20% to 40%, in accordance with a 20% load up to a 100% load. Conversely, the efficiency of the ICE remains stable at different loads, thanks to the flexible start-up/shut-down separated unit.

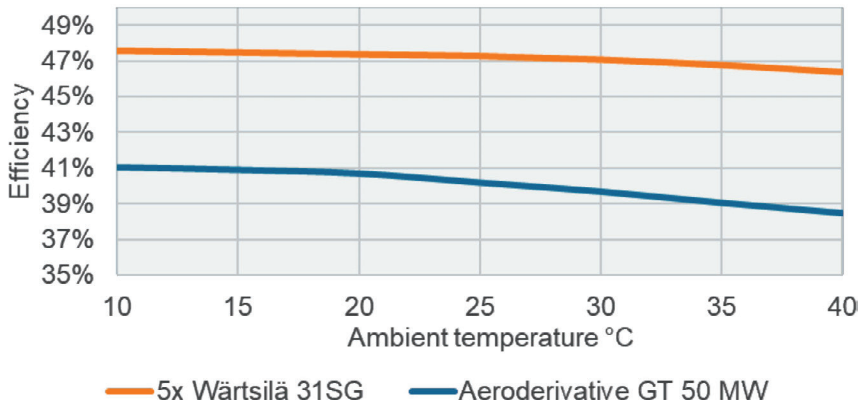


Figure 2-7: Net efficiency at different ambient temperatures

2. Start-up time

Figure 2-7 shows that the ICE has a much faster start-up time than gas turbines. They can reach full power in 2 minutes, while simple cycle gas turbines take more than 15 minutes to ramp up to full output. For example, the Wärtsilä 34SG power plant requires only 30 seconds to complete startup preparations, speed acceleration, and synchronization to the grid. Loading to full power occurs rapidly in just 90 seconds. Under cold start-up conditions, the Wärtsilä 34SG power plant can reach full load in 10 minutes.

As a comparison, with coal-fired thermal technology, the warm start up time and cold start up time of sub-critical coal power plants is 5 hours and 10 hours, respectively; of super-critical coal power plants 8 hours and 10 hours, respectively; and of ultra-super-critical coal power plants 4 hours and 12 hours, respectively.

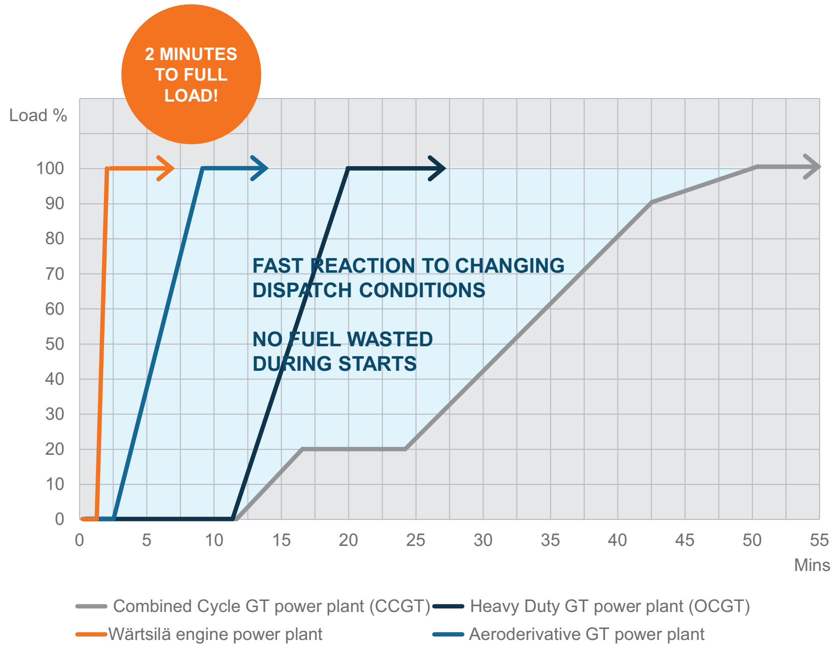


Figure 2-8: Comparison of startup times

3. Ramp rate

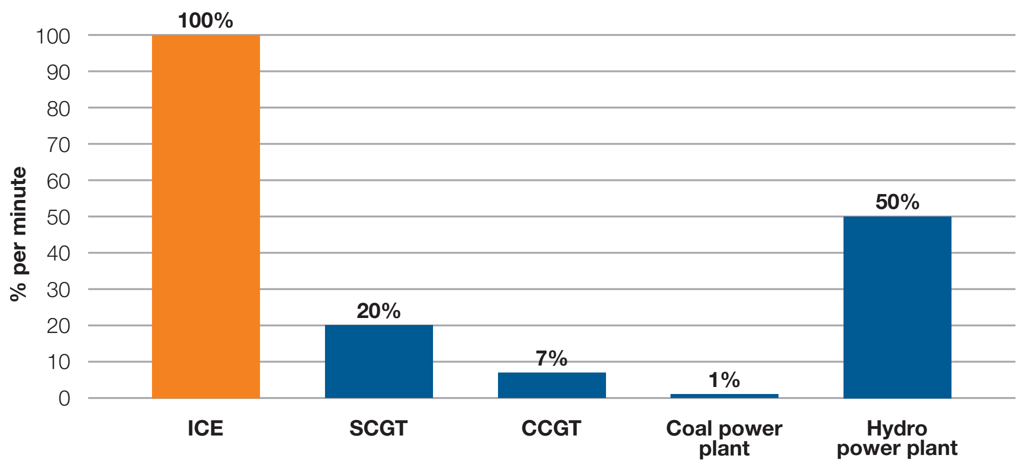


Figure 2-9: Comparison of ramp rate

Figure 2-8 shows that the ICE has a ramp rate that outperforms other technologies. Although hydro-electricity is known to be a technology capable of changing capacity rapidly, the control gates are still inertial when closed and opened. Meanwhile, with the connecting of many small modules to a power plant, the ability to change the power of ICE is very fast, reaching 100% per minute. In reality, an ICE can ramp from 10% to 100% load (or down) in just 42 seconds.

4. Stopping time

The ICE can be stopped within one minute, while gas power plants such as OCGTs or CCGTs require more than 15 minutes to shut down. The shut down time depends heavily on the capacity of the unit since large units have greater inertia. An ICE power plant unit has small enough capacity to stop quickly.

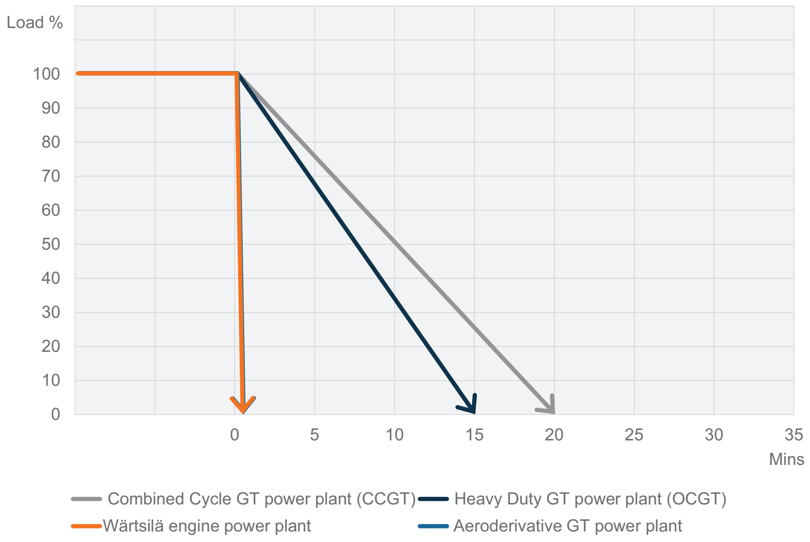


Figure 2-10: Comparison of stopping times

5. Minimum up and down time

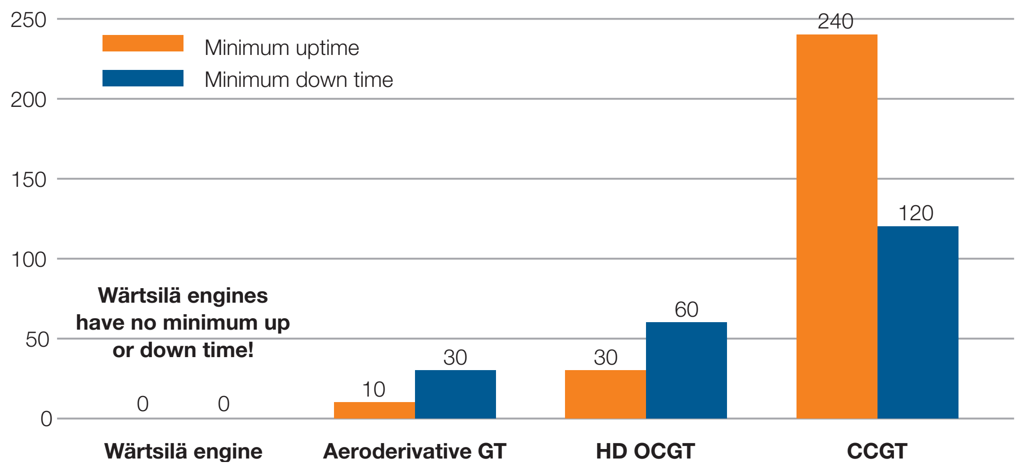


Figure 2-11: Comparison of unit minimum up and down time in minutes

The Wärtsilä 31SG engine has no minimum up and down time. An ICE allows for several start-ups and stops per day, while a CCGT has a minimum up time of 240 minutes and a minimum down time of 120 minutes.

6. Minimum stable load

Figure 2-11 illustrates the minimum stable load comparison between ICEs, aeroderivative GTs, HD OCGTs and CCGTs. In particular, the minimum stable load of an ICE is 10% while the minimum stable load of HD OCGTs, CCGTs and aeroderivative GTs are much higher, at 40%, 40% and 50%, respectively. Therefore, as with hydro power plants, an ICE is capable of operating with a wide power range. It can reduce output flexibly when renewable energy sources provide high generation, such as mid-day mode or windy days.

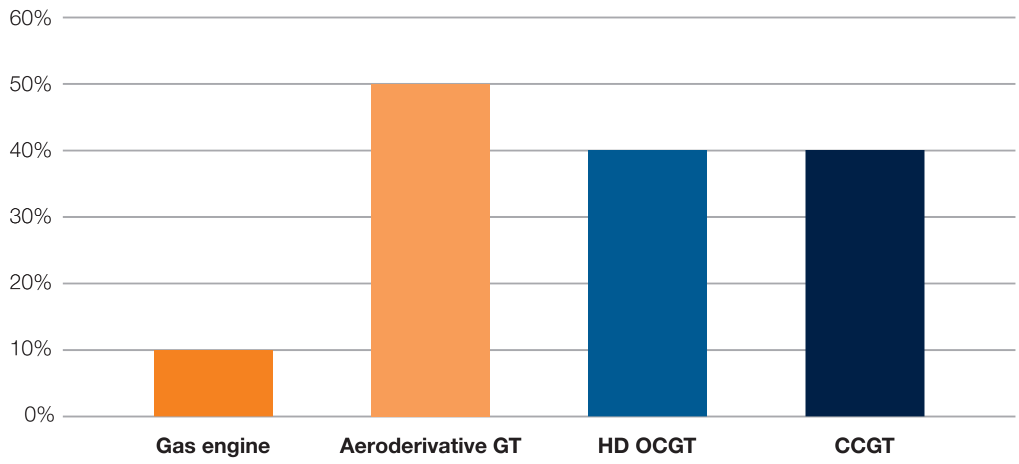


Figure 2-12: Comparison of minimum stable loads

2.5. The need for ICE power plants in Vietnam's power system

After nearly 4 years from the time of approval, the revised PDP7 has made noticeable changes in the current context. A series of Southern power plants, such as Long Phu TPP, Song Hau TPP, Vinh Tan 3 TPP, O Mon CCGT and Kien Giang CCGT, have been behind schedule, leading to the Government approving the investment policy of Quang Trach - Doc Soi - Pleiku 2500 kV line to ensure sufficient power supply to the South for the period 2018-2025. Renewable energy sources such as wind and solar power are registered for supplementation planning on a large-scale. In particular, up to May 2020, approximately 10.5 GW of solar power and 4.3 GW of wind power have been approved for supplementation planning. It is expected that the renewable energy capacity supplemented to the plan in the coming period will continue to increase. For the period 2026–2030 in the South, the Ninh Thuan I and II Nuclear Power Plants with a total capacity of approximately 4600 MW have been approved for removal by 2030 by the National Assembly. The volume of gas in the Southeast and Southwest is in danger of being in short supply, thus affecting the operation of a number of plants, such as Phu My, O Mon clusters, and others.

Although the options for securing the electricity supply and a study on connecting renewable energy sources to the power system have been implemented, Vietnam's power system still faces a number of challenges:

- High demand for electricity
- Risk of power shortage due to delay in power plant construction
- Difficulty in operating when integrating a large proportion of renewable energy sources

In this context, the characteristics of an ICE power plant have many advantages for Vietnam's power system, which can contribute to minimizing the above-mentioned challenges. Specifically, these include:

A. Contributing to ensuring sufficient power supply to handle the load growth, especially the load central areas in the North and South

According to the forecasted load in PDP7 revised, the national Pmax will reach 42 GW, 63 GW and 91 GW in 2020, 2025 and 2030, respectively, and for sale electricity will reach 235 billion kWh, 352 billion kWh and 506 billion kWh, respectively. As a developing country, Vietnam is forecasted to have a high load growth rate compared to other countries in the world, with a for sale electricity growth rate of 8.5%/year for the period 2021–2025 and a reduction to 7.5%/year for the period 2026–2030. On the other hand, according to the base load in the draft PDP8, the growth rate of for sale electricity in the periods 2021–2025 and 2026–2030 is the same as the forecasted result in PDP7 revised. In the periods of 2031–2035, 2036–2040, 2041–2045, the load will grow slowly, reaching 5.3%/year; 3.9%/year and 2.9%/year, respectively. However, with limited resources for generating electricity, high load remains a significant challenge for the power sector in particular, and for the whole country in general in meeting the requirements for developing the national economy.

Currently, Vietnam's power system is operating mainly on hydro power plants and coal-fired thermal power plants, with the proportion in 2019 being at 30% and 36%, respectively. In the future, the potential for developing various types of primary fuel sources will be limited. The current installed capacity of hydro power plants (excluding small hydro power plants) is around 17000 MW and has essentially been used to its full potential. Coal-fired thermal power plants are difficult to develop because they are unlikely to receive consent from local authorities on environmental grounds. As regards gas thermal power plants, from the period after 2020, Southwest gas is likely to be in short supply to meet the demand from the Ca Mau Gas - Electricity - Fertilizer Complex. Two large gas fields are expected to be developed, including the Block B field and the Blue Whale field, but these are only capable of supplying electricity to O Mon CCGT, Mien Trung CCGT, and Dung Quat CCGT, which are expected to operate to 2030.

ICE power plants are designed with a flexible output range (10–700 MW) by connecting multiple ICE units. Therefore, it is possible to choose to build either a power plant on a large scale, or many distributed power plants having a smaller scale. The ability to use many different types of primary fuel, including gas (natural gas, LNG, biogas, ethane, LPG) or liquid fuel (crude, LFO, diesel, liquid biofuel, HFO, fuel-water emulsion) creates the flexibility to select different fuel supplies depending on the situation. ICE power plants allow the temporary use of other fuels while waiting for the main fuel infrastructure construction, thereby avoiding delays due to an insufficient fuel supply. This has happened to some gas power plants, such as O Mon CCGT, Mien Trung CCGT, and Dung Quat CCGT. The rapid conversion process between fuels, which enhances the reliability of the electricity supply, ensures the power supply throughout the 24/7 load. In addition, ICE power plants have lower emission levels, and a smaller construction area than gas thermal power plants (the power density of an ICE power plant is 18 kW/m^2 while the power density of a gas power plant is 19 kW/m^2). So it is possible to construct them near the load center, minimizing the volume of transmission lines.

ICE power plants, when put into operation, will promptly meet the national load demand in both the short term and long term, especially in high load scenarios.

B. Contributing to offsetting power shortages caused by some power plants being behind schedule

According to the latest power generation progress update, some coal-fired thermal power plants expected to become operational in the period of 2021–2025 are likely to be delayed: Vinh Tan 3 (3 x 660 MW), Song Hau 2 (2 x 1000 MW), and Long Phu 2 (2 x 660 MW). Power plants expected to be operating in the period of 2026–2030 have many unclear projects. These include the Tan Phuoc 1, Tan Phuoc 2, and Long An Nuclear Power Plants (total scale of 4600 MW, annually providing an equal output of approximately 5.7% of the system power) and the TPP Bac Lieu coal plant (2 x 600 MW) are scheduled to be eliminated from the plan by 2030.

Regarding gas-fired thermal power plants, the Block B gas field is expected to come online in 2021, although the risk of delay is already evident which has led to a delay in the progress of O Mon CCGT compared to PDP7 revised. The same situation occurred with the Mien Trung CCGT and Dung Quat CCGT projects, which rely on the Blue Whale gas field, delaying progress from 2023–2024 to 2025–2026. In the Southeast region, the Nhon Trach I, II thermal power cluster will continue to use the Southeast gas source until 2030. From 2023–2024 onwards, the area will have to import LNG to supply the Nhon Trach III, IV, Son My CCGT cluster, and provide additional supplies to Phu My, Ba Ria. However, PVN has not yet completed the feasibility study (F/S) of the Son My terminal, has not completed negotiations with LNG suppliers, and has not prepared the Pre F/S and F/S of thermal power plants. Therefore, the likelihood that the Son My II power plant projects will not be on schedule is very high, and are expected to be delayed until after 2025.

ICE power plants have a very short construction time (less than 12 months) compared to other traditional thermal power plants (24–36 months for a CCGT plant). The plant can be delivered as a floating or land-based plant within an economic area, thereby avoiding the risk of being delayed due to challenges with site clearance. The plant is also in the form of many easily expandable modules that allow diverging the investment capital. Therefore, along with wind and solar power sources, ICE power plants are a useful solution in quickly and promptly compensating for the shortage of capacity due to some power plants being behind schedule over the short and medium term.

C. Flexible operating characteristics suitable for a power system having a large proportion of renewable energy sources

According to Vietnam's Renewable Energy Development Strategy to 2030, with a vision to 2050 approved by the Prime Minister, the percentage of electricity produced from renewable energy in the total electricity production nationwide will be around 38% in 2020, about 32% in 2030, and about 43% in 2050. Currently, the total amount of solar power registered for supplementation planning is about 36.5 GW, and this is expected to increase. Until May 2020, approximately 10.5 GW of solar power has been approved for supplementation to the plan. Regarding wind power sources, the total installed capacity registered for supplementation planning is about 34 GW and is expected to become higher. In particular, some 4.3 GW of wind power has been approved for supplementation to the plan. On March 19, 2020, the Ministry of Industry and Trade submitted to the Prime Minister Document No. 1931/BCT-DL regarding the consideration and supplementation to plan of about 7000 MW of wind power. Given the uncertainty in the generation capacity graph of wind and solar power sources, integrating a large share of renewable energy requires high flexibility in the power system in order to ensure redundancy for the variable capacity balance from these intermittent energy sources. Vietnam has an advantage in developing renewable energy due to the large proportion of hydropower sources, which are capable of increasing or decreasing generation capacity immediately. Currently, the capacity of hydroelectricity (excluding small hydroelectricity) is about 17000 MW, accounting for 30% of the national power generation structure, but this resource has essentially been fully exploited. Therefore, in the future, it is necessary to study other solutions to improve flexibility.

ICE power plants have flexible operating characteristics, making them very suitable for power systems with a large proportion of renewable energy sources. These characteristics include the quick startup within 2 minutes; the ability to increase or decrease output quickly which can change the load from 10% to 100% in just 42 seconds; the ability to stop quickly within 1 minute; no minimum up and down time; and the ability to operate at 10% load. With the integrated design of many modules, the ICE power plant allows each module to be operated individually, thereby reducing mechanical inertia when changing output while maintaining stable efficiency. An ICE power plant's generating output to the grid can change almost instantaneously to accommodate sudden fluctuations in wind and solar power availability. In addition, it is possible to operate in many power plant modes, such as quick start, load following, baseload, quick stop, which is difficult for any traditional power plant.

Thus, ICE power plants contribute to the flexibility of the power system, and support the operation of a power system integrated with a large proportion of renewable energy sources, thereby promoting a more rapid development of renewable energy sources in the future.

Figure 2-13: Flexibility of ICE power plants (red lines) when there is a sudden drop in wind generation (green line) in the USA

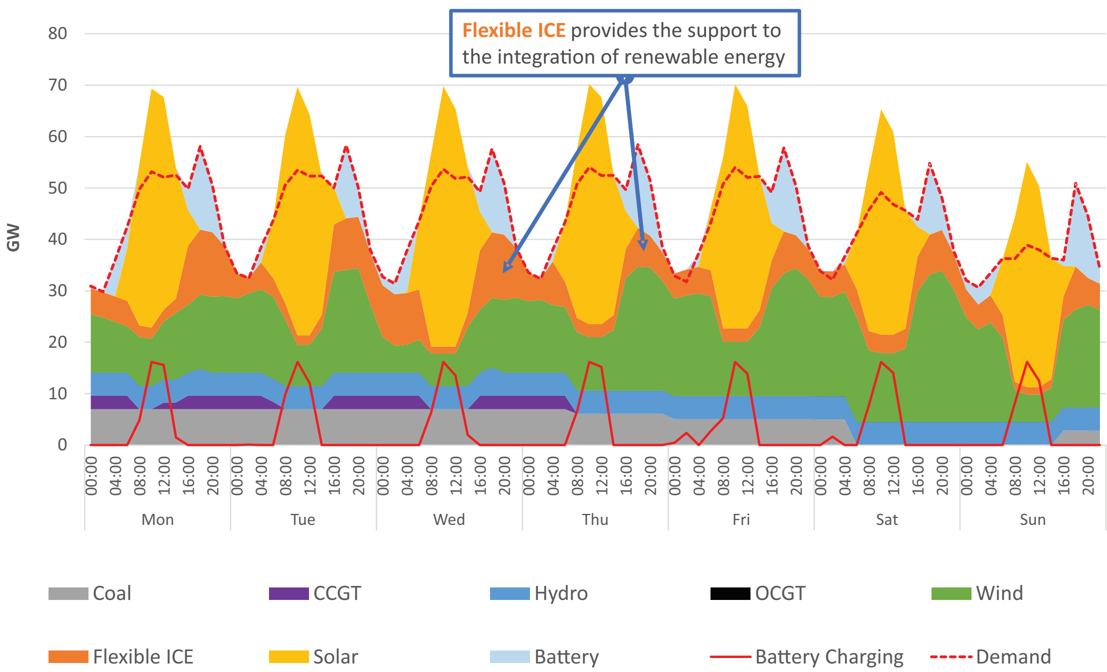


Figure 2-14: An example of dispatch modeling of a power system within 1 week with flexible ICE power plants

Chapter 3. Methodology and input assumption

3.1. Methodology

To study the possibility of developing ICE power plants for Vietnam's power system, the study uses the methodology of modelling the long term power system for the national power development planning (PDP8). The structure for developing national power generation is modeled and optimized to meet the demand of each region with the following criteria: "Minimize the system cost over the entire planning period and satisfy the power system operational constraints, policy constraints, and potential limits".

The electricity generation costs of the power system in this study include: the investment cost, operation and maintenance costs, fuel cost, unit commitment cost, the external cost of emissions, inter-regional transmission costs, and the unserved energy cost.

Power system operational constraints include:

- To ensure the dispatching and operation ability of thermal power plants when integrating wind and solar power. Meeting operational constraints of different types of technology: efficiency, full load hours (FLHs), unit commitment parameters, emission targets, hydro power plant reservoir parameters, wind speed and solar profile by hour by region, province ...
- To meet the 8760 h load chart for each region
- To ensure the reliability of the power system: Selecting the Loss of load expectation (LOLE) is less than 12 hours/year for each region of the power system, corresponding to 99.86% reliability.

Policy constraints and potential limitations include:

- RE targets, emissions reduction: Calculate policy-targeted scenarios according to documents, such as Decision 2068/QD-TTg on Vietnam's renewable energy development strategy, Resolution 55-NQ/TW on the strategic direction for the development of Vietnam's energy sector in the period up to 2030, with a vision to 2045, Vietnam's commitment to reducing GHG emissions at COP21
- Maximum ability to exploit domestic primary energy sources for electricity production (domestic coal, domestic gas)
- Maximum potential to build different types of renewable energy sources in each region and province
- Ability to import fuel for electricity production. Potential scale construction of imported coal, imported gas, nuclear power plants by region
- Ability to import electricity, and to exchange electricity with neighboring countries

ICE power plants using LNG fuel will be simulated in a similar way as with other types of power generation technology. The need for ICE power plants in the power system will be determined by the calculation of the model, following the cost criteria with the above-mentioned constraints. Based on the analysis of scenarios, the study then proposes the capacity of ICE power plant in the future.

The potential development of the ICE power plants will be calculated by region. The study divided the Vietnam power system into 6 regions: North (from Ninh Binh to the north), North Central (from Thanh Hoa to Quang Binh), Center Central (from Quang Tri to Quang Ngai), Highlands (from Kon Tum to Dak Nong), South Central (from Binh Dinh to Binh Thuan) and South (Southeast and Southwest provinces).

Figure 3-1: Map of the 6 regions of Vietnam's power system

3.2. Modeling tools

The project uses a combination of the following 3 models:

+ BALMOREL MODEL

To calculate the future capacity expansion of the power system, the study uses the BALMOREL model. This is a model supported by the Danish Energy Department for the Electricity and Renewable Energy Authority (EREA) through the Danish Energy Partnership Program. The BALMOREL Vietnam model has been used in the Vietnam Energy Outlook Report 2019 and the Vietnam Power Development Plan 8.

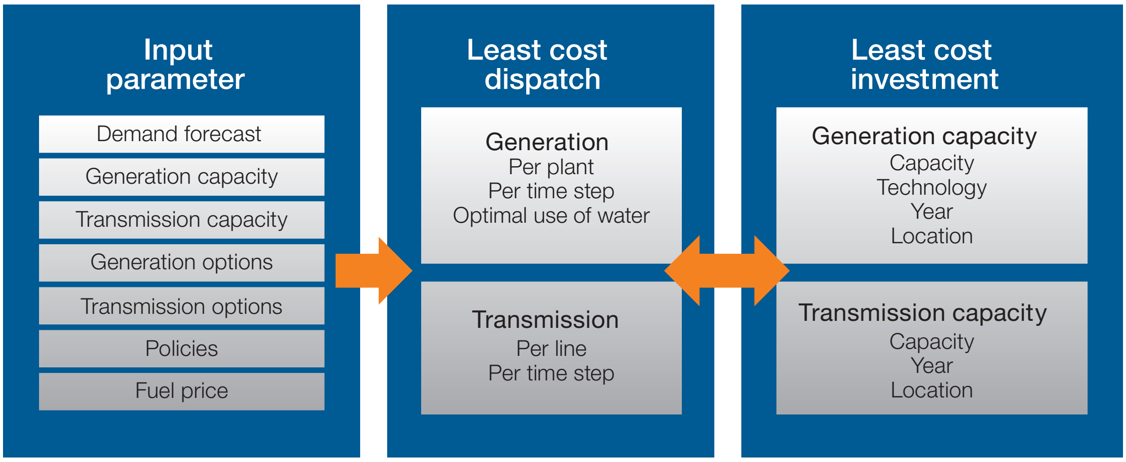


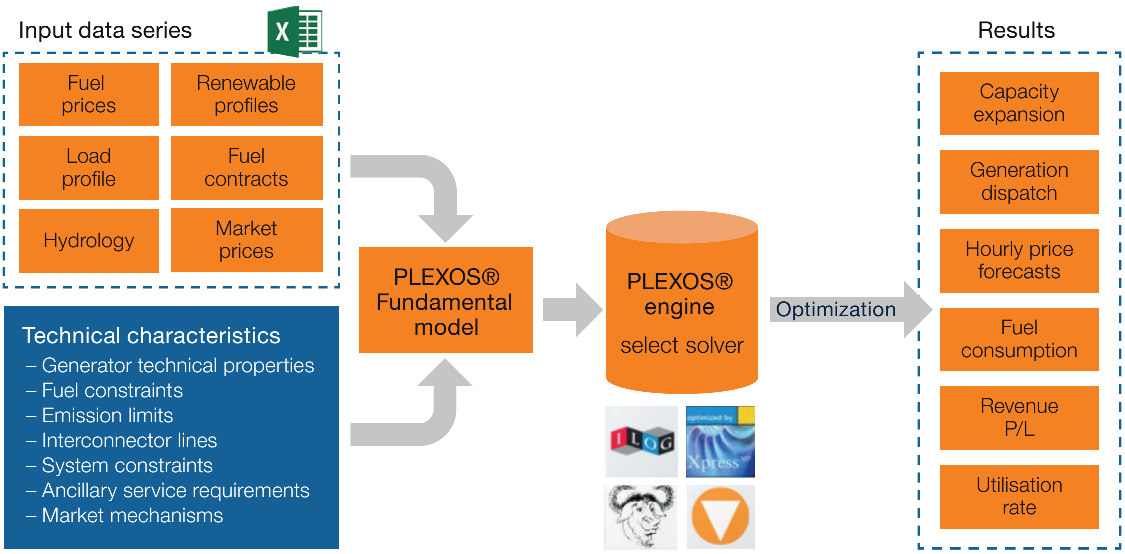
Figure 3-2: Methodology in the Balmorel model

The BALMOREL model, developed by Hans Ravn, is an open source model, using GAMS and SOLVER software to solve the optimal problem. The model can be simulated hourly or aggregated to reduce run time. The system is divided into regions linked by transmission lines that simplify according to capacity. The variation of load, wind, and solar power can be simulated into 8670 hours per year, thus using the BALMOREL model is suitable for calculations of a long term for power system with a high level of integrated wind and solar.

BALMOREL has now been used in more than 30 countries around the world to calculate power planning and outlook reports. It is applied in many large countries, including some European countries, China, South Africa, the UK, Indonesia, Mexico, East Africa, and Canada.

+ PLEXOS MODEL

In parallel with the use of the BALMOREL model to calculate capacity expansion, the project also uses the PLEXOS model to compare and agree the results from the BALMOREL model. PLEXOS integrated energy model software is globally offered for commercial power market modelling and as a simulation tool. It has been developed by Energy Exemplar. The software can be used for planning capacity expansion, generation dispatch, modelling, and forecasting future energy prices and production costs, modelling hydro energy



resources, energy storage technologies and smart-grid systems, and for analyzing power transmission investment planning and energy system risks. Basically, the objective of the software is to offer support for an investment and operation decision, to model scenarios, and to analyse power flows and provide a contingency analysis. One of the most widely used study cases is that of studying the impact of renewable power generation into power systems and the market. PLEXOS simulation software is used in 47 countries and users include policy makers and regulators, operators, power generator companies, transmission system operator companies, manufacturer and construction companies, consultants, analysts and researchers.

+ PDPAT MODEL

To calculate power generation dispatching, the study uses the PDPAT (Power Development Planning Assistant Tool) model. PDPAT is a model supported by the Japan Energy Research Institute for Vietnam in developing the PDP in previous stages. The model simulates generating sets for an entire power system, including many sub-systems (up to 10 sub-systems) linked together by transmission lines. PDPPAT can calculate the supply-demand balance on economic dispatching power plants and inter-regional transmission lines. Currently, the PDPAT model has been significantly improved in terms of wind and solar power simulation. The result of future installed capacity from the BALMOREL model will be included in the PDPAT model to calculate the power generation dispatching, power balance, and LOLE index by region.

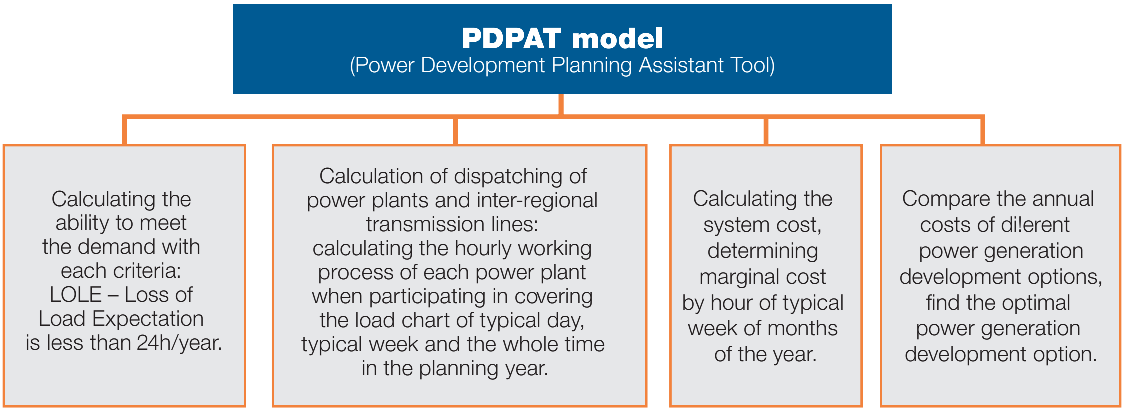


Figure 3-3: The calculation functions of the PDPAT model

3.3. Input assumption

a) Economic and technical parameters of different electricity production technologies

The economic and technical parameters of different electricity production technologies are used according to Vietnam's technology catalogue, which has been supported by the Danish Energy Department in 2019. Parameters included in the model have been selected and evaluated by the project team with high probability in the future. All costs are converted to USD in 2016, excluding annual inflation.

Table 3-1: Economic and technical parameters of different electricity production technologies in the planning period

Technology	Operation year	Construction cost (include IDC) (kUSD/ MW)	Fixed O&M cost (kUSD/ MW)	Variable O&M cost (USD/ MWh)	Efficiency (%)	Technical lifetime (Year)
Nuclear power plant	2030–2045	5950	69.33	2.62	33%	50
Subcritical coal fired power plant	2020–2029	1515	30.5	2.3	36%	30
	2030–2045	1503	29.5	2.1	36%	30
Supercritical coal fired power plant	2020–2029	1814	32.2	2.28	38%	30
	2030–2045	1776	31.5	2.2	39%	30
Ultra-supercritical coal fired power plant	2030–2045	1998	42.9	2.0	43%	30
Advanced ultra-supercritical coal fired power plant	2035–2045	2500	50.9	2.0	50%	30
Subcritical CO_2 extraction	2030–2045	5340	109.6	2.28	36%	30
Combined cycle gas turbine	2020–2029	930	29.35	2.19	58%	25
	2030–2045	870	28.50	2.0	60%	25
Small hydro power plant	2020–2045	1762	38.00	0.46	FLHs	50
High onshore wind turbine (wind speed ≥ 6 m/s)	2020–2024	1650	40.86	4.24	FLHs	27
	2025–2029	1474	38.54	3.99	FLHs	29
	2030–2039	1348	36.18	3.73	FLHs	30
	2040–2045	1245	33.99	3.46	FLHs	30
Medium onshore wind turbine (wind speed 5,5–6 m/s)	2020–2024	1947	47.88	4.96	FLHs	27
	2025–2029	1738	45.44	4.70	FLHs	29
	2030–2039	1531	42.91	4.43	FLHs	30
	2040–2045	1378	40.77	4.15	FLHs	30
Low onshore wind turbine (wind speed 4,5–5,5 m/s)	2020–2024	2038	50.11	5.2	FLHs	27
	2025–2029	1820	47.56	4.92	FLHs	29
	2030–2039	1602	44.92	4.63	FLHs	30
	2040–2045	1493	42.67	4.34	FLHs	30
Offshore wind turbine (fixed bottom)	2020–2024	3110	81.0	3.70	FLHs	27
	2025–2029	3040	75.3	3.40	FLHs	27
	2030–2039	2573	43.0	3.10	FLHs	30
	2040–2045	2390	39.5	2.80	FLHs	30
Offshore wind turbine (floating)	2020–2024	4310	138.9	3.70	FLHs	27
	2025–2029	4210	129.2	3.40	FLHs	27
	2030–2039	3614	60.4	3.10	FLHs	30
	2040–2045	2677	44.2	2.80	FLHs	30
Large scale solar	2020–2024	1119	9.20	–	FLHs	25
	2025–2029	1003	8.25	–	FLHs	25
	2030–2039	886	7.30	–	FLHs	25
	2040–2045	786	6.75	–	FLHs	25
Geothermal power plant	2020–2029	2983	20.00	0.37	10%	30
	2030–2045	2671	18.50	0.34	11%	30
Biomass power plant	2020–2029	2010	47.60	3.00	31%	25
	2030–2045	1892	43.80	2.80	31%	25

Technology	Operation year	Construction cost (include IDC) (kUSD/ MW)	Fixed O&M cost (kUSD/ MW)	Variable O&M cost (USD/ MWh)	Efficiency (%)	Technical lifetime (Year)
Waste power plant	2020–2029	4986	234.70	24.10	28%	25
	2030–2045	4563	224.80	23.40	29%	25
Tidal power plant	2020–2045	2961	21.75	4.00	FLHs	30
Solar rooftop	2020–2024	1119	18.56		FLH	20
	2025–2029	1003	16.53		FLH	20
	2030–2039	886	14.51		FLH	20
	2040–2045	786	12.91		FLH	20
ICE using LNG fuel	2021–2029	740	15	5.0	47.5%	25
	2030–2039	690	13.6	4.5	48%	25
	2040–2045	650	13.5	4.4	48.5%	25
Single cycle gas turbine	2021–2029	620	23.2		33%	25
	2030–2039	580	22.5		36%	25
	2040–2045	540	21.8		39%	25

Source: Data from the Balmorel model report and Vietnam technology catalogue, 2019, Electricity and Renewable Energy Authority. All costs are converted to USD in 2016, excluding annual inflation

Table 3-2: Economic and technical parameters of battery storage (Lithium-ion battery)

	Operation year	Investment cost for battery (include IDC) (kUSD/ MWh)	Investment cost for inverter (include IDC) (kUSD/ MW)	Fixed O&M cost (kUSD/ MW)	Variable O&M cost (USD/ MWh)	Efficiency (%)	Technical lifetime (year)
Battery	2020–2029	280	310	0.62	2.28	91%	20
	2030–2039	210	200	0.62	2.06	92%	25
	2040–2045	150	150	0.62	1.83	92%	30

Source: Data from the Balmorel model report and Vietnam technology catalogue, 2019, Electricity and Renewable Energy Authority.

Table 3-3: Economic and technical parameters of a pump storage power plant

Project (region)	Construction cost (million USD)	Investment rate (kUSD/ MWh)	Installed capacity (MW)	Size of reservoir (MWh)	MWh/ MW
PSPP Moc Chau (North)	653	106	900	6178	6.9
PSPP Dong Phu Yen (North)	1064	118	1200	8984	7.5
PSPP Tay Phu Yen (North)	1070	143	1000	7500	7.5
PSPP Chau Thon (North Central)	1116	149	1000	7500	7.5
PSPP Don Duong (South Central)	1120	125	1200	8956	7.5
PSPP Ninh Son (South Central)	1023	114	1200	8948	7.5
PSPP Ham Thuan Bac (South Central)	1011	113	1200	8948	7.5
PSPP Bac Ai (South Central)	1008	109	1200	9247	7.7

Source: Vietnam Pumped Storage Power Development Strategy, Lahmayer International – WB. All costs are converted to USD in 2016, excluding annual inflation

Table 3-4: Unit commitment of current and future thermal power plants

Technology	Capacity of a unit (MW)	Start-up cost (USD/ MW)	Minimum stable load (% of MW)	Ramp rate (%/minute)	Minimum up time (hour)	Minimum down time (hour)
Nuclear power plant	1000	260	50%	1.2	6	6
Subcritical coal fired power plant	600	180	60%–30%	0.6–2.4	4	2
Supercritical coal fired power plant	600	180	60%–30%	0.6–2.4	4	2
Ultra-supercritical coal fired power plant	600	180	40%–30%	3.0	4	2
CCGT	250	131	45%–20%	4.2 –12	3	2
ICE	20	0	10%	100	0.08	0.08
SCGT	50	24	20%–15%	20	0.5	0.5
Biomass power plant	25	180	40%–30%	6	4	2

Source: Data from the Balmorel model report and Vietnam technology catalogue, 2019, Electricity and Renewable Energy Authority. The following number is the projection for 2045.

Table 3-5: Emissions from different fuels

Fuel	CO_2 kg/GJ	SO_2 kg/GJ	NO_2 g/GJ	Dust (total) g/GJ
Antraxit coal – CFB boiler	88.89	0.04	30.8	8.22
Antraxit coal – PC boiler	96.10	0.06	168	8.89
Bitum coal – PC boiler	96.10	0.07	130	5.56
Natural gas – CCGT	55.82	0.00	68	0.00
Natural gas – ICE	55.82	0.006	150	0.00
Natural gas – SCGT	55.82	0.00	80	0.00
FO oil	76.88	0.41	108.4	3.56
DO oil	76.88	0.21	108.4	3.56

Source: AP 42 US EPA, Document No. 330/BĐKH-GNPT dated 29/3/2019 of MONRE and emissions from Vietnam's transmission grid in 2017, Vietnam Technology Catalogue 2019. Emission factors apply to existing power plants that use exhaust fume treatment equipment

b) Fuel price forecast for electricity generation

Fuel price forecasts for electricity generation are referred to in the "Vietnam Energy Outlook Report 2019" fuel price forecast document supported by the Danish Department of Energy, to the Electricity and Renewable Energy Authority, as well as updated import fuel prices according to short term forecasts by the World Bank and IMF, and updated domestic fuel price forecasts.

The global prices of coal, LNG, and crude oil are forecasted under the new policy scenario in the International Energy Agency's (IEA) World Energy Outlook report 2019. This is the base fuel price forecast scenario of the study.

The price of primary fuel for electricity production is calculated for the power plant and is converted into USD value in 2016 (excluding annual inflation).

Forecast results are shown in the following table:

Table 3-6: Fuel price forecast for power plants (base scenario)

Fuel	Heat rate (Kcal/kg)	2020	2025	2030	2035	2040	2050
		Fuel price (USD/ton)					
Coal 4b_5	5200	73.0	70.6	76.4	77.7	78.9	81.5
Coal 6	4500	61.9	59.9	64.8	65.9	66.9	69.1
Coal 7	3900	52.6	50.9	55.0	55.9	56.9	58.7
Imported coal	6000	89.0	86.2	97.9	99.4	100.9	104.0
FO oil	10533	386.1	420.3	587.3	642.5	684.7	684.7
DO oil	10724	670.8	729.9	1020.0	1115.7	1189.8	1189.8
Gas fuel refers to hydrocarbon gas (41MJ/m³- HHV)	**(0.03895 MMBTU/m³)**	**Fuel price (USD/MMBTU)**					
South East gas		7.95	9.98	11.33	11.42	11.42	11.42
South West gas + purchase from Malaysia		7.60	9.88	11.80	11.80	11.89	11.89
Block B gas		10.89	10.89	10.89	10.89	10.89	10.89
Blue Whale gas		9.05	9.05	9.05	9.05	9.05	9.05
LNG		10.40	11.00	11.80	11.80	11.90	11.90

Source: International Energy Outlook 2019, EIA
Fuel price forecast document – Vietnam Energy Outlook Report 2019, DEA,
World fuel price forecast of the World Bank,
Price agreement of gas fields expected to develop, formula of imported LNG gas price to power plants of PVN and other investors.

c) External cost forecast

Based on the calculation of the external costs for Vietnam by international organizations such as: "Valuation of some environmental costs within the GMS Energy Sector Strategy"– Måns Nilsson, Report to the Asian Development Bank; January 25, 2007 MS, document "Getting Energy Prices Right – from principle to practice" published by the International Monetary Fund in 2014, the study suggests the external costs of SO_X, NO_X and PM2.5 emissions as follows (expected future prices will increase in line with Vietnam's population growth):

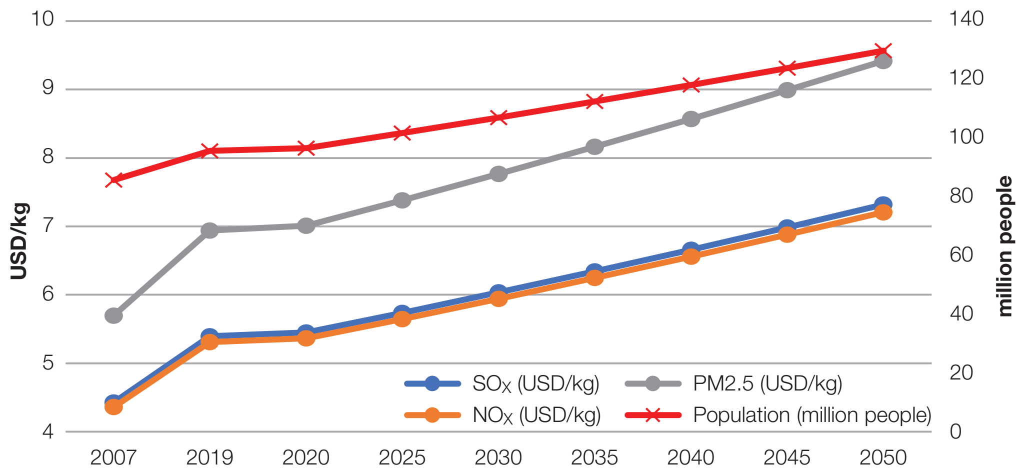


Figure 3-4: External cost forecast in Vietnam

Source: Valuation of some environmental costs within the GMS Energy Sector Strategy – ADB, 2007 and Getting Energy Prices Right – from principle to practice – IMF, 2014

Regarding the external cost of CO_2, according to the website of the world CO_2 market (**https://www.eex.com/en/market-data/environmental-markets/derivatives-market/certified-emission-reductions-futures**), the price of CO_2 on the market in 2019 is an average of USD 0.3–0.5/ton, which is relatively low because currently the CO_2 market is almost saturated and has few transactions. Currently in Vietnam, investments in power generation are still by centralized planning, so the external cost of CO_2 emissions will be taken at the general market price of CO_2. As energy use behavior in countries around the world has changed (switching from coal to gas and renewable energy), CO_2 market prices are not expected to increase as much as in previous periods. Therefore, the study takes the external cost of CO_2 at 0.4 USD/ton (equal to the average market price in 2019). The CO_2 price during the following years within the planning period will be assumed to remain at 0.4 USD/ton.

Regarding the cost of processing solar panels at the end of the project, the study refers to End-of-life management for Solar PV panels – IRENA, 6/2016. Accordingly, the expected cost of processing solar panels at the end of the project is 200 Euro/ton (equivalent to 0.0206 MUSD/ MW). This cost will be included in the investment cost for solar power.

The cost of handling chemicals used in Lithium-Ion batteries at the end of the project life is 5000 USD/ton (according to information provided by the National Argonne Lab (USA).

The land cost will be calculated in addition to the cost of renewable energy with large land use, such as a solar farm.

Table 3-7: Land cost of a large-scale solar farm

No	Region	Average land cost (USD/m^2)
1	North	2.75
2	North Central	2.88
3	Center Central	2.57
4	Highland	4.57
5	South Central	6 – 8.5
6	South	6 – 10.3

Source: Decisions of the People's Committees of the provinces on the land price updated to January 2020

d) Transmission investment cost forecast and power loss in an inter-regional transmission line

Based on the transmission distance between regions, the investment costs for a new inter-regional transmission grid is shown in the following table:

Table 3-8: Transmission investment costs and power loss in an inter-regional transmission line

Inter-regional transmission line	Voltage (kV)	Length (km)	Investment cost ($/ MW)	Power loss
North – North Central	500	330	238 000	3.2%
North Central – Center Central	500	450	310 000	3.6%
Center Central – Highland	500	200	160 000	2.5%
Center Central – South Central	500	420	292 000	3.8%
Highland – South	500	300	220 000	3.5%
South Central – South	500	250	190 000	3.0%
Highland – South Central	500	300	220 000	2.4%

Source: Investment unit cost of Sumitomo and ABB, unit cost of actual projects in Vietnam. Power loss is based on a study from the PSS/E model

3.4. Calculation constraints

a) Progress of firm build projects

The study updated the implementation progress of the projects already included in the PDP7 Revised. Power plant projects with scheduled progress in the 2021–2025 period will be considered as certain construction projects (firm build) and will be committed in the model.

Table 3-9: Progress of committed gas power plants

No	Domestic gas (Power plant, gas field)	Capacity (MW)	Progress according to PDP7R	Investor, status	Updated progress
1	CCGT Dung Quat I (CVX)	750	2023	BOT, in PDP7R	2026
2	CCGT Dung Quat II (CVX)	750	2024	EVN, prepare FS	2024
3	CCGT Dung Quat III (CVX)	750	2026	EVN, prepare FS	2025
4	CCGT mien Trung I (CVX)	750	2023	PVN, prepare FS	2024
5	CCGT mien Trung II (CVX)	750	2024	PVN, prepare FS	2025
6	CCGT Quang Tri (Bao Vang)	340	2024	In PDP7R	2026
7	CCGT O Mon III (Block B)	1050	2020	EVN, Loan negotiation ODA	2025
8	CCGT O Mon IV (Block B)	1050	2021	EVN, Under construction	2023
9	CCGT O Mon II (Block B)	1050	2026	BOT, prepare FS	2026
10	CCGT Nhon Trach 3&4 (imported LNG)	2x750	2021–2022	Signed PPA	2023–2024
	Total	**8740**			

Source: Updated progress of EREA and National Steering Committee on power development – April 2020. To facilitate the exploitation of domestic gas fields, all planned domestic gas power plants are committed to being built in the model.

Table 3-10: Progress of committed coal power plants

No	Power plant	Capacity (MW)	Progress according to PDP7R	Status	Updated progress
1	TPP Na Duong II	110	2019	Under construction and capital arrangement	The first quarter of 2023
2	TPP An Khanh II	650	2022	Prepare FS	6/2023
3	TPP Thai Binh 2	2x600	2017–2018	Under construction, expected to use mix domestic coal and imported coal	1/2021 + 6/2021
4	TPP Hai Duong	2x600	2020–2021	Under construction, expected to use mix domestic coal and imported coal	1/2021 + 6/2021
5	TPP Nam Dinh I	2x600	2021–2022	Signed BOT and PPA, expected to use mix domestic coal and imported coal	12/2024 + 6/2025
6	TPP Nghi Son II	2x600	2021–2022	Under construction	6/2022 + 12/2022
7	TPP Vung Ang II	2x600	2021–2022	Signed BOT	1/2025 + 6/2025
8	TPP Quang Trach I	2x600	2021–2022	Complete technical design	1/2024 + 6/2024
9	TPP Quang Trach II	2x600	2028+2029	Prepare FS	2025
10	TPP Van Phong	2x660	2022–2023	Signed PPA	6/2023 + 1/2024
11	TPP Vinh Tan III	3x660	2022–2023	Negotiate BOT	6/2025 + 1/2026
12	TPP Duyen Hai II	2x600	2021	Under construction	2021–2022
13	TPP Song Hau I	2x600	2019	Under construction	2021–2022
14	TPP Long Phu I	2x600	2019	Under construction	2024–2025
15	TPP Song Hau II	2x1000	2021–2022	Negotiate BOT	2025
	Total	**18 060**			

Source: Updated progress of EREA and National Steering Committee on power development – April 2020.

Table 3-11: Committed wind and solar power plants

Type	Operated	Signed PPA (not operate)	Supplemented to plan (not sign PPA)	Registered, not supplement to plan	Committed to 2025
Solar farm + rooftop (MW)	5 696	3 450	3500 (expected to operate in 2020)	25 300	14 000
Onshore wind (MW)	377	748	10000 (expected to operate in 2021)	30 300	5 000

Source: Updated progress of EREA and National Steering Committee on power development – April 2020; rooftop solar is being encouraged with a high FIT price, it is possible to add 2 GW by 2025 according to EVN.

b) Domestic primary fuel supply limit

The ability to supply domestic coal and domestic gas for electricity production is taken from the following documents: Coal development plan for the period up to 2030; Gas development plan for the period up to 2035; National energy development plan for the period up to 2035; Development of a competitive energy market in the period up to 2025, with a vision to 2030. Accordingly, the ability to supply domestic coal and domestic gas is put into the model as follows:

Table 3-12: Domestic primary fuel supply limit

Year	Domestic coal (million tons/year)	Domestic gas (billion m^3/year)
2020	35	7.7
2025	36.3	14.6
2030	39.8	9.2
2035	39.5	7.7
After 2035	39.5 (assumption)	7.7 (Maintain exploitation in Block B, Blue Whale fields)

c) The potential scale of constructing power generation by region

The study evaluates the potential scale of constructing coal-fired thermal power plants and CCGTs using LNG fuel in the power system by the summary of investment registration projects and the preliminary assessment of potential construction sites in coastal provinces. A summary of the potential scale (candidate projects) is included in the model as follows:

Table 3-13: Potential scale of constructing coal-fired thermal power plants and CCGTs using LNG fuel

Region	Imported coal-fired thermal power plant	CCGT using imported LNG
North	19 100	29 000
North Central	6 050	11 000
Center Central	9 200	16 000
South Central	9 200	21 750
South	16 200	34 250
Total (MW)	**59 750**	**112 000**

Regarding renewable energy, the potential scale is included according to the economic – technical potential evaluated in the project "National RE Development Plan in the period up to 2035" prepared by the Institute of Energy in 2018.

Table 3-14: Potential scale of RE included to the model

Region	Offshore wind	Onshore wind (above 4.5 m/s)	Solar (farm)	Solar (rooftop)	Bio-mass	Small hydro power	Waste	Bio-gas	Geo-thermal	Tidal
North	13 000	12 565	14 600	10 724	1 611	1 474	359	918	255	530
North Central	5 000	10 717	3 350	5 542	548	242	65	239	51	
Center Central	0	11 235	10 300	3 521	336	410	33	120	77	5
Highland	0	74 386	117 600	2 448	663	384	14	128	0	
South Central	118 000	34 764	81 000	4 165	521	278	46	162	60	15
South	26 200	73 638	110 000	22 091	1 638	70	999	388	18	
Total	**162 200**	**217 305**	**336 850**	**48 491**	**5 316**	**2 860**	**1 517**	**1 957**	**461**	**550**

Regarding imported electricity from neighboring countries, the capacity of potential import projects can be as much as 19 GW from China, Laos and Cambodia. However, importation will depend on the political conditions and cooperation among countries. Therefore, in order to ensure domestic energy security, the study fixed the amounts of import capacity (from China: 700 MW, from Laos: about 3000 MW in 2025 and about 5000 MW in 2030 – according to the memorandum between the Government of Vietnam and Laos in 2016). The total import capacity to 2030 is 5500 MW with electricity of approximately 21–22 billion kWh/year.

Nuclear power is also included in the model in eight potential locations in South Central (Binh Dinh, Ninh Thuan, Phu Yen provinces), Center Central (Quang Ngai province) and North Central (Ha Tinh province) according to the Prime Minister's Decision No. 906/QD-TTg dated June 17, 2010 on the planning of nuclear power development.

ICE power plants can be located next to an LNG terminal, or at a distance from the terminal with the fuel transported by tanker, barge or pipeline. Therefore, ICE power plants can be built in all 6 regions, depending on the needs of the power system and the selection by the model.

d) Demand forecast in the period up to 2050

The report used the first draft demand forecast of the PDP8 (February 2020) to calculate the potential development for ICE power plants in the power system. In June 2020, the PDP8 revised its demand forecast due to the impact of COVID-19. A comparison of the demand forecast used for this study and the updated version of PDP8 is as follows:

Table 3-15: National demand forecast in scenarios for the period up to 2050

Unit :TWh

Demand forecast scenarios	2021	2025	2030	2035	2040	2045	2050
Demand forecast of this project	**283.0**	**390.8**	**555.2**	**714.9**	**866.8**	**1001.6**	**1093.9**
Updated PDP8 – High case	279.0	393.8	569.7	746.7	916.3	1074.2	1199.9
Updated PDP8 – Base case	277.0	381.1	536.6	687.8	829.3	959.4	1062.5

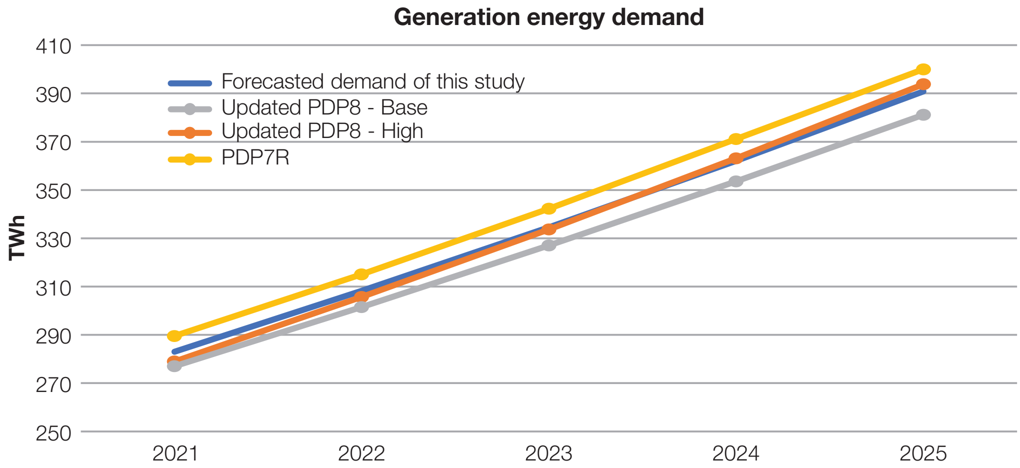


Figure 3-5: Comparison of demand forecast for the period 2021–2025 in scenarios

In the short term 2021–2025, the demand forecast in this study is equivalent to the updated version of the PDP8. In the long term, the demand forecast in this study is equivalent and higher than that of the base case in the updated PDP8. The demand forecast selected in this study is still within the updated forecast range of the PDP8 (between the high case and the base case).

Because an ICE power plant is able to be quickly built, it will help to reduce the risk of short term power shortages in the case of high demand. Therefore, the study chooses to calculate the occurrence of an ICE power plant with the proposed demand forecast to increase the ability to ensure power supply redundancy (especially in the short term).

Chapter 4. Analyzing the operational ability of an ICE power plant in Vietnam's power system

4.1. Determining the power generation expansion for Vietnam's power system in the period up to 2050

4.1.1. Power generation development scenarios

In order to evaluate the development of flexible ICE power plants, the study considers different power generation development scenarios. Three groups of scenarios will be analyzed i.e. long-term, medium-term, and short-term scenarios:

a) Long term scenarios

In this scenario group, the study considers the potential development of power generation from 2020 up to 2050 with and without a policy on renewable energy targets. In the long term scenarios, committed projects are included in the model. The study assumes that committed projects are projects identified in the PDP7 revised, which has updated the expected operation time for these new power plant projects in the period 2021–2025 (details are presented in Chapter 3). Therefore, there are 3 long term scenarios with baseline input parameters (normal water year, base investment cost, and the forecasted fuel prices as described in Chapter 3). The study will select a base scenario from these long term scenarios for Vietnam's power generation development plan for the period up to 2050.

- **Scenario LT1A – No RE target, no external cost:** This scenario does not take into account the renewable energy (RE) target policy. The types of power generation chosen to be developed in the future are based entirely on cost competitiveness, and do not consider the external cost in an objective function.
- **Scenario LT1B – No RE target, with external cost:** This scenario does not take into consideration the renewable energy target policy, but considers the external cost in an objective function. Here, the external cost is the cost of CO_2, SO_X, NO_X and PM2.5 emissions.
- **Scenario LT2B – With RE target, with external cost:** This scenario uses constraints on the RE targets according to Vietnam's Renewable Energy Development Strategy for the period up to 2030, with a vision to 2050 (Decision 2068/QD-TTg dated November 25, 2015). Accordingly, the proportion of electricity produced from renewable energy sources (including large hydro power plants) within the total electricity production of the entire country will reach 38% in 2020, 32% in 2030 and 43% in 2050. Therefore, the proportion of electricity produced from renewable energy sources will linearly decrease during the period from 2020-2030 and linearly increase during the period from 2031-2050, and it is expected to reach 34.8% in 2035, 37.5% in 2040 and 40.3% in 2045. The RE share in this strategy is also in line with the Resolution 55-NQ/TW on February 11, 2020, which approved the proportion of renewable energy sources in the total primary energy supply as reaching 15–20% in 2030 and 25–30% in 2045. The equivalent proportion of electricity produced nationally from renewable energy sources is approximately 30% in 2030 and 40% in 2045.

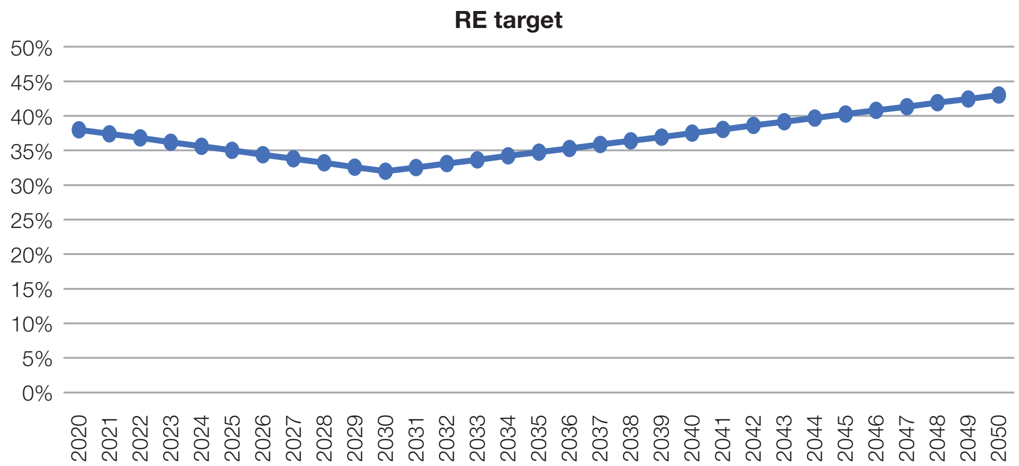


Figure 4-1: The RE target in scenario LT2B

- **Scenario LT3 – No ICE:** After selecting the long term power development scenario, to evaluate the effectiveness of having an ICE power source in the system, the project calculated the scenario without an ICE source (LT3_No_ICE). This scenario is calculated based on the selected scenario, but does not include an ICE investment in the system.

b) Medium term & short term scenarios

In the Medium term scenarios (2020–2030), the installed capacity is optimized without considering the committed projects until 2025 in the model. The purpose of these scenarios is to minimize the investment, lower the production costs, and generate savings in the power system.

Whereas in the short term scenario (2020–2025) the purpose is to evaluate the possible alternative of fast-track projects i.e. ICE power plants which can be built within just 1 year and which meet the electricity supply shortage caused by delays in the thermal power plant projects until 2025.

The expected 3 scenarios of the sensitivity analysis are as follows:

- **Scenario MT1_Free optimization:** This scenario does not include power generation projects under construction and which are expected to become operational by 2025 (committed projects) in the model. This is a free optimization scenario, considering only the power generation structure having the least cost. This scenario will be calculated in order to suggest the change in committed projects for a lower system cost than the current short- & medium-term plan.
- **Scenario MT2_ Free optimization with lower RE CAPEX:** This scenario does not include committed projects in the model and considers a lower CAPEX for RE (wind, solar). Renewables are now the cheapest source of electricity across more than two-thirds of the world. Vietnam will experience a similar transition in the coming years when competitive auctions will be introduced for new solar and wind projects. Therefore, this scenario will give the optimal capacity mix in the medium term if the investment costs for solar and wind are lower than the forecasted figures in the long term scenarios. The CAPEX of wind and solar power is taken from Bloomberg New Energy Finance (BNEF) forecasts for Vietnam (1st half of 2020) as follows:

Table 4-1: Forecasted CAPEX of wind and solar by scenarios

No	Year	Wind High* (USD/kW)	Wind Medium* (USD/kW)	Wind Low* (USD/kW)	Solar PV (USD/kW)
1	Base scenario				
	2020	1530	1800	1880	1080
	2025	1360	1600	1680	960
	2030	1240	1410	1480	840
2	Scenario MT2_ Free optimization _lower RE capex				
	2020	1500	1758	1840	1020
	2025	1317	1543	1615	757
	2030	1156	1355	1418	628

* Based on the wind speed, three different prices are considered for wind. Wind high: wind speed is >=6 m/s, wind medium: wind speed is between 5.5 to 6 m/s; wind low: wind speed is between 4.5 to 5.5 m/s.

- **Scenario ST1_Delay of committed projects:** This scenario considers in the model the possibility of delays to committed projects. Some specific thermal power plants have a high possibility of being delayed further than the assessed progress in the base scenario as follows:

Table 4-2: Assumption progress of some committed projects

Project	Capacity (MW)	Operation year in Base scenario	Operation year in Scenario ST1_Delay of committed projects
Thai Binh 2 TPP	2x600	2021	2023
Long Phu 1 TPP	2x600	2024	2024–2025
Nhon Trach 3&4 CCGT	2x750	2023	2023–2024
Duyen Hai 2 TPP	2x600	2021–2022	2022
Vinh Tan 3 TPP	3x660	2024–2025	2025–2026

By 2025, there will be about 1320 MW of coal-fired thermal power plants behind schedule. In addition, by 2025 approximately 5 GW of wind power and 14 GW of solar power (including rooftop and the existing scale) committed to be built in the base scenario will be reduced to only 3.8 GW of wind power and 11.4 GW of solar power in Scenario ST1_outlining the delay of committed projects.

4.1.2. Analyzing the results of long term scenarios

Calculation results of the capacity expansion from the Balmorel model in scenarios are shown below:

a) Installed capacity structure

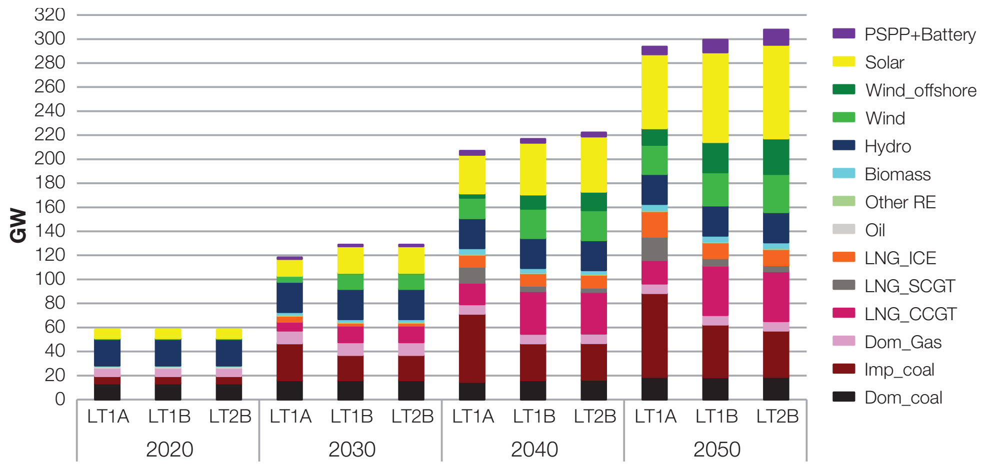


Figure 4-2: Installed capacity structure in long term scenarios (not including the import capacity from China and Laos)

The results show that renewable energy, especially wind and solar power, will be selected for large-scale development in the future. Coal and gas are the fossil fuel sources that will continue to be used in all scenarios. Oil fuel will not be used to supply the peak load after 2025.

In the no RE target, no external cost scenario (LT1A), coal-fired thermal power plants will continue to be developed on a large scale, from 19.5 GW in 2020 to 47 GW in 2030 and 88 GW in 2050. The capacity scale of LNG power plants will also increase in 2050 due to limitations in the potential construction location of coal-fired thermal power plants in load center areas (North and South) and the requirement to build only technology ultra-supercritical (USC) for coal-fired thermal power plants operating after 2035. However, most of the gas power capacity using LNG will be ICE flexible power plants to supply peak load and to ensure reserves, so the amount of electricity produced from LNG will not be high. ICE power plants will be introduced, scaling from 5 GW in 2030, 10 GW in 2040 to 21 GW in 2050. Renewable energy sources, especially wind and solar, are still selected for development on a large scale (wind: 38 GW, solar: 61 GW in 2050). In terms of the installed capacity mix, renewable energy (including large levels of hydropower) will reach 40% in 2030 and 44% in 2050.

Scenario LT1B with external cost will reduce coal-fired thermal power plant investments, increase gas-fired thermal power plant investments (CCGT), and will also increase wind and solar power plant investments. The capacity of RE is similar to scenario LT2B in 2030 but lower than the RE development strategy in the years after 2030. In scenario LT1B, ICE power plant is developed with the capacity of 2.5 GW in 2030, 10.6 GW in 2040 and 13.4 GW in 2050.

In the renewable energy target scenario (LT2B), renewable energy sources are developed to ensure attainment of the target, and the renewable energy capacity will be 1.2 to 1.5 times higher than in scenario LT1A. The capacity of coal-fired thermal power plants will be lower; CCGT will be selected for increased development with more electricity generated from LNG fuel. In scenario LT2B, ICE power plants are developed equivalent to scenario LT1B (2.5 GW in 2030, 10.6 GW in 2040 and 13.4 GW in 2050).

b) Electricity generation structure

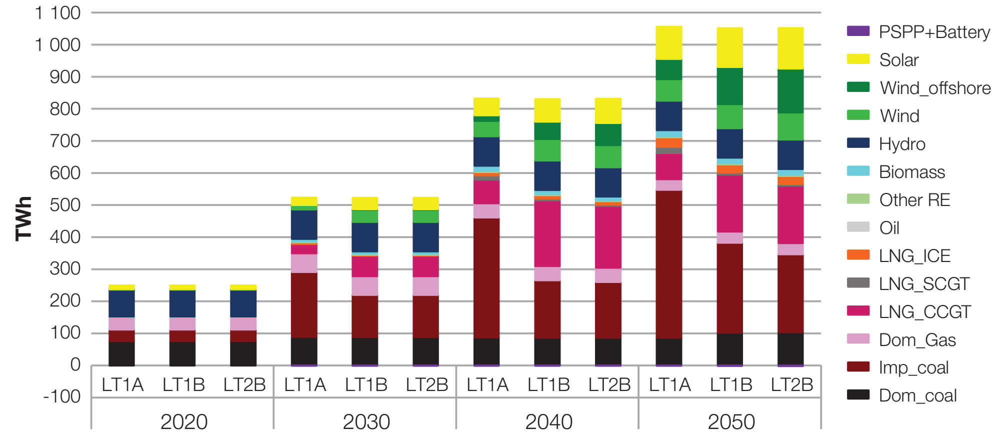


Figure 4-3: Electricity generation structure in long term scenarios (not including the import capacity from China and Laos)

The electricity generation structure of scenario LT1A will depend largely on coal-fired thermal power plants (56% in 2030 and 52% in 2050). RE will only account for 26% in 2030 and 32% in 2050. In this scenario, ICE power plants are running with a capacity factor of about 10%. When considering external costs, scenario LT1B has a renewable energy proportion equivalent to the RE development strategy target in 2030 (32%) but will not reach the target in 2050 (only 36%).

In scenario LT2B, the proportion of electricity produced from renewable energy sources will reach the target. Because of this increase, electricity generation from coal-fired power plants is much reduced. Electricity generation from gas-fired thermal power plants will be close to that of coal in 2040 and much higher than in scenario LT1A.

In the long term scenarios, ICE power plants are running at an annual capacity factor of around 10%. ICE power plants come online during peak periods and also when the solar power diminishes during the evening. These flexible ICE power plants are providing power system reserves to the grid.

c) Comparison of system costs in long term scenarios

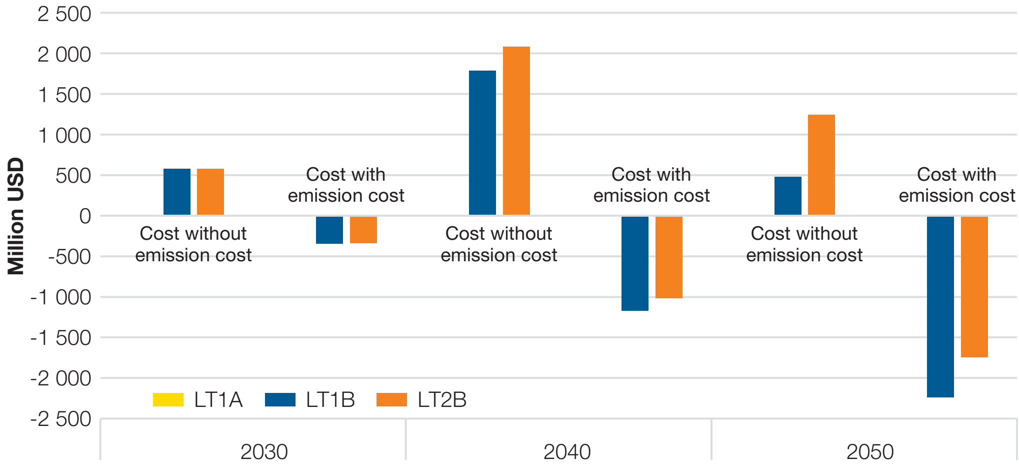


Figure 4-4: Difference system costs in other scenarios compared with the LT1A scenario

From the comparison graph of system costs, it can be seen that when excluding external costs, the LT1A scenario has the lowest cost. When including external costs, the scenarios with external costs in objective function (LT1B and LT2B) have lower costs than in scenario LT1A.

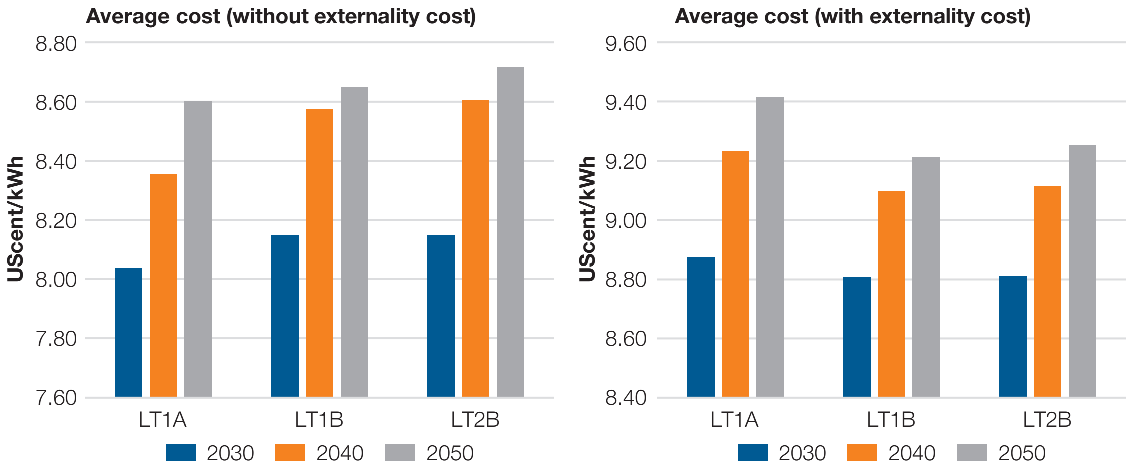


Figure 4-5: System average costs

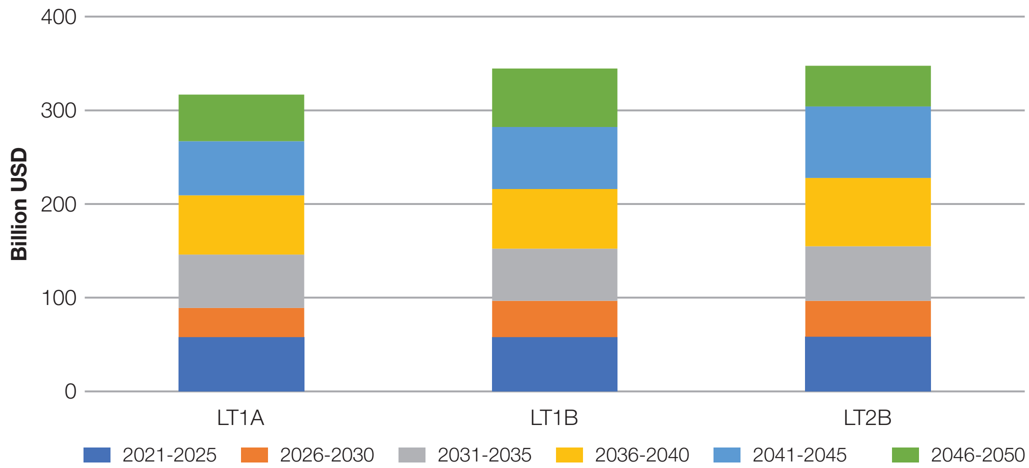


Figure 4-6: Investment costs for new generation units in long term scenarios

The LT1B and LT2B scenarios have similar system and investment costs.

d) Comparison of CO_2 emissions in long term scenarios

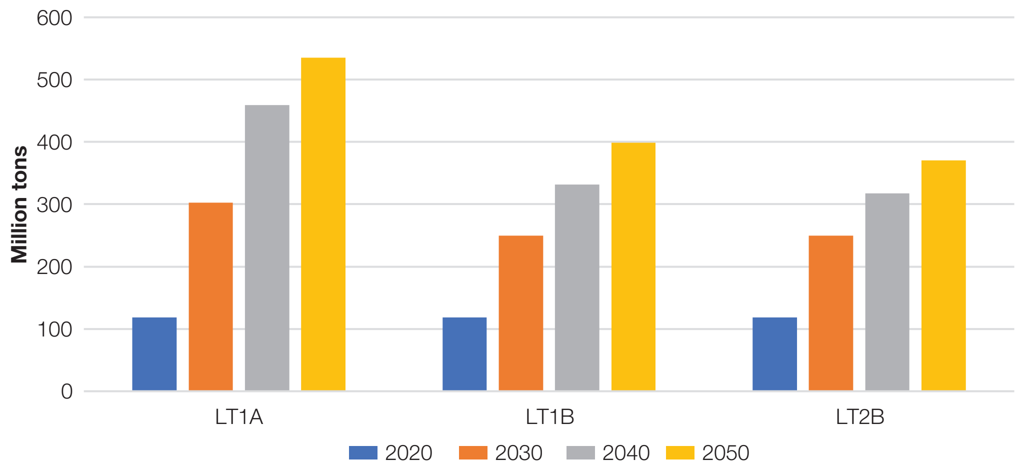


Figure 4-7: CO_2 emissions in long term scenarios

Scenario LT1A has the highest CO_2 emissions, while scenario LT2B has the lowest CO_2 emissions due to more renewables generation in the power system.

Table 4-3: CO_2 emission reduction rates of the scenarios as compared to the LT1A scenarios

Scenario/year	2030	2040	2050
LT1B	18%	28%	25%
LT2B	18%	31%	31%

Compared to scenario LT1A, the CO_2 emission reduction rates of the scenarios are within the commitment range for implementing the goal to reduce greenhouse gas emissions by 8%–25% (according to Vietnam's commitments in the international convention on reducing greenhouse gas emissions – contributions are decided by each individual country). In the years after 2030, the LT2B scenario has high greenhouse gas reduction targets (over 25%).

e) Comparison of inter-regional transmission capacity in long term scenarios

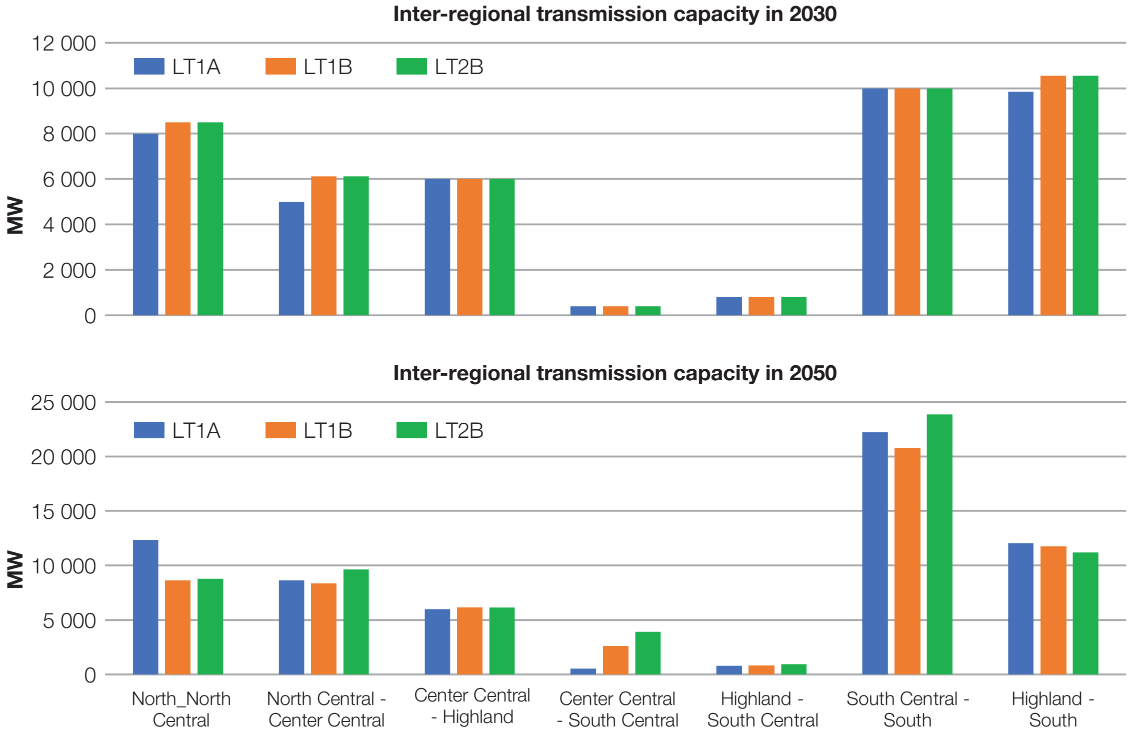


Figure 4-8: Inter-regional transmission capacities in long term scenarios

In general, all three scenarios have similar scales of inter-regional transmission capacity in the period up to 2050, and the difference between the scenarios is not large.

f) Selecting the base scenario for Vietnam's power generation development

Summarized evaluation scenarios are as follows:

- Scenarios LT1A and LT1B: do not meet the RE target according to current policies (RE Development Strategy and Resolution 55-NQ/TW). Therefore, they will not be selected.
- Scenario LT2B meets current policy targets on renewable energy and greenhouse gas emissions (RE targets meet the RE Development Strategy and Resolution 55-NQ/TW, reducing greenhouse gas emissions as committed by Vietnam at the International Convention). Average system costs and CO_2 emissions are low and the proportion of electricity generation between fuels is balanced.

The summarized evaluation shows that scenario LT2B has many advantages. The study proposes the selection of scenario LT2B (RE target, with external cost) as Vietnam's long term power generation development scenario (base scenario).

Table 4-4: Summary of proposed installed capacity development for the period up to 2050 – Scenario LT2B

Type of source	2020	2030	2040	2050
Domestic_coal	13.3	16.2	16.9	16.9
Import_coal	6.0	20.7	30.2	40.7
Domestic_gas	7.4	10.6	7.9	7.9
LNG_CCGT		14.0	34.3	41.4
LNG_ICE		2.5	10.6	13.4
LNG_SCGT			3.3	5.0
Oil	1.4	0.1		
Other RE	0.3	0.8	1.3	1.3
Biomass	0.3	2.0	2.9	4.8
Hydro	21.6	25.5	25.5	25.5
Wind	0.7	12.9	24.9	31.8
Wind_offshore		0.5	15.0	29.6
Solar	7.1	22.0	43.8	78.0
PSPP+Battery		1.2	5.4	12.4
Import from China+Laos	1.3	5.5	5.5	5.5
Total installed capacity (GW)	**59.3**	**134.6**	**227.5**	**314.2**
Peak load – Pmax (GW)	**41.3**	**87.9**	**137.7**	**159.2**

Source: Result from Balmorel model

In the base scenario (LT2B), the capacity of ICE power plants expected to operate in the period 2026–2030 and using LNG is 2.5 GW.

g) Assessing the effectiveness of the installing ICE power sources in the long term

The study calculates the expansion capacity with selection scenario (LT2B) but without ICE source. The calculation results compared to the LT2B scenario are as follows:

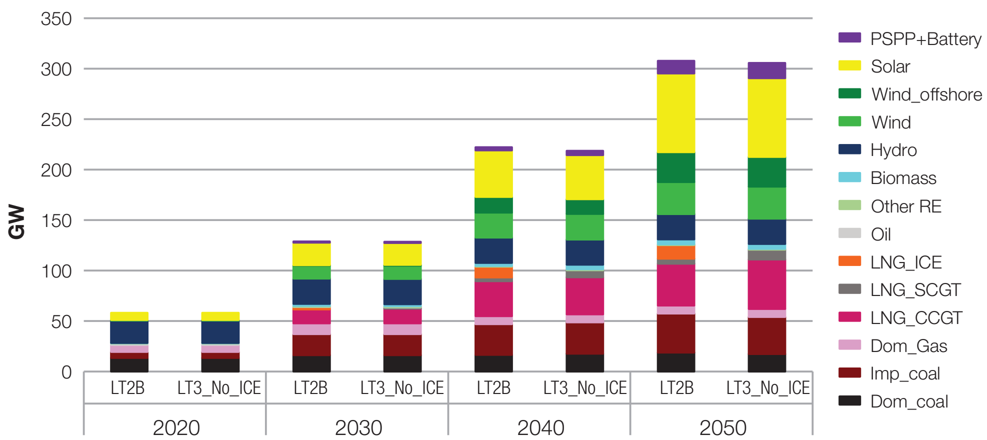


Figure 4-9: Comparison of capacity expansions for LT3_No_ICE with LT2B

In scenario LT3_No_ICE, the CCGT, SCGT and battery solutions will be built more than in scenario LT2B, which will result in higher total system costs as shown in the below table.

Table 4-5: Total system costs (excluding external costs) by year for the LT3_No_ICE and LT2B scenarios

Scenario/year	2030	2040	2050
LT2B (MUSD)	42803	71608	91923
LT3_No_ICE (MUSD)	42981	71764	91977
Difference (LT3_No_ICE – LT2B) (MUSD)	178.1	155.8	53.9

With ICEs in the system, total system costs will be reduced by 50–180 million USD/year as compared to the scenario without ICEs.

4.1.3. Analyzing the results of medium term and short term scenarios

Scenario LT2B, having the RE target & external costs, is selected from the above discussed long term scenarios and will be considered as the base scenario for comparison of the results with the medium-term & short-term scenarios.

a) Scenario MT1_Free optimization:

In the MT1 scenario, power plants that are planned to become operational during the period from 2021–2025 will not be included in the model (except for domestic gas relating to the exploitation of fields, maritime sovereignty, etc.). Instead, BALMOREL will run this scenario to find the most cost optimal solution for Vietnam's power system from 2020 to 2030. In this way, the capacity planned in the base case can be compared with the optimized solution.

Results for the installed capacity structure by year in the period 2020–2030 are as follows:

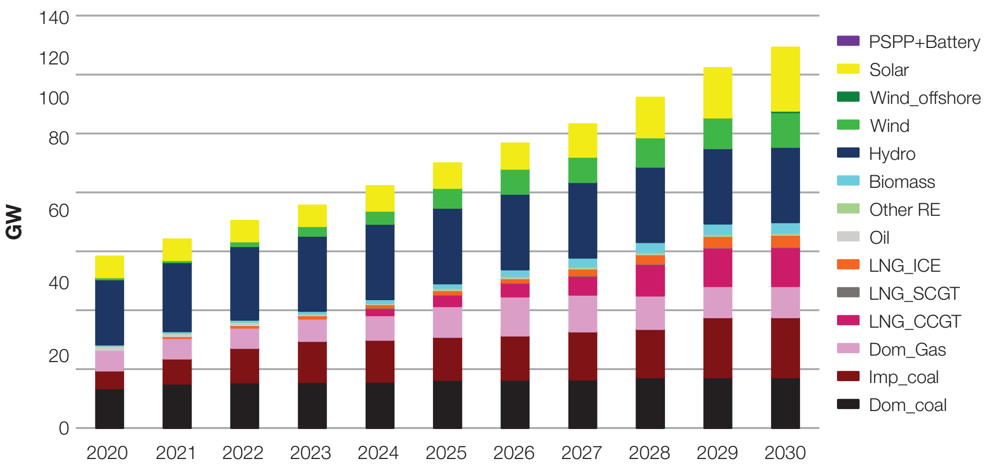


Figure 4-10: Installed capacity structure by year for the period 2020–2030 in Scenario MT1_Free optimization (not including the import capacity from China and Laos)

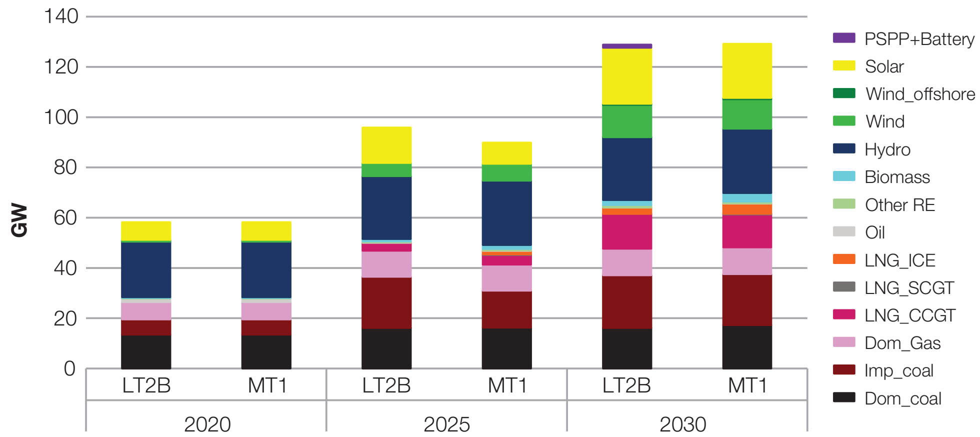


Figure 4-11: Comparing the installed capacity of the MT1 scenario (Free optimization) to the LT2B scenario (Base Case).

In this scenario, the total installed capacity by 2025 is less than that in the base case LT2B. Coal-fired power plants will not be built at all during the period from 2021–2025 as committed in the base scenario, but will be spread out with gradual investments in the period up to 2030. The installed capacity structure in 2030 is similar to the base scenario except for the increasing capacity of ICE power plants and biomass power plants in scenario MT1. In the period up to 2025, compared to the base scenario, wind power and biomass will receive greater investment, and ICE power plants will be built from the year 2021 to supply peak load and reserve capacity for the South. In the period 2026–2030, investment in ICE power plants is higher than the base scenario by approximately 1600 MW. The increase in ICE capacity will replace 1200 MW of energy storage in the base scenario.

ICE power plants are developed in scenario MT1_Free optimization as follows:

Table 4-6: Capacity of ICE power plants in scenario MT1_Free optimization

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total installed capacity of ICEs (MW)	623	837	1120	1120	1390	1390	2321	3182	3768	4070
North							574	789	1045	1045
South	623	837	1120	1120	1390	1390	1747	2393	2723	3025

With an investment decision such as in scenario MT1_Free optimization, investment cost pressure will be reduced for the first phase, and system costs for the period of 2021–2030 will also be reduced compared to the base scenario. The total system costs for 2025 and 2030 in MT1_Free optimization are lower than in the Base Scenario by approximately 592 million USD.

Table 4-7: Comparison of system costs for 2025, 2030 in scenario MT1_Free optimization and the base scenario

Scenario	2025	2030	Total 2025 and 2030
Base (LT2B) (MUSD)	31 007	42 803	73 810
MT1_Free optimization (MUSD)	29 933	43 285	73 218

b) Scenario MT2_Free optimization_lower RE CAPEX:

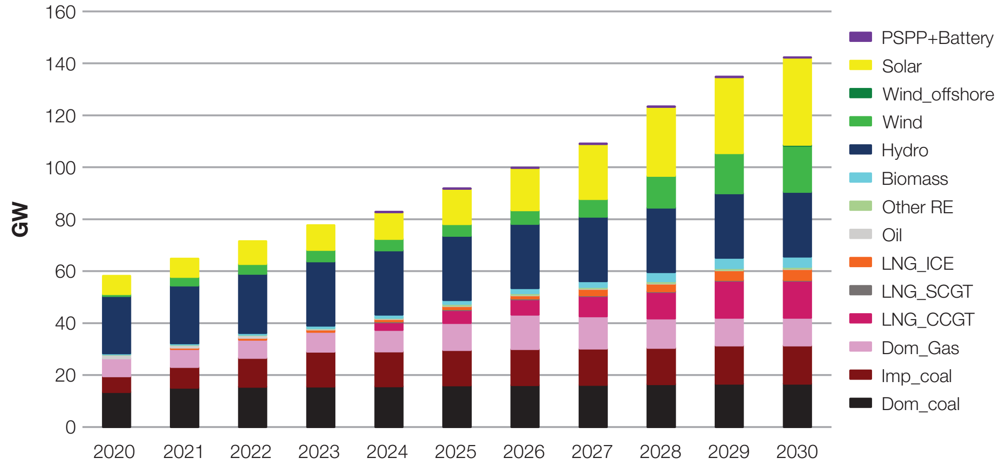


Figure 4-12: Installed capacity structure by year for the period 2021–2030 in Scenario MT2_Free optimization_lower RE CAPEX (not including the import capacity from China and Laos)

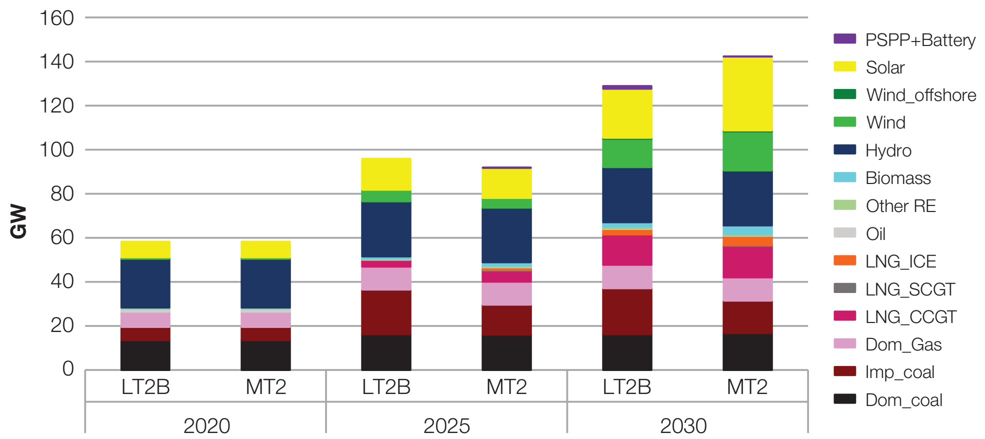


Figure 4-13: Comparing the installed capacity of the MT2 scenario with the LT2B scenario

In the coming years, Renewables will become cheaper in Vietnam. The country will experience a similar transition as is happening in two-thirds of the world where Renewables are the cheapest source of electricity. Competitive auctions will be introduced for new solar & wind projects. This scenario reflects the situation whereby the CAPEX of renewables is expected to decrease to relatively low levels during the period to 2030 (40% reduction). The results show that more wind and solar power plants are chosen for new investments, thus exceeding the RE target (reaching 40% of national electricity generation, while the target is only 32%). Compared to the base scenario, scenario MT2_Free optimization_lower RE CAPEX will reduce investments in coal-fired thermal power plants, increase investments in gas-fired power plants, and in wind and solar power. The capacity of ICE power plants is also increased compared to the base scenario of about 1800 MW, while energy storage will decrease by 1100 MW.

The development of ICE power plants in scenario MT2_Free optimization_lower RE CAPEX is as follows:

Table 4-8: Capacity of ICE power plants in scenario MT2_Free optimization_lower RE CAPEX

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total installed capacity of ICE (MW)	512	734	945	945	1206	1206	2432	2934	3729	4225
North							512	734	1145	1145
South	512	734	945	945	1206	1206	1920	2200	2584	3080

c) Scenario ST1_Delay of committed projects

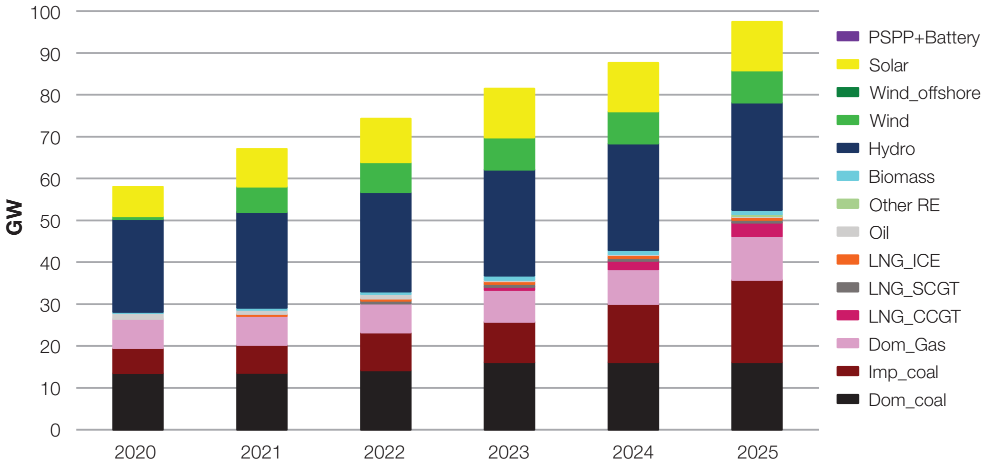


Figure 4-14: Installed capacity structure by year for the period 2021–2025 in Scenario ST1_Delay of committed projects (not including the import capacity from China and Laos)

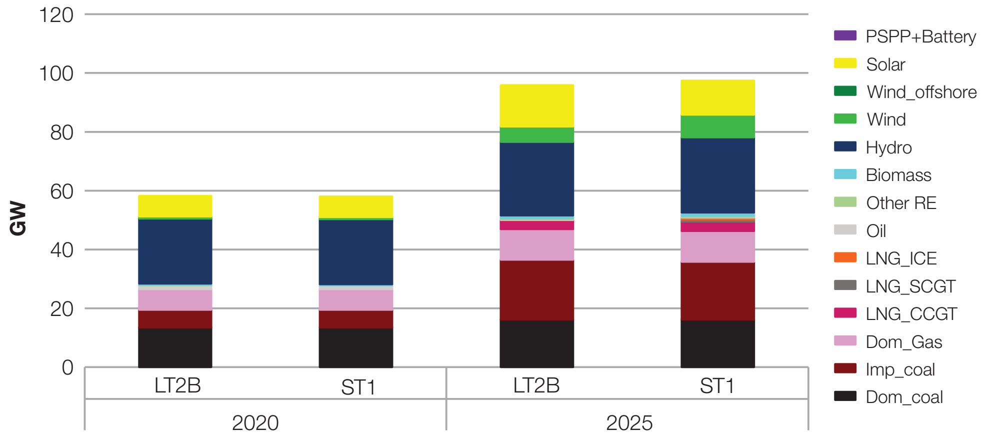


Figure 4-15: Comparing the installed capacity of the ST1 scenario with the LT2B scenario

In this scenario, some of the power plants committed by 2025 and which were considered in the long term scenarios, are assumed to be delayed further in their operational schedule. The list of these projects can be seen in Table 4.2. This scenario studies the possible options for fast-track power plants that could be built from 2021 to avoid expected power shortages in the country. The BALMOREL model optimizes the power system with more power sources, mainly ICE power plants, onshore wind, and biomass. The ICE source was selected to be put into operation during 2021–2023 with a scale of 480–640 MW. The onshore wind source will be developed more than the base scenario by 2.4 GW in 2022-2023. The biomass source will also be higher than the base scenario by approximately 150 MW during the period 2022–2023.

Table 4-9: Capacity of ICE power plants in scenario ST1_Delay of committed projects

Year	2021	2022	2023	2024	2025
Total installed capacity of ICE (MW)					
South	486	486	643	643	643

ICE power plants are chosen for investment in the South with 480–640 MW in the period from 2021–2025. These plants will act as a back-up for delayed committed power plant projects.

d) Comparison of CO_2 emissions between the short term (ST1) and medium term (MT1, MT2) scenarios with the long term scenario (LT2B)

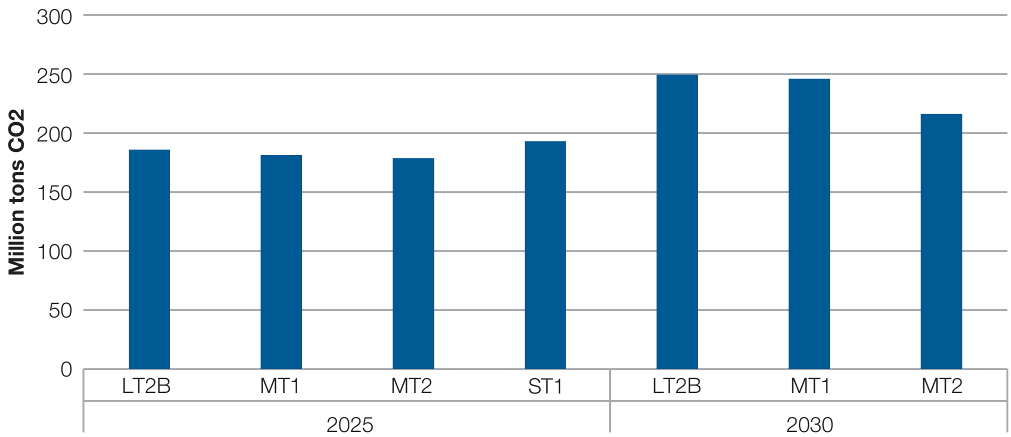


Figure 4-16: Comparing CO_2 emissions for the ST1, MT1, MT2 scenarios with those of the LT2B scenario

With free optimisation, the CO_2 emissions in the MT1 and MT2 scenarios are lower than in the LT2B scenario. CO_2 emissions in the ST1 scenario in 2025 are higher than in the LT2B scenario because of delays to the solar and wind projects.

e) Proposing the capacity of ICE power plants in the short & medium term

Analysis of the medium term scenarios shows that ICE power plants should be considered and put into operation sooner than in the base scenario (LT2B) to prevent risks, such as delays to large power plant projects.

In the period up to 2025, the option of investing in additional ICEs, wind power and biomass, along with a delayed schedule for coal-fired thermal power plants, will result in lower system costs than maintaining the committed schedule for the coal-fired plants. Taking into consideration the time needed for researching, preparing documents and construction, the proposed earliest operational time for an ICE power plant will be in 2022.

To prevent the possibility of power shortages from 2021 onwards, due to further delays in the construction of committed power sources, the study proposes the building of ICE-based capacity with the selected scale as per the ST1 scenario in the period to 2025.

In the period after 2025, due to the inability to cancel committed projects listed in the PDP7 Revised, the development scale of ICE sources was selected as being per the LT2B scenario.

From the above analysis, the study proposes ICE power plant capacity for the period up to 2030 as follows:

Table 4-10: Proposed capacity of ICE power plants in the period 2021–2030

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total installed capacity of ICE (MW)	**400**	**650**	**650**	**650**	**650**	**650**	**1250**	**1850**	**2450**
North							300	600	900
South	400	650	650	650	650	650	950	1250	1550

4.2. Determining the operating mode of the proposed capacity of ICE power plants in the regional power system

The study determines the operational mode of ICE power plants by year using the PDPAT model. In this exercise, the committed projects during the period up to 2025 are still assumed to be behind schedule, as in the ST1_Delay committed project scenario, and new capacity from 2025 onwards is according to the selected scenario (LT2B). The capacity of ICE power plants will be added to the power system during the period up to 2045, as proposed in the above section. The results showing the power and energy balance by region are presented in the appendix.

4.2.1. Operational mode of ICE power plants in a normal water year

Table 4-11: National power balance up to 2045

Unit: GW

Year	2020	2025	2030	2035	2040	2045
Peak load	**41.3**	**62.1**	**87.9**	**113.5**	**137.7**	**159.2**
Total installed capacity	**59.4**	**101.0**	**134.6**	**181.7**	**227.5**	**276.7**
• Coal-fired TPP	19.3	35.2	36.9	39.1	47.1	59.9
• Gas TPP (CCGT+SCGT) + oil	8.7	15.5	24.7	40.4	45.5	48.1
• **North ICE – LNG**			**0.9**	**3.3**	**5.7**	**6.3**
• **South ICE – LNG**		**0.65**	**1.55**	**2.45**	**4.25**	**5.45**
• **South Central ICE – LNG**					**0.6**	**0.6**
• Hydro power plant	21.6	24.9	25.5	25.5	25.5	25.5
• Wind power plant	0.7	5.7	13.4	26.1	39.9	53.1
• Solar power plant	7.1	14.5	22.0	32.0	43.8	58.3
• Biomass + other RE	0.6	1.5	2.8	3.3	4.2	4.9
• PSPP + Battery			1.2	3.9	5.4	9.0
• Import	1.3	3.1	5.5	5.5	5.5	5.5

Table 4-12: National energy balance up to 2045 (normal water year)

Unit: TWh

Year	2020	2025	2030	2035	2040	2045
Demand	**259.0**	**390.8**	**555.2**	**714.9**	**866.8**	**1001.6**
Generation energy	**259.0**	**390.8**	**555.2**	**714.9**	**866.8**	**1001.6**
• Coal-fired TPP	113.7	182.0	223.5	241.9	277.7	360.0
• Gas TPP (CCGT+SCGT)+oil	46.8	66.9	135.1	218.5	254.6	246.7
• **North ICE – LNG**			**1.02**	**2.86**	**7.10**	**7.49**
• **South ICE – LNG**		**0.35**	**1.61**	**1.78**	**3.68**	**3.99**
• **South Central ICE – LNG**					**0.51**	**0.51**
• Hydro power plant	80.6	89.8	92.1	92.1	92.1	92.1
• Wind power plant	1.9	14.7	33.3	73.9	123.2	166.4
• Solar power plant	10.7	23.8	35.3	50.3	70.1	93.1
• Biomass + other RE	1.3	3.7	14.4	16.2	20.4	16.1
• PSPP + Battery			-0.1	-0.2	-0.7	-1.0
• Import	5.9	11.8	22.3	21.1	21.1	20.7
• Curtailment of RE	1.99	2.26	3.53	3.59	3.03	4.30

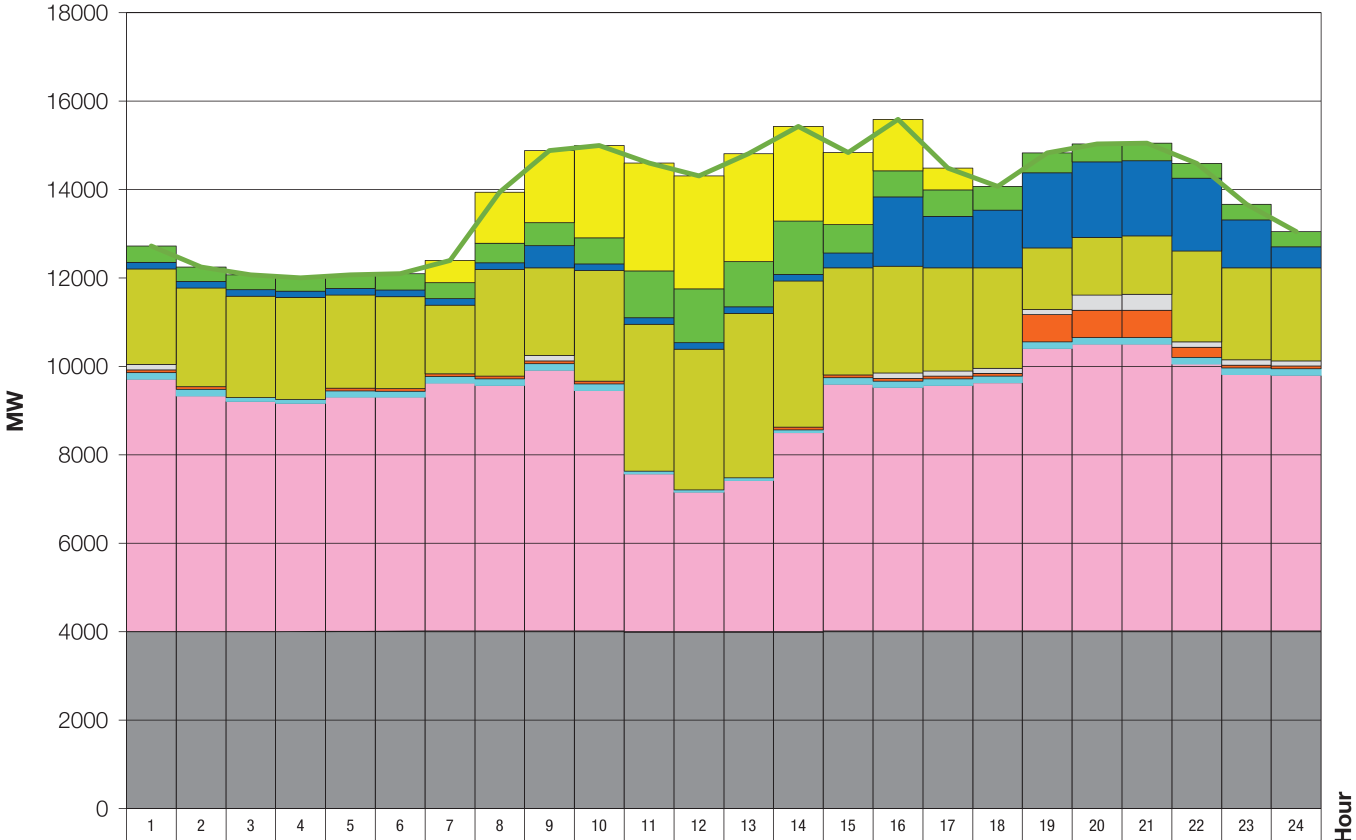
Table 4-13: Installed capacity and annual electricity generation of ICEs in the period 2022–2030 – Normal water year

Item/year	2022	2023	2024	2025	2026	2027	2028	2029	2030
1. North ICE – LNG									
– Installed capacity (MW)	0	0	0	0	0	0	300	600	900
– Electricity generation (GWh)	0	0	0	0	0	0	698	382	1023
– Full load hours – Tmax (h)							2327	637	1137
2. South ICE – LNG									
– Installed capacity (MW)	400	650	650	650	650	650	950	1250	1550
– Electricity generation (GWh)	1168	2076	1284	348	331	371	494	758	1608
– Full load hours – Tmax (h)	2920	3194	1975	535	509	571	520	606	1037

In the short term (2021–2025), the study evaluates the effect of possible delays to committed thermal power projects, as shown in the ST1_Delay of committed projects. Meanwhile, ICE power plants in the South will be mobilized to operate for rather a high number of hours. Full load hours would be approximately 2000–3000 hours/year in the period 2022–2024. From 2025, when the committed thermal power plants are built and operating, the full load hours of ICE power plants in the South will decrease to about 500 h/year for the period 2025–2029. ICE power plants in the North will also be mobilized with full load hours of up to 2300 hours in 2028.

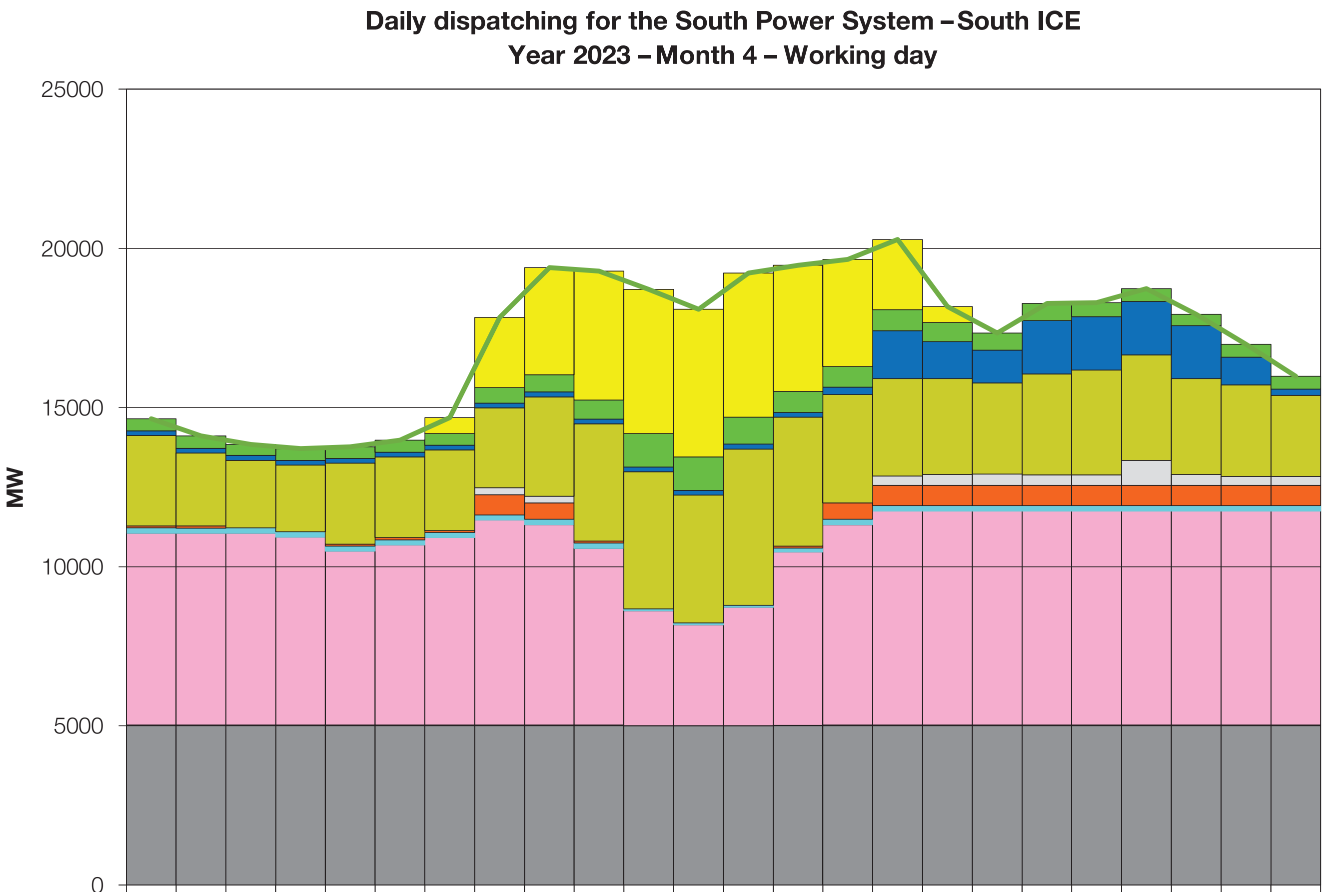
The results of dispatching power generation in a typical day from the PDPAT model are shown below:

Daily dispatching for the South Power System – South ICE
Year 2023 – Month 2 – Holiday



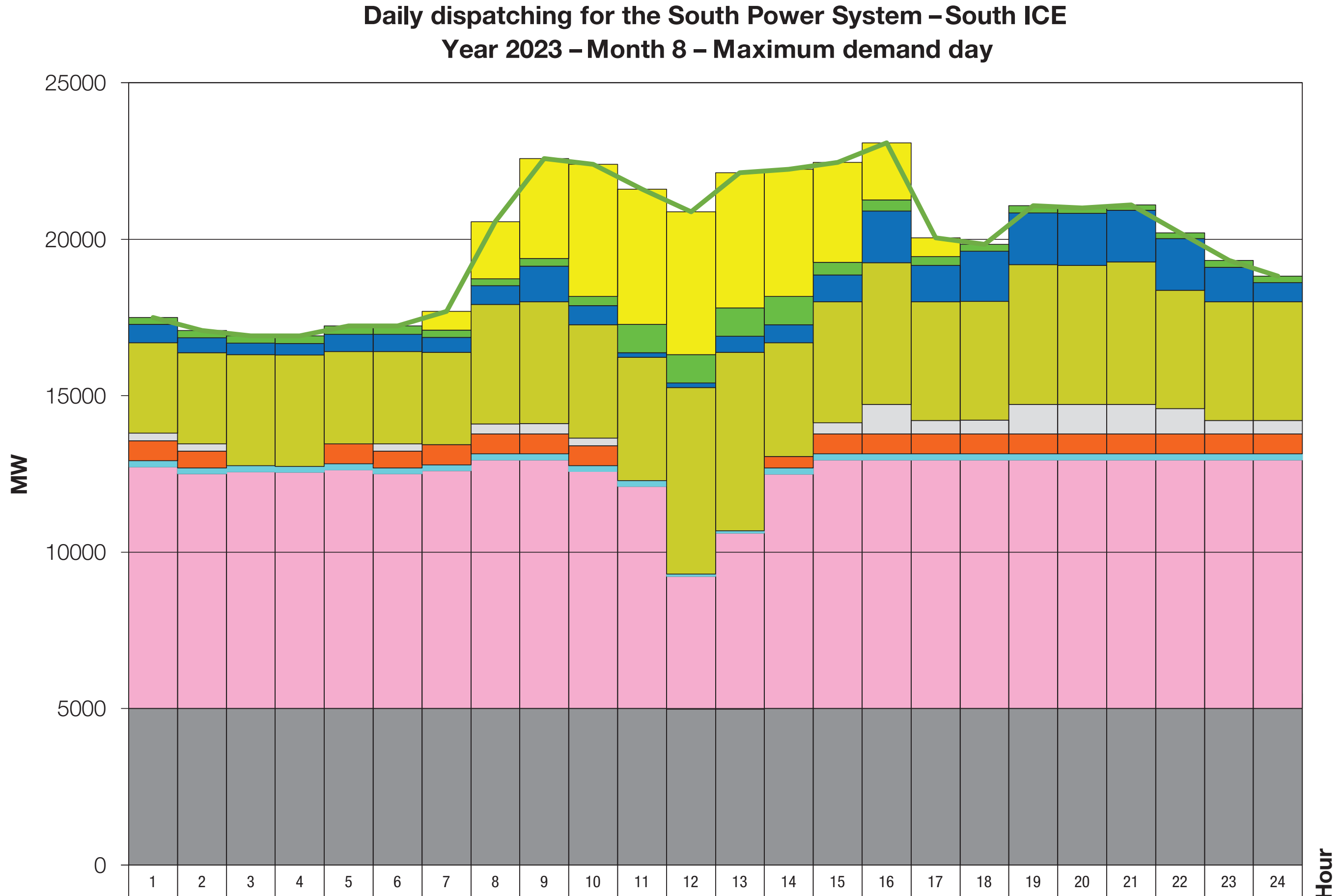
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PSPP+Battery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOLAR	0	0	0	0	0	0	500	1160	1624	2088	2436	2552	2436	2148	1624	1160	500	0	0	0	0	0	0	0
WIND	368	323	341	298	311	367	367	437	522	592	1055	1219	1024	1206	648	592	592	536	448	406	393	337	350	350
Hydro	149	149	149	149	149	149	149	149	506	149	149	149	149	149	335	1573	1169	1308	1703	1703	1703	1654	1085	475
Transmission	2163	2232	2288	2306	2107	2080	1547	2415	1983	2503	3329	3176	3720	3301	2421	2415	2330	2272	1394	1306	1326	2051	2081	2102
Oil	117	0	0	0	0	0	0	0	117	0	0	0	0	0	0	117	117	117	117	344	358	117	117	117
LNG_ICE	62	62	0	0	62	62	62	62	62	62	0	0	0	62	62	62	62	62	616	616	616	234	62	62
LNG_SCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	148	148	93	83	139	135	148	148	148	148	59	59	59	59	148	148	148	148	148	148	148	148	148	148
LNG_CCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dom_gas	5800	5418	5310	5274	5399	5399	5712	5658	6003	5542	3675	3257	3529	4613	5683	5607	5657	5715	6492	6592	6592	6141	5906	5885
Coal	3912	3912	3892	3892	3904	3903	3912	3912	3912	3912	3892	3892	3892	3892	3912	3912	3912	3912	3912	3912	3912	3912	3912	3912
DEMAND	12719	12244	12073	12002	12071	12095	12397	13941	14877	14996	14595	14304	14809	15430	14833	15586	14487	14070	14830	15027	15048	14594	13661	13051

Figure 4-17: Daily dispatching for the South power system in 2023 – holiday (minimum demand day) – dry season



Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PSPP+Battery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOLAR	0	0	0	0	0	0	500	2204	3364	4060	4524	4640	4520	3956	3364	2204	500	0	0	0	0	0	0	0
WIND	380	393	341	367	367	384	367	493	535	592	1055	1055	855	660	648	660	604	536	536	448	406	350	406	406
Hydro	149	149	149	149	149	149	149	149	158	149	149	149	149	149	241	1510	1167	1034	1669	1669	1669	1669	872	198
Transmission	2835	2294	2125	2101	2553	2533	2533	2510	3121	3682	4305	4005	4911	4050	3393	3051	3012	2859	3176	3297	3321	3012	2875	2546
Oil	0	0	0	0	0	0	0	220	215	0	0	0	0	0	0	305	344	361	334	333	787	344	286	287
LNG_ICE	63	63	0	0	63	63	63	629	512	63	0	0	0	63	518	629	629	629	629	629	629	629	629	629
LNG_SCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	167	167	167	167	157	167	167	167	167	167	67	67	67	127	167	167	167	167	167	167	167	167	167	167
LNG_CCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Dom_gas	6339	6330	6336	6210	5776	5963	6193	6744	6607	5862	3920	3482	4028	5762	6607	7037	7037	7037	7037	7037	7037	7037	7037	7037
Coal	4715	4715	4715	4715	4706	4715	4715	4715	4715	4715	4691	4691	4691	4695	4715	4715	4715	4715	4715	4715	4715	4715	4715	4715
DEMAND	14648	14111	13833	13709	13771	13974	14687	17831	19394	19290	18711	18089	19221	19462	19654	20278	18175	17338	18263	18295	18731	17923	16987	15985

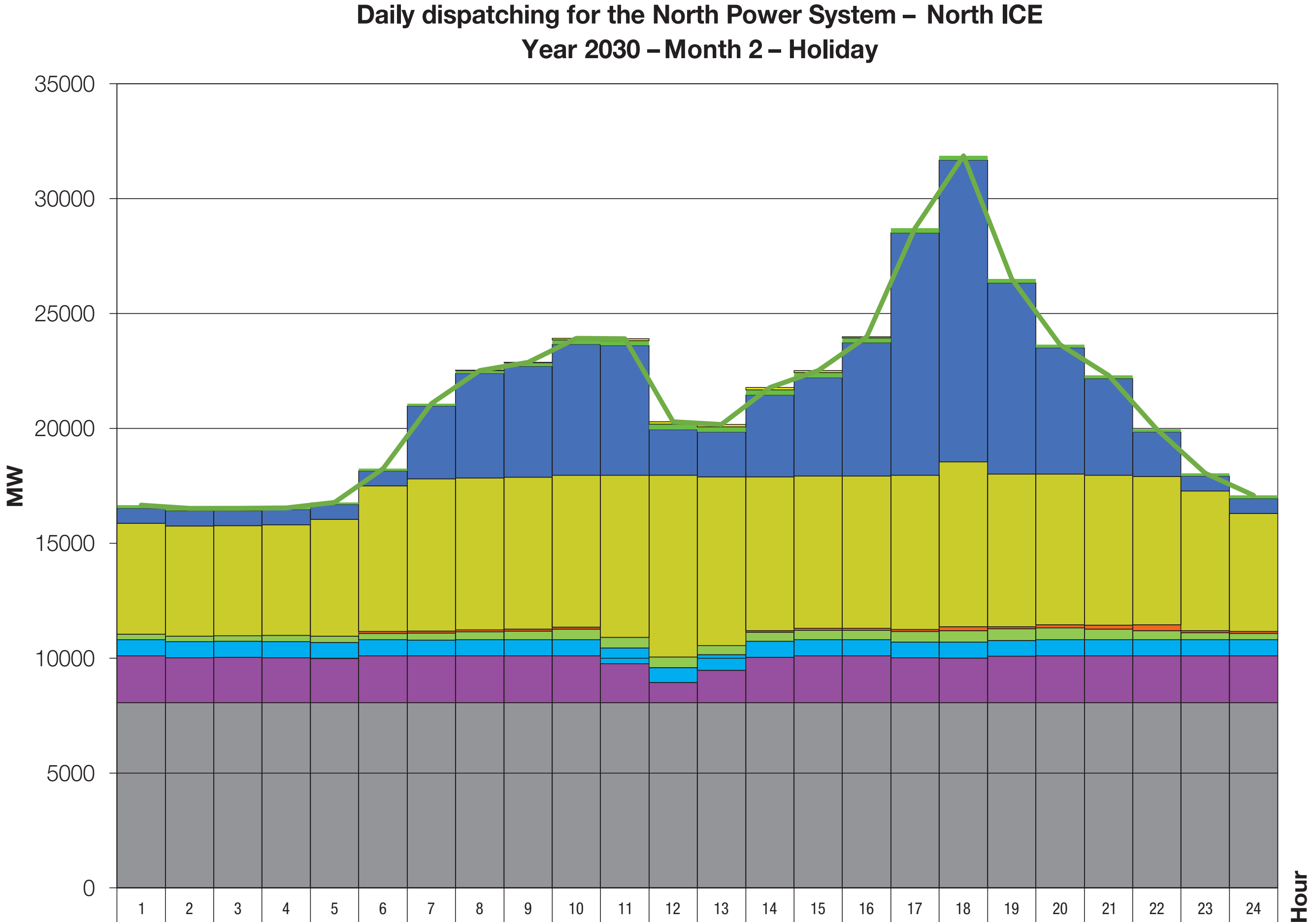
Figure 4-18: Daily dispatching for the South power system in 2023 – working day – dry season



Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PSPP+Battery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOLAR	0	0	0	0	0	0	600	1824	3184	4230	4326	4568	4326	4066	3184	1824	600	0	0	0	0	0	0	0
WIND	210	223	236	254	266	266	221	221	254	296	904	904	904	904	405	358	283	223	223	178	178	178	223	210
Hydro	597	486	370	357	551	551	486	600	1135	600	149	149	512	579	860	1654	1157	1598	1654	1654	1654	1654	1101	606
Transmission	2886	2905	3549	3562	2953	2948	2947	3813	3887	3625	3938	5951	5705	3633	3866	4530	3799	3801	4474	4453	4555	3781	3790	3798
Oil	242	237	0	0	0	237	0	319	334	242	0	0	0	0	356	936	423	434	936	936	936	810	432	424
LNG_ICE	642	541	0	0	642	539	642	642	642	642	0	0	0	370	642	642	642	642	642	642	642	642	642	642
LNG_SCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	185	185	185	185	185	185	185	185	185	185	185	74	74	185	185	185	185	185	185	185	185	185	185	185
LNG_CCGT	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dom_gas	7246	7014	7086	7072	7148	7014	7122	7466	7466	7092	6611	3771	5147	7013	7466	7466	7466	7466	7466	7466	7466	7466	7466	7466
Coal	5485	5485	5485	5485	5485	5485	5485	5485	5485	5485	5485	5458	5458	5485	5485	5485	5485	5485	5485	5485	5485	5485	5485	5485
DEMAND	17493	17077	16911	16915	17230	17225	17688	20555	22572	22397	21598	20875	22126	22235	22449	23080	20040	19834	21065	20999	21101	20201	19324	18816

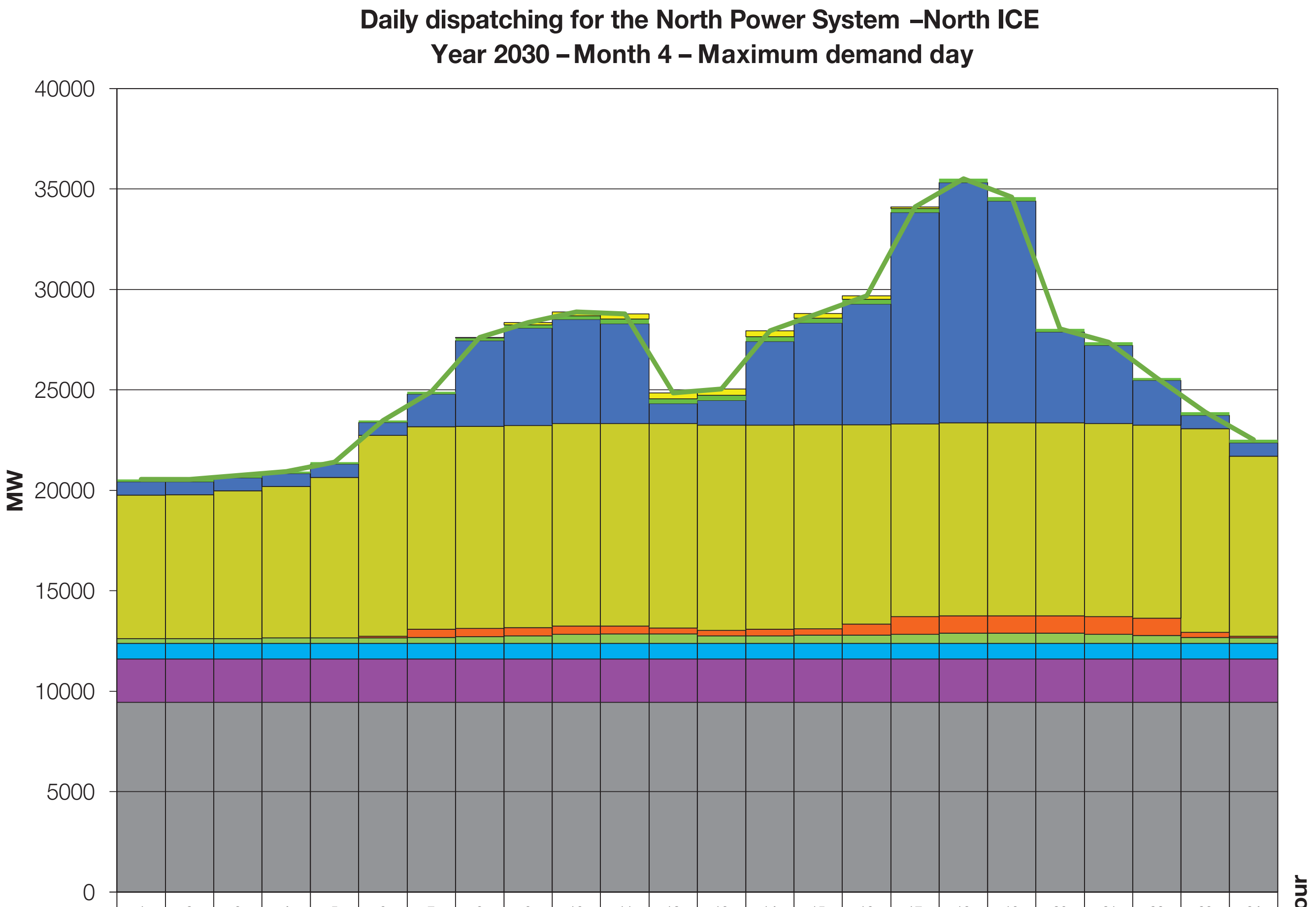
Figure 4-19: Daily dispatching for the South power system in 2023 – maximum demand day – rainy season

In 2023, ICE power plants would be installed in the South, due to the possibility of delays to the committed thermal power plant projects, so they could be mobilized quite well with a high number of operating hours. The output of ICE power plants is dispatched at their maximum during the peak load from 8–10 am and after 3 pm. When the load is low at night and the solar power is high at noon, the ICE power plants are not dispatched. In low load days and holidays, ICE power plants are mainly dispatched during the evening peak load time from 7–9pm.



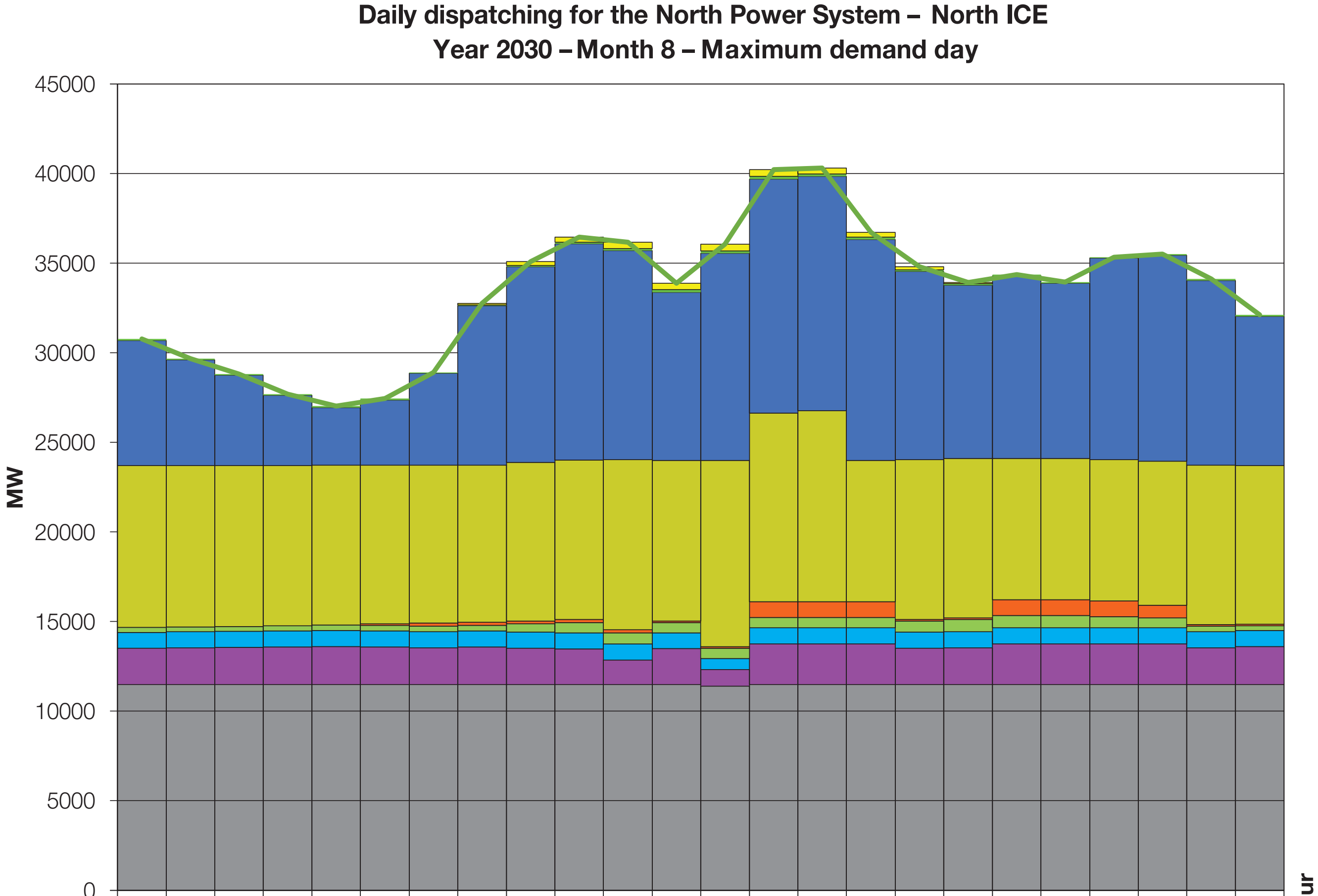
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PSPP+Battery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOLAR	0	0	0	0	0	0	0	11	15	68	87	104	103	100	79	59	0	0	0	0	0	0	0	0
WIND	124	103	102	80	80	99	98	118	165	184	205	230	230	230	230	204	206	187	167	147	149	124	125	125
Hydro+Import Laos	657	657	657	657	657	657	3159	4548	4825	5694	5649	1985	1955	3556	4281	5804	10545	13141	8327	5492	4199	1941	657	657
Transmission	4824	4795	4793	4822	5080	6334	6631	6620	6620	6619	7055	7927	7348	6687	6620	6620	6718	7166	6650	6570	6532	6455	6074	5135
LNG_ICE	0	0	0	0	0	84	84	84	84	84	0	0	0	84	84	84	84	168	84	135	174	249	84	84
LNG_SCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
China Import	246	246	246	277	277	277	308	339	370	463	463	463	385	385	416	416	462	509	509	509	462	402	308	277
Biomass	696	696	696	696	696	696	696	696	696	696	696	645	696	696	696	696	696	696	696	696	696	696	696	696
LNG_CCGT	2049	1965	1978	1957	1930	2049	2038	2049	2049	2049	1697	876	1404	1981	2049	2049	1951	1941	2018	2048	2047	2048	2049	2049
Coal	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053	8053
DEMAND	16649	16515	16525	16542	16773	18249	21067	22518	22877	23910	23905	20283	20174	21772	22508	23985	28715	31861	26504	23650	22312	19968	18046	17076

Figure 4-20: Daily dispatching for the North power system in 2030 – holiday (minimum demand day) – dry season



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PSPP+Battery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOLAR	0	0	0	0	0	0	0	21	104	190	250	301	316	295	240	189	72	0	0	0	0	0	0	0
WIND	125	124	103	102	101	99	100	146	165	185	232	232	247	231	230	232	207	187	188	169	150	124	152	152
Hydro+Import Laos	657	657	657	657	657	657	1640	4262	4859	5187	4988	1002	1249	4186	5071	6006	10514	11964	11047	4517	3911	2217	657	657
Transmission	7142	7149	7348	7529	7988	9989	10078	10064	10060	10062	10079	10174	10205	10158	10151	9919	9609	9609	9610	9610	9610	9610	10138	8962
LNG_ICE	0	0	0	0	0	87	396	408	411	411	393	297	267	315	321	552	864	864	864	864	864	864	252	87
LNG_SCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
China Import	246	246	246	277	277	277	308	339	370	463	463	463	385	385	416	416	462	509	509	509	462	402	308	277
Biomass	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779	779
LNG_CCGT	2143	2143	2143	2143	2143	2143	2143	2144	2145	2144	2145	2145	2144	2144	2144	2145	2143	2143	2143	2143	2143	2143	2143	2143
Coal	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453	9453
DEMAND	20545	20551	20729	20940	21398	23484	24897	27616	28346	28874	28782	24846	25045	27946	28805	29691	34103	35508	34593	28044	27372	25592	23882	22510

Figure 4-21: Daily dispatching for the North power system in 2030 – maximum demand day – dry season



Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PSPP+Battery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOLAR	0	0	0	0	0	0	0	95	202	281	343	361	375	370	330	263	176	80	0	0	0	0	0	0
WIND	75	75	75	73	73	72	52	51	72	93	114	140	140	140	139	113	93	73	73	53	54	55	77	77
Hydro+Import Laos	7001	5904	5055	3931	3226	3641	5126	8890	10928	12073	11673	9389	11553	13065	13065	12342	10498	9682	10195	9783	11245	11493	10314	8336
Transmission	9016	8990	8967	8938	8919	8848	8803	8770	8840	8880	9498	8953	10384	10522	10661	7875	8918	8892	7875	7875	7874	8041	8898	8838
LNG_ICE	0	0	0	0	0	87	174	174	174	174	174	87	87	885	885	885	87	87	885	885	885	717	87	87
LNG_SCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
China Import	277	277	277	277	308	308	308	308	462	586	617	571	571	571	571	571	617	679	679	679	617	540	308	277
Biomass	900	900	900	900	900	900	900	900	900	900	900	900	634	900	900	900	900	900	900	900	900	900	900	900
LNG_CCGT	2025	2051	2074	2103	2122	2106	2064	2097	2027	1986	1369	2001	914	2282	2282	2282	2036	2062	2282	2282	2282	2283	2056	2116
Coal	11475	11475	11475	11475	11475	11475	11475	11475	11475	11475	11475	11475	11397	11475	11475	11475	11475	11475	11475	11475	11475	11475	11475	11475
DEMAND	30769	29672	28823	27697	27023	27437	28902	32760	35080	36448	36163	33877	36055	40210	40308	36706	34800	33930	34364	33932	35332	35504	34115	32106

Figure 4-22: Daily dispatching for the North power system in 2030 – maximum demand day – rainy season

In 2030, ICE power plants will be built in the North. In the Northern power system, ICE power plants will be dispatched at maximum capacity during the afternoon and evening peak load hours, but will not be dispatched at night and during noon hours.

Weekly dispatching from the Balmorel model shown in the graphs below:

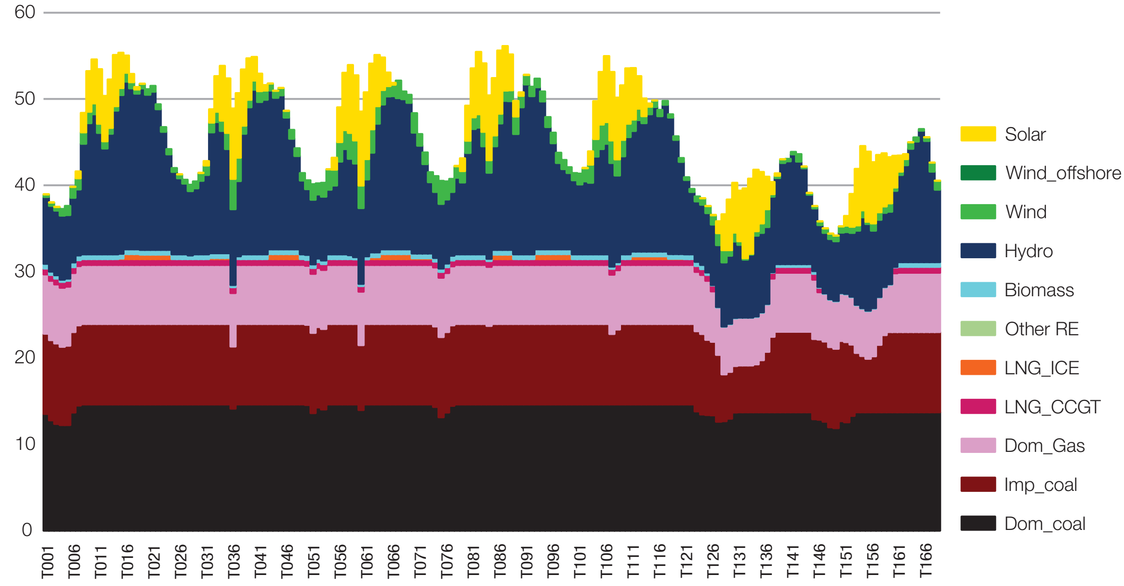


Figure 4-23: Dispatching of high demand week in 2023, rainy season (in August)

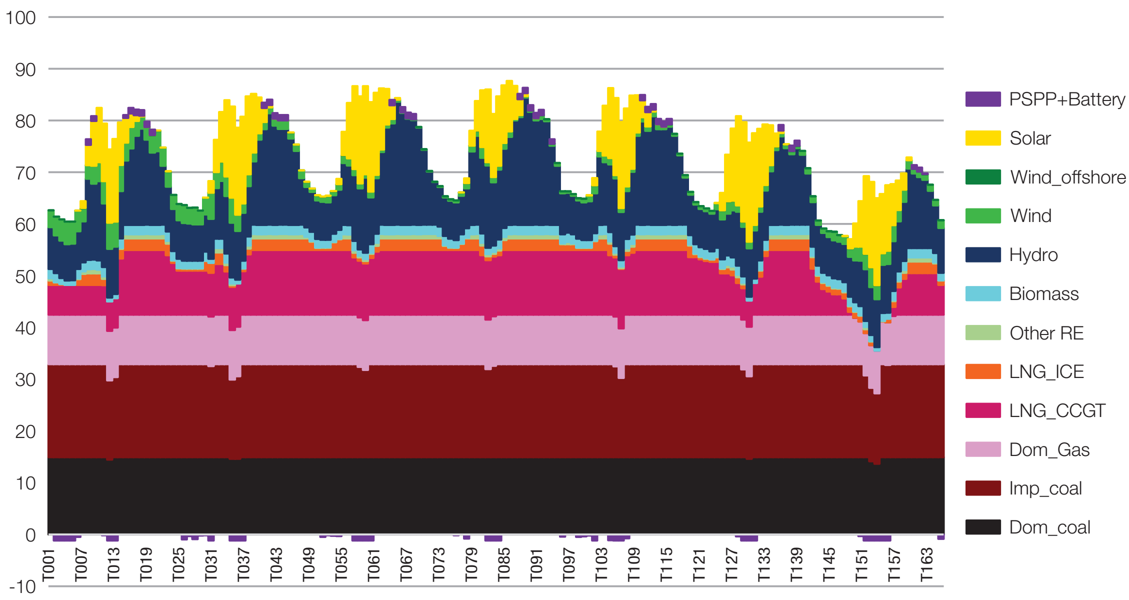


Figure 4-24: Dispatching of high demand week in 2030, less windy, rainy season (in June)

Therefore, when the renewable energy source is low, the ICE power plants are dispatched to the maximum capacity with more hours of operation.

4.2.2. Operational mode of ICE power plants in a dry year

In this calculation, the committed projects for the period up to 2025 are still assumed to be behind schedule, as in the ST1_Delay committed project scenario, and new capacity from 2025 onwards is according to the selected scenario (LT2B). The study calculates in the case of dry years with a water frequency of 75% for national hydro power plants, the hydro power production decreases by nearly 20 billion kWh/year. This means that coal-fired and LNG thermal power plants will be dispatched higher to meet the system demand, while ICE power plants will be dispatched higher than in a normal water year. Specifically, this is as per the tables below:

Table 4-14: National energy balance up to 2045 (dry year)

Unit: TWh

Year	2020	2025	2030	2035	2040	2045
Demand	**259.0**	**390.8**	**555.2**	**714.9**	**866.8**	**1001.6**
Generation energy	**259.0**	**390.8**	**555.2**	**714.9**	**866.8**	**1001.6**
• Coal-fired TPP	118.6	187.1	229.3	243.7	281.1	368.2
• Gas TPP (CCGT+SCGT)+oil	58.9	79.7	144.8	234.1	268.1	255.9
• **North ICE – LNG**			**1.31**	**4.14**	**8.61**	**8.06**
• **South ICE – LNG**		**0.72**	**2.07**	**2.32**	**4.82**	**5.65**
• **South Central ICE – LNG**					**0.51**	**0.51**
• Hydro power plant	64.6	71.8	73.7	73.7	73.7	73.7
• Wind power plant	1.9	14.6	34.4	73.3	122.5	165.5
• Solar power plant	9.8	23.6	35.0	49.5	68.9	91.5
• Biomass + other RE	1.8	4.7	14.8	17.5	22.1	17.7
• PSPP + Battery			-0.1	-0.3	-0.8	-1.1
• Import	5.3	11.2	21.1	19.4	19.4	19.0
• Curtailment of RE	1.91	2.67	1.23	2.38	2.03	3.01

Table 4-15: Installed capacity and annual electricity generation of ICEs in the period 2022-2030 – Dry year

Item/year	2022	2023	2024	2025	2026	2027	2028	2029	2030
1. North ICE - LNG									
– Installed capacity (MW)	0	0	0	0	0	0	300	600	900
– Electricity generation (GWh)	0	0	0	0	0	0	253	535	1306
– Full load hours- Tmax (h)							843	892	1451
2. South ICE - LNG									
– Installed capacity (MW)	400	650	650	650	650	650	950	1250	1550
– Electricity generation (GWh)	2205	3260	2792	720	442	484	756	1102	2066
– Full load hours- Tmax (h)	5513	5015	4295	1108	680	745	796	882	1333

Conclusion:

The results of power generation dispatching from the Balmorel and PDPAT models show that ICE power plants operate very flexibly. With no start-up cost and fast ramp rate characteristics, ICE power plants can assume the responsibility to supply the peak load, provide reserve capacity, and efficiently balance the grid with a high proportion of wind and solar power installed.

Chapter 5. Conclusion and recommendations

5.1. Conclusion

ICEs represent a flexible, reliable, and affordable power generation technology, with many advantages compared to traditional technologies, namely:

- Having flexible operating characteristics, including: synchronization to the grid in less than 30 seconds from start-up; reaching full load in less than 2 minutes; the ability to increase or decrease output quickly; can stop quickly within 1 minute; designed to start and stop – at the push of a button – time after time without any impact on maintenance; no minimum up time or minimum down time; the ability to operate with loads as low as 10%, etc. Therefore, ICE technology is very suitable for power systems with a large integration of renewable energy sources. With its integrated modular design, the flexible ICE power plant allows the operation of each module individually, thereby reducing mechanical inertia when changing capacity but maintaining stable efficiency. The generating capacity to the grid can change almost instantaneously due to sudden fluctuations of the wind and solar power sources. In addition, with a flexible ICE power plant it is possible to operate in many modes, such as quick start, load following, base load, quick stop. For conventional thermal power plants, this level of flexibility is not possible.
- Designed with a flexible output range (10–700 MW) by connecting multiple modular ICE units. This makes it possible to build a power plant on a large scale, or to build many distributed smaller scale power plants. At the same time, it is possible to construct an ICE power plant near the load center, minimizing the volume of tranmission lines.
- Ability to use many different types of primary fuel, including gas (natural gas, LNG, biogas, ethane, LPG) or liquid fuel (crude, LFO, diesel, liquid biofuel, HFO, fuel-water emulsion), thus creating a broad selection of fuel options, depending on the situation. ICE power plants allow the temporary use of other fuels while waiting for the main fuel infrastructure to be constructed, thereby avoiding the risk of delay due to an insufficient supply of fuel. The switch between fuels takes place instantly with just the press of a button, which enhances reliability and ensuring a sufficient power supply for the 24/7 load.
- Having a very short construction time (within 1 year only) compared to other traditional thermal power plants, the plant can be delivered as a floating or land-based power plant to quickly meet the demand in the short term. It can be built within an economical area, thus avoiding the risk of being delayed due to challenges with site clearance. The plant is also designed with a high level of modularity and can be easily expandable as a stepwise investment to meet future increases in demand.

With the above advantages, it is necessary to study the possibility of installing ICE power plants using LNG in Vietnam's power system in the coming periods. It is a most suitable option in the context of developing renewable energy on a large scale, the high possibility of slow progress with the large power projects, and high load growth in the short term.

The study uses the method of calculating and optimizing a power generation development plan for Vietnam's power system with the objective of minimizing the system cost taking into account the constraints. Powerful modelling tools, including BALMOREL, PDPAT and PLEXOS, have been utilised. The calculation results and proposed capacity of ICE power plants using LNG fuel are as follows:

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total installed capacity of ICE (MW)	**400**	**650**	**650**	**650**	**650**	**650**	**1250**	**1850**	**2450**
North							300	600	900
South	400	650	650	650	650	650	950	1250	1550

The study proposes the early building of ICE power plants in the South in 2022–2023 with a capacity of 650 MW. These would act as a back-up for high demand, delays to some coal and CCGT power projects, or drought which could put a risk of power shortages in the South in the period up to 2025.

In the long term, there is a strong need to develop ICE power plants to provide reserves and to supply peak demand , as well as to balance the system with a high level of RE sources (according to the RE development strategy and Resolution 55/NQ-TW): 2.5 GW in 2030, 10.6 GW in 2040 and 13.4 GW in 2050. With ICEs in the system, total system costs will be reduced by 180 million USD/year in 2030 and similar savings can be achieved in the future years as compared to the scenario without ICEs.

The daily & weekly dispatch graphs for the coming years show that ICE power plants are dispatched very flexibly. They do not have any start-up cost and the ability to increase or decrease output quickly makes them most suitable for balancing the grid with a high share of renewable generation.

In normal conditions (normal water year, no delays in construction of power plants), ICE power plants have full load hours of approximately 1000 h/year, corresponding to a capacity factor of about 10%. In the case of risks, such as drought, delays to power plant construction, or high demand, ICE power plants will be dispatched more with full load hours of some 3000–5000 h/year, corresponding to a capacity factor of 30–55%.

5.2. Recommendations

Flexible ICE power plants using LNG will be essential for the power system in order to provide load following and reserve for wind and solar power, especially where the system has a high proportion of variable renewable energy sources. With their ability to be built quickly (within 1 year only), the study proposes that the authorities quickly consider adding 650 MW of ICE power plant projects in its Power Development Plan No. 8 (PDP8) for the Southern power system in 2022–2023 (in addition to adding wind and solar power sources as currently planned). This will ensure a reliable power supply for the load in the event of risk (high load, delayed power plants, dry weather). In power system operation, the capacity factor of ICE power plants is not high due to its lower number of running hours than conventional thermal power plants (coal & CCGT). To ensure the financial viability of the ICE power plant project, this study proposes the development of a mechanism for reserve capacity payment for flexible power plants, and the development of an ancillary services market for Vietnam's power system.

Appendix

Table 1: National power balance in the period up to 2045 (selected scenario)

No	Item/year (Unit: MW)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045
A.	**TOTAL DEMAND OF NORTH**	17958	19649	21453	23358	25373	27512	29787	32200	34749	37455	40308	52893	66088	79315
	Installed capacity	20685	22393	22558	24748	25028	26218	27308	28690	30300	31750	33250	50150	63650	77950
I.	HPP + PSPP + RE + import	11308	11706	11871	12211	12931	13521	14011	14693	15203	15553	15953	19153	20753	23453
II.	TPP	9377	10687	10687	12537	12097	12697	13297	13997	15097	16197	17297	30997	42897	54497
-	Coal power plant	9377	10687	10687	12537	12097	12697	13297	13197	13197	13197	13197	13797	20997	31397
-	North LNG (CCGT+SCGT)	0	0	0	0	0	0	0	800	1600	2400	3200	13900	16200	16800
-	North LNG (ICE)	0	0	0	0	0	0	0	0	300	600	900	3300	5700	6300
B.	**TOTAL DEMAND OF NORTH CENTRAL**	2385	2607	2842	3086	3341	3609	3890	4183	4490	4809	5139	6598	7947	9095
	Installed capacity	3822	4082	4890	5865	6915	9595	10440	10440	10590	10590	10740	13440	14445	17050
I.	HPP + RE + import	1892	2152	2360	2735	3185	3335	3580	3580	3730	3730	3880	4180	4385	4590
II.	TPP	1930	1930	2530	3130	3730	6260	6860	6860	6860	6860	6860	9260	10060	12460
C.	**TOTAL DEMAND OF CENTER CENTRAL**	2179	2356	2543	2737	2941	3154	3378	3612	3855	4107	4368	5506	6525	7365
	Installed capacity	3073	3373	3559	3859	6859	7908	9528	10318	10718	10868	10968	13318	14123	14928
I.	HPP + RE + import	3043	3343	3529	3829	4579	4908	5778	6228	6628	6778	6878	7628	8433	9238
II.	TPP	30	30	30	30	2280	3000	3750	4090	4090	4090	4090	5690	5690	5690
D.	**TOTAL DEMAND OF HIGHLAND**	1179	1281	1386	1493	1602	1713	1827	1944	2061	2181	2302	2774	3116	3297
	Installed capacity	3995	4325	4625	4825	5385	5585	7005	8205	9951	11615	12861	15161	18861	21861
I.	HPP + RE + import	3995	4325	4625	4825	5385	5585	7005	8205	9951	11615	12861	15161	18861	21861
II.	TPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E.	**TOTAL DEMAND OF SOUTH CENTRAL**	2080	2246	2420	2601	2791	2989	3197	3413	3636	3865	4098	5057	5818	6315
	Installed capacity	10554	12254	12688	13908	14668	16188	17148	17808	18508	19208	19908	21708	31308	43308
I.	HPP + RE + PSPP	6250	7950	8384	8944	9044	9244	9544	10204	10904	11604	12304	14104	22804	34204
II.	TPP	4304	4304	4304	4964	5624	6944	7604	7604	7604	7604	7604	7604	8504	9104
-	Coal power plant	4304	4304	4304	4964	5624	6944	7604	7604	7604	7604	7604	7604	7604	7604
-	South Central LNG (ICE)	0	0	0	0	0	0	0	0	0	0	0	0	600	600
-	South Central LNG (SCGT)	0	0	0	0	0	0	0	0	0	0	0	0	300	900
F	**TOTAL DEMAND OF SOUTH**	17455	19059	20729	22449	24222	26053	27947	29899	31903	33973	36092	45922	54495	61129
	Installed capacity	17231	20731	24581	29631	32531	35503	36849	39491	42999	44780	46856	67884	85148	101648
I	HPP + import + RE	4868	7168	9418	11818	12368	13068	14568	15568	16568	17468	18668	36168	49168	63068
II	TPP	12363	13563	15163	17813	20163	22435	22281	23923	26431	27313	28188	31716	35980	38580
-	Gas power plant (CCGT+SCGT) + Oil power plant	8693	8693	8693	10493	11243	12515	12361	14003	16211	16793	17368	19996	22460	23860
-	South LNG (ICE)	0	0	400	650	650	650	650	650	950	1250	1550	2450	4250	5450
-	Coal power plant	3670	4870	6070	6670	8270	9270	9270	9270	9270	9270	9270	9270	9270	9270
G	**Whole country**														
	Total demand Pmax	41324	45098	49071	53210	57546	62066	66806	71760	76937	82329	87927	113519	137663	159178
	Total installed capacity	59359	67157	72900	82835	91385	100996	108277	114951	123065	128810	134582	181660	227534	276744

Table 2: National energy balance in the period up to 2045 (selected scenario – normal water year)

No	Item/year (Unit: GWh)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045
A.	**TOTAL DEMAND OF NORTH**	101197	110725	120894	131626	142983	155034	167854	181453	195816	211065	227143	298062	372420	446958
	Total electricity production	100799	106465	111457	117251	124285	125953	133454	134283	147435	152788	164812	241293	293222	365892
	Balance	-398	-4260	-9437	-14375	-18698	-29081	-34400	-47170	-48381	-58277	-62331	-56769	-79198	-81066
I.	HPP + PSPP + RE + import	43951	44890	46003	47056	48610	50379	52543	54080	57256	58801	61104	64390	69253	70914
II.	TPP	56848	61574	65453	70195	75674	75574	80910	80203	90179	93987	103708	176903	223969	294978
-	Coal power plant	56848	61574	65453	70195	75674	75574	80911	79780	84890	84826	85845	89895	121374	199347
-	North LNG (CCGT+SCGT)	0	0	0	0	0	0	0	424	4591	8778	16840	84150	95498	88145
-	North LNG (ICE)	0	0	0	0	0	0	0	0	698	382	1023	2858	7097	7486
B	**TOTAL DEMAND OF NORTH CENTRAL**	12607	13782	15021	16313	17663	19076	20560	22114	23732	25418	27162	34879	42010	48074
	Total electricity production	17812	19416	21387	26916	27396	30591	35795	42548	42813	44826	49317	61866	68872	78381
	Balance	5205	5634	6366	10603	9733	11515	15235	20434	19081	19408	22155	26987	26862	30307
I.	HPP + import + RE	5895	6868	7404	8811	9945	10523	10966	11435	11535	11771	12004	12642	13407	13598
II.	TPP	11918	12548	13983	18104	17451	20068	24829	31113	31278	33055	37313	49225	55465	64783
C.	**TOTAL DEMAND OF CENTER CENTRAL**	11786	12855	13981	15154	16381	17663	19008	20415	21876	23395	24964	31918	38280	43654
	Total electricity production	10409	11611	12434	12773	15868	30133	36755	41090	43989	46393	48033	53452	56591	57177
	Balance	-1377	-1244	-1547	-2381	-513	12470	17747	20675	22113	22998	23069	21534	18311	13523
I.	HPP + import + RE	10352	11537	12348	12698	13440	16576	18593	20765	22530	23467	23934	24596	24980	26766
II.	TPP	57	73	87	75	2428	13557	18162	20325	21460	22925	24099	28857	31612	30411
D.	**TOTAL DEMAND OF HIGHLAND**	5839	6369	6919	7484	8065	8661	9276	9907	10551	11210	11880	14615	16753	18097
	Total electricity production	12546	13125	12659	13248	14521	14658	16941	18322	22164	25564	29308	34979	44450	49352
	Balance	6707	6756	5740	5764	6456	5997	7665	8415	11613	14354	17428	20364	27697	31255
I.	HPP + import + RE	12546	13125	12659	13248	14521	14658	16941	18322	22164	25564	29308	34979	44450	49352
II.	TPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E.	**TOTAL DEMAND OF SOUTH CENTRAL**	11808	12863	13972	15126	16329	17587	18905	20281	21691	23143	24624	30796	35874	39391
	Total electricity production	37182	39351	42096	46652	50016	55360	60206	65019	67006	68605	71097	75029	102046	134866
	Balance	25374	26488	28124	31526	33687	37773	41301	44738	45315	45462	46473	44233	66172	95475
I.	HPP + PSPP + RE	13872	17026	19118	20434	21610	22212	22784	23409	24254	25104	25979	30216	59294	92672
II.	TPP	23310	22325	22978	26218	28406	33147	37422	41610	42753	43501	45119	44813	42752	42194
-	Coal power plant	23310	22325	22978	26218	28405	33147	37423	41610	42753	43500	45119	44813	41994	40932
-	South Central LNG (ICE)	0	0	0	0	0	0	0	0	0	0	0	0	505	505
-	South Central LNG (SCGT)	0	0	0	0	0	0	0	0	0	0	0	0	253	758
F.	**TOTAL DEMAND OF SOUTH**	115779	126417	137499	148906	160666	172813	185377	198324	211618	225344	239405	304604	361474	405475
	Total electricity production	80267	93044	108253	117770	130000	134140	137829	151231	161877	181400	192610	248255	301630	315981
	Balance	-35512	-33373	-29246	-31136	-30666	-38673	-47548	-47093	-49741	-43944	-46795	-56349	-59844	-89494
I.	HPP + PSPP + import + RE	11866	16105	18845	23028	26784	27274	28988	32795	35844	39067	41553	83033	111797	128699
II.	TPP	68401	76939	89408	94742	103216	106866	108841	118436	126033	142333	151056	165222	189833	187282
-	Gas power plant (CCGT+SCGT) + oil power plant	46793	52839	52154	52159	55563	53335	50155	58866	67286	83764	94197	103458	126588	125165
-	South LNG (ICE)	0	0	1168	2076	1284	348	331	371	494	758	1608	1777	3683	3994
-	Coal power plant	21607	24099	36085	40507	46370	53182	58355	59199	58253	57812	55251	59986	59563	58123
G.	**WHOLE COUNTRY**														
	Total demand	259016	283011	308286	334609	362087	390834	420980	452494	485284	519575	555178	714874	866811	1001649
	Total electricity production	259015	283011	308286	334609	362087	390834	420980	452494	485284	519575	555178	714874	866811	1001649
	Balance: surplus(+), shortage(-)	-1	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3: National energy balance in the period up to 2045 (selected scenario – dry year)

No	Item/year (Unit: GWh)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045
A.	TOTAL DEMAND OF NORTH	101197	110725	120894	131626	142983	155034	167854	181453	195816	211065	227143	298062	372420	446958
	Total electricity production	95023	99940	105050	111229	115449	114831	117591	121147	133519	144403	156215	238725	287488	356348
	Balance	-6174	-10785	-15844	-20397	-27534	-40203	-50263	-60306	-62297	-66662	-70928	-59337	-84932	-90610
I.	HPP + PSPP + RE + import	36264	37102	38017	39043	40197	41752	43610	45028	47889	49702	51634	54942	58638	60301
II.	TPP	58759	62839	67033	72186	75252	73079	73981	76119	85631	94701	104581	183783	228850	296048
-	Coal power plant	58759	62839	67033	72186	75252	73079	73981	75836	82070	85034	85829	89901	121376	199080
-	North LNG (CCGT+SCGT)	0	0	0	0	0	0	0	283	3307	9131	17446	89743	98868	88912
-	North LNG (ICE)	0	0	0	0	0	0	0	0	253	535	1306	4138	8607	8055
B	**TOTAL DEMAND OF NORTH CENTRAL**	12607	13782	15021	16313	17663	19076	20560	22114	23732	25418	27162	34879	42010	48074
	Total electricity production	17508	18820	21630	27868	28741	34890	40797	47554	47312	48796	52294	63413	71548	81601
	Balance	4901	5038	6609	11555	11078	15814	20237	25440	23580	23378	25132	28534	29538	33527
I.	HPP + import + RE	4825	5709	6257	7634	8600	9107	9534	10007	10071	10304	10479	11089	12028	12060
II.	TPP	12682	13110	15372	20234	20141	25783	31263	37547	37241	38492	41816	52324	59520	69541
C.	**TOTAL DEMAND OF CENTER CENTRAL**	11786	12855	13981	15154	16381	17663	19008	20415	21876	23395	24964	31918	38280	43654
	Total electricity production	8376	9501	10137	10666	14150	28194	34196	39500	43611	45641	47837	52098	57638	58629
	Balance	-3410	-3354	-3844	-4488	-2231	10531	15188	19085	21735	22246	22873	20180	19358	14975
I.	HPP + import + RE	8309	9425	10056	10588	11229	13595	15741	18231	20376	21034	21533	21143	22635	24299
II.	TPP	67	77	81	78	2921	14599	18455	21269	23235	24607	26304	30955	35004	34330
D.	**TOTAL DEMAND OF HIGHLAND**	5839	6369	6919	7484	8065	8661	9276	9907	10551	11210	11880	14615	16753	18097
	Total electricity production	10657	12036	11381	13120	12667	12115	14644	16813	19762	22963	28202	33164	42125	47654
	Balance	4818	5667	4462	5636	4602	3454	5368	6906	9211	11753	16322	18549	25372	29557
I.	HPP + import + RE	10657	12036	11381	13120	12667	12115	14644	16813	19762	22963	28202	33164	42125	47654
II.	TPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E.	**TOTAL DEMAND OF SOUTH CENTRAL**	11808	12863	13972	15126	16329	17587	18905	20281	21691	23143	24624	30796	35874	39391
	Total electricity production	37245	40307	42157	46233	48218	55235	61481	65162	66421	68690	70980	73351	100515	135611
	Balance	25437	27444	28185	31107	31889	37648	42576	44881	44730	45547	46356	42555	64641	96220
I.	HPP + PSPP + RE	11386	14749	16970	18204	19098	19803	20528	21117	21995	22855	23750	28004	57176	91233
II.	TPP	25859	25559	25186	28029	29119	35432	40952	44045	44426	45835	47229	45348	43339	44378
-	Coal power plant	25859	25558	25187	28029	29119	35432	40952	44045	44426	45834	47230	45348	42580	43115
-	South Central LNG (ICE)	0	0	0	0	0	0	0	0	0	0	0	0	507	505
-	South Central LNG (SCGT)	0	0	0	0	0	0	0	0	0	0	0	0	253	758
F.	**TOTAL DEMAND OF SOUTH**	115779	126417	137499	148906	160666	172813	185377	198324	211618	225344	239405	304604	361474	405475
	Total electricity production	90207	102406	117932	125493	142861	145570	152272	162318	174658	189082	199650	254122	307496	321805
	Balance	-25572	-24011	-19567	-23413	-17805	-27243	-33105	-36006	-36960	-36262	-39755	-50482	-53978	-83670
I.	HPP + PSPP + import + RE	10051	15128	18017	22100	26239	26887	28776	32677	35463	38260	42153	82291	111052	127724
II.	TPP	80156	87278	99914	103393	116622	118683	123496	129641	139195	150822	157498	171831	196444	194081
-	Gas power plant (CCGT+SCGT) + oil power plant	58925	63017	61857	59205	66931	65151	65349	70527	80599	91742	101028	112522	131719	129612
-	South LNG (ICE)	0	0	2205	3260	2792	720	442	484	756	1102	2066	2318	4821	5647
-	Coal power plant	21231	24261	35853	40927	46899	52813	57706	58630	57840	57977	54403	56992	59905	58822
G.	**WHOLE COUNTRY**														
	Total demand	259016	283011	308286	334609	362087	390834	420980	452494	485284	519575	555178	714874	866811	1001649
	Total electricity production	259016	283011	308286	334609	362087	390834	420980	452494	485284	519575	555178	714874	866811	1001649
	Balance: surplus(+), shortage(-)	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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