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Decarbonisation pathways for Southeast Asia

Main report

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Decarbonisation pathways for Southeast Asia - Main report

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Breslauer Strasse 48, 76139 Karlsruhe, Germany
Johannes Eckstein, johannes.eckstein@isi.fraunhofer.de

Authors

Viktor Paul Müller, viktor.paul.mueller@isi.fraunhofer.de;
Johannes Eckstein, johannes.eckstein@isi.fraunhofer.de;
Joshua Fragoso, joshua.fragoso@isi.fraunhofer.de;
Wolfgang Männer, wolfgang.maenner@isi.fraunhofer.de;
Wolfgang Eichhammer, wolfgang.eichhammer@isi.fraunhofer.de

Contributing institutes

Artelys
Agora Energiewende
NewClimate Institute

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Contents

List of abbreviations

ASEAN	Association of Southeast Asian Nations
BEV	Battery electric vehicle
CASE	Clean, Affordable and Secure Energy for Southeast Asia
CO_2	Carbon Dioxide
FLH	Full Load Hours
GDP	Gross Domestic Product
GG	Green Gases Scenario
H2	Hydrogen
HE	Highly Electrified Scenario
IDN	Indonesia
LEAP	Low Emissions Analysis Platform
LNG	Liquefied Natural Gas
PHL	Philippines
PV	Photovoltaics
RE	Renewable Energy
RES	Renewable Energy Sources
THA	Thailand
USD	US Dollar
VNM	Vietnam

Executive Summary

Two scenarios to study possible decarbonisation pathways

The modelling project presented here aims to understand the specific challenges of decarbonising the energy systems in the ASEAN (Association of Southeast Asian Nations) region. We focus on the four countries studied in detail in the CASE[1] project: **Indonesia, Philippines, Thailand and Vietnam**, with a more aggregated view on the rest of the region. As a fast-growing region, Southeast Asia plays a crucial role in achieving global climate goals.

Two different scenarios are analysed for each modelled country, both reaching the same decarbonisation **target of zero CO_2 emissions in the energy sector by 2070 at latest**, with variations depending on the countries' net-zero targets. Zero emissions in the energy sector can be considered as a prerequisite for net zero total emissions.

- The **"Highly Electrified" scenario** builds on a strong electrification rate and uses green gases only where there is no alternative.
- The **"Green Gases" scenario** builds on increased use of green gases, particularly hydrogen, in all applications where this is a viable option.

The two scenarios represent realistic, but extreme pathways which explore the corridor of decarbonisation. These should not be seen as alternatives, but as study material to understand the impact of certain technological choices on the region's energy system. This techno-economic analysis thus aims to support the policy choices towards decarbonisation.

To reach zero CO_2 emissions in Southeast Asia by 2070 at latest, we identify the following key findings.

Energy efficiency is a key factor in reducing energy demand and CO_2 emissions

Energy efficiency improvements are an immediate and effective option for transforming energy systems and should be prioritised[2]. Put simply, energy efficiency means reducing energy losses within a system and being able to do more with the same amount of energy. In both scenarios, final energy demand continues to grow, and peaks around 2050 due to the assumed efficiency gains, notably from the switch to battery electric vehicles in transport, the use of heat pumps in industry and improved appliances in buildings. At this point, transport and industry contribute almost equally to the remaining emissions. Oil remains the main source of energy emissions until 2050 due to its dominant use in transport. In the "Highly Electrified" scenario, the direct use of electricity, e.g. switching from internal combustion engines to battery electric vehicles, leads to higher implicit energy efficiency gains than the use of hydrogen in the "Green Gases" scenario, given the considerably higher efficiency of electric motors compared to internal combustion engines.

A strong expansion of renewable energies in the power sector is crucial under all circumstances

Both scenarios assume that electrification is the main technological driver for decarbonising energy demand. However, decarbonisation through electrification can only be achieved in conjunc-

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[1] CASE: Clean, Affordable and Secure Energy for Southeast Asia, see https://caseforsea.org/ for details on the project.

[2] Further information on energy efficiency and its political significance can be found at Energy efficiency first principle (europa.eu)

tion with a decarbonised power sector. This will require a strong expansion of PV, wind and storage capacity, combined with concerted action to rapidly phase out fossil fuels and increase the flexibility of the power system.

All four CASE countries can meet most of their electricity demand from indigenous renewable energy sources. However, an analysis of the regional renewable energy potential (PV and wind) shows that a high share of wind resources is only available at low full load hours, resulting in lower capacity factors and relatively higher specific electricity generation costs. Overall, the potential for utility-scale PV is much higher than for onshore wind. Storage is required for all systems, both short-term battery storage and long-term hydrogen storage.

The trajectory for building renewable energy capacity varies across the four countries, depending on the current electricity generation mix and existing potential. Indonesia has large hydropower and geothermal potential that could serve as renewable baseload, supporting the integration of variable renewable generation into the electricity market. Without concerted policy efforts, Vietnam is likely to maintain a high share of coal-fired power in the medium term due to recently built overcapacity. Thailand, on the other hand, has a large number of gas-fired power plants in its current electricity system and is much less reliant on coal by regional standards. If the Philippines is unable to develop its offshore wind resources, the country will likely have to rely on more hydrogen-fuelled power plants in the long term, further exposing its economy to the risk of import dependency.

The “Highly Electrified” scenario requires more domestic renewable energy capacity than the “Green Gases” scenario to meet the higher direct electricity demand. However, we assume in these scenarios that the entire final demand for green hydrogen is covered by imports and that domestically produced hydrogen is only used as long-term storage in the electricity sector. This would externalise a substantial part of the energy supply in the "Green Gases" scenario, leading to greater import dependency and likely higher costs. Alternative scenarios with higher domestic hydrogen production lead to an increase in the required renewable capacity and the use of less favourable potentials with lower full load hours. In Indonesia, this mainly means an increase in PV capacity, while in Thailand, Vietnam and especially the Philippines, the assumed potential of PV and wind power plants is pushed to its limits. It should therefore be further investigated to what extent domestic hydrogen production is applicable in each country. Where local production of hydrogen is likely to be limited, domestic use of hydrogen should be directed to those sectors that need it most.

The model results illustrate the need for system flexibility and energy efficiency to utilise the available renewable energy resources as efficiently as possible

Shifting battery electric vehicle charging to midday is used as an example of demand response. The results show how this can reduce the need for storage capacity, thereby easing the burden on renewable energy expansion. Demand flexibility and other sector coupling options such as smart grids should therefore play an important role in the planning of the future energy system, especially in systems heavily dominated by solar PV generation.

Energy imports remain an issue in the region in all scenarios.

Historically, most ASEAN countries have been importers of fossil fuels, with the share of imports increasing over the past two decades and set to increase further if decarbonisation efforts fail. Decarbonisation through energy efficiency and the development of local renewable resources could help reduce dependence on fossil fuel imports. However, the modelling results show that future demand for hydrogen is unlikely to be fully met by local production, especially if it is used on a large scale in many applications. Therefore, an increased focus on hydrogen for decarbonisation will create a new import dependency for hydrogen, possibly of a similar magnitude to the current demand for natural gas.

In the “Highly Electrified” scenario, we see an overall higher demand for electricity than in the “Green Gases” scenario (where the electricity for hydrogen production is generated elsewhere), which would require a greater expansion of renewable energy potentials, in some cases pushing them to their limits. On the other hand, the “Green Gases” scenario requires substantially higher hydrogen imports, increasing the dependency on hydrogen imports, while prices remain uncertain. Greater energy sovereignty - in addition to improved overall efficiency - therefore argues for limiting the use of hydrogen to sectors where there are no, or even more expensive, alternatives.

1 Introduction

As one of the fastest-growing regions, Southeast Asia plays a crucial role in achieving global climate goals. Deccarbonising the energy supply, transformation and demand sectors is essential for all countries to meet their emission targets. The modelling project presented here aims to understand the challenges of decarbonising energy systems in the ASEAN (Association of South East Asian Nations) region. It places particular emphasis on the role of gases in the energy futures of the four countries analysed in detail by the CASE[3] project: Indonesia, Philippines, Thailand and Vietnam. Among these, three have announced net zero targets – Indonesia (2060), Thailand (2065), and Vietnam (2050) – while the Philippines has pledged a 2030 target reduction of 75% compared to BAU scenario (IEA 2022; New Climate Institute et al. 2023b). The four countries account for more than three quarters of the ASEAN region's CO_2 emissions. The rest of the region is therefore analysed in an aggregated form.

It is often argued that fossil gas, due to its lower emission factor compared to other fossil fuels, can serve as a "transition fuel" or "bridging fuel" on the way to renewable energy systems. In fact, over the past 15 years, gas has contributed significantly to reducing energy intensity in many wealthier countries of the Global North, including the UK, the US and Europe, by displacing coal-fired power generation. However, as the climate crisis becomes more urgent and the Paris Agreement targets are seriously compromised, there is little room for additional fossil fuels of any kind. This applies to the entire globe and thus also to Southeast Asia. Rapidly falling costs for wind and solar energy mean that these resources, along with hydropower and geothermal energy, are a cost-effective alternative to fossil fuels and can be deployed on a large scale. Similar advances in energy storage technologies mean that, in some countries, the combined cost of wind and solar with storage is already lower than the cost of flexible peaking gas power plants. Investing in new gas infrastructure therefore risks occupying investment portfolios that could be used to expand renewables. Fossil gas could end up being a "wall" rather than a bridge for the development of renewables. In fact, as the world decarbonises, some of today's investments in gas infrastructure could become stranded assets. Others could lead to lock-in effects that later require replacement with alternative clean fuels such as hydrogen as an exit option, which is both more inefficient and usually more expensive than direct electrification.

As the demand for alternative clean fuels grows globally, the question arises whether countries could become exporters of hydrogen (or its derivatives) or even turn out to be importers themselves. In the ASEAN region, the discussions around clean fuels are very much in their early stages and have so far taken a subordinate priority in national strategies. However, there is a growing consensus on the need to reduce coal use - and as the pervasive paradigm of energy security currently focuses on securing fossil fuel supplies, natural gas (along with biofuels) is often seen as the prime solution. This modelling report aims to bring more clarity by examining the regional potential for renewable energy and discussing which energy sources should be used most effectively to meet emissions targets.

In the following, we first give a brief overview of the methodology underlying the modelling (Chapter 2). The modelling results are presented and discussed in detail in Chapter 3, comparing countries and scenarios. Conclusions are given for each section. We discuss socio-economic drivers, the final energy demand, renewable energy potentials, power supply and fuel production. For extended reading, figures with separate country results are given in Chapter 4, while Chapter 5 gives a more detailed description of the methodology. In addition to this report, the technical

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[3] CASE: Clean, Affordable and Secure Energy for Southeast Asia, see https://caseforsea.org/ for details on the project.

background report provides further information on various aspects of the role of gases and alternative fuels in the energy transition in the ASEAN region. The technical background report serves as a basis for modelling assumptions and is therefore often referred to in the following report.

2 Methodology

To shed light into the question of the role of gases in the decarbonisation of the ASEAN region, this report discusses a detailed modelling exercise of the ASEAN energy system. The four CASE countries Indonesia, Philippines, Thailand and Vietnam are modelled in detail, while the rest of the ASEAN region is analysed using an aggregated and simplified approach (see section 5). Key figures and results are presented at country level for the CASE countries and as aggregated totals for the other six countries.

2.1 Decarbonisation pathways and scenario rationale

Decarbonisation can follow a multitude of different pathways depending on the technology and policy options chosen. In this project, we analyse two different scenarios for each modelled region, both reaching the same decarbonisation target of zero emissions:

- The **"Highly Electrified" scenario** builds on electrification as the preferred option wherever possible and uses green gases only where there is no ready alternative on the current horizon (see technical background report chapter 3). Energy efficiency improvements are more pronounced in this scenario, as direct electrification often simultaneously reduces the final energy demand of different end-uses compared to other technology options, e.g. in road transport with battery electric vehicles or in process heat generation with heat pumps.
- The **"Green Gases" scenario** is less optimistic about the rate and depth of direct electrification. The constraint of full decarbonisation means that green gases, especially hydrogen, need to be used increasingly in all applications where this is a viable option (e.g. higher share of fuel cell trucks and industrial hydrogen boilers instead of battery electric vehicles and heat pumps). As electrification is less pronounced, this is in turn accompanied by lower energy efficiency gains.

The two scenarios explore realistic, but extreme, pathways which thus represent the boundaries of a decarbonisation ‘corridor’, within which we can safely assume future pathways to land. These should therefore not be read as alternatives, but as study material to understand the effect certain technology choices have on the energy system of the region. This techno-economic analysis thereby aims to inform policy discourses towards an accelerated energy transition. Both scenarios are based on consistent historical data and assumptions around the main drivers of final energy demand, mainly gross domestic product (GDP) and population, as well as consistent sectoral drivers.

2.2 Emissions reductions targets considered

The overarching modelling constraint was to reduce energy-related CO_2 emissions from demand sectors and electricity generation in line with stated national targets to ultimately achieve zero CO_2 emissions in the region by 2070 at the latest. For Thailand, the target was set five years earlier to be consistent with its net-zero target for 2065 (New Climate Institute et al. 2023c), while a maximum of 200 Mt CO_2e was set for 2050. Even though Vietnam has a net-zero target for 2050 (New Climate Institute et al. 2023d), this still includes 185 million metric tons of CO_2-equivalent emissions without sinks (e.g., LULUCF). This value was therefore taken as target for 2050, while absolute zero emissions are reached by 2070 at the latest. The same is true for Indonesia, where 848 Mt CO_2e is the committed emissions cap without sinks in 2050 (New Climate Institute et al. 2023a). Since the Philippines has neither an official net-zero target nor a self-declared emissions maximum for 2050, we set real zero CO_2 emissions from demand sectors and electricity generation in 2070 as the target, which is in line with Indonesia and Vietnam. For all four CASE countries, the unconditional NDC targets for 2030 are included as a minimum requirement in the models. An overview of the different emission targets can be found in Table 1.

Table 1: Overview of emission targets for the four CASE countries

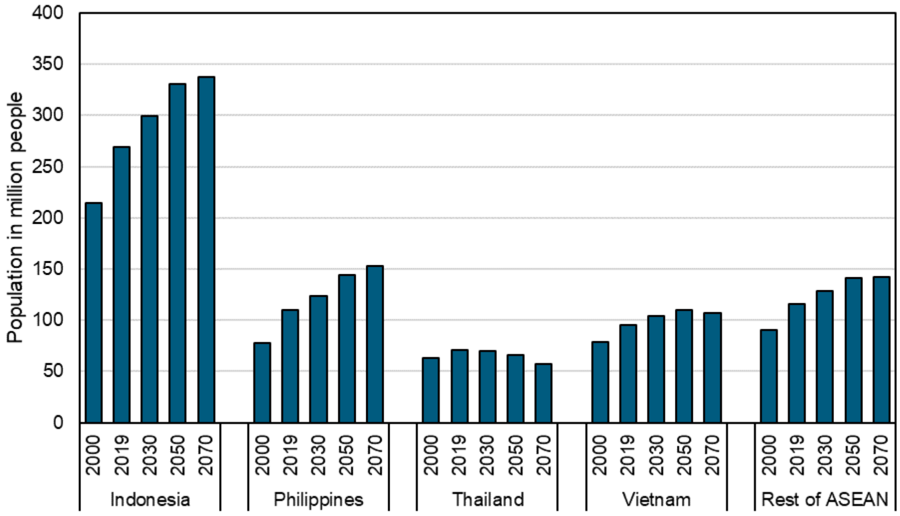
	Indonesia	Philippines	Thailand	Vietnam
2030 unconditional NDC target (excl. LULUCF)	1805 Mt CO_2e	384 Mt CO_2e	389 Mt CO_2e	863 Mt CO_2e
2030 conditional NDC target (excl. LULUCF)	1710 Mt CO_2e	96 Mt CO_2e	333 Mt CO_2e	620 Mt CO_2e
Absolute emissions level 2050 (excl. LULUCF)	848 Mt CO_2e	-	180 - 200 Mt CO_2e	185 Mt CO_2e
Formulation of target	Towards net-zero emissions by 2060 or sooner	-	Carbon neutrality 2050 / net-zero GHG 2065	Net zero by 2050

Source: Own collection based on (New Climate Institute et al. 2023a, 2023b, 2023c, 2023d)

2.3 Socio-economic assumptions

Figure 1 shows the historical development of population between 2000 and 2019 and the projected development until 2070 based on the medium variant of the UN projections (United Nations, Department of Economic and Social Affairs, Population Division 2022). Indonesia is by far the most populous country in the region. While there were already more than 200 million people living in Indonesia in 2000, the number grew to 270 million in 2019 and is expected reach about 340 million in 2070. All these numbers are more than double those of any other country in the ASEAN region. The second largest country is the Philippines, with a population of 110 million in 2019, projected to rise to about 150 million by 2070. While the populations of Indonesia and the Philippines are expected to grow through 2070, Vietnam's population is predicted to peak around 2050 at just over 100 million. In Thailand, the population is even seen declining soon, from about 70 million people in 2019 to less than 60 million in 2070. The rest of ASEAN combined had about 115 million people in 2019 and is projected to increase to about 140 million by 2070.

Figure 1: Evolution of population for the four CASE countries and the rest of ASEAN

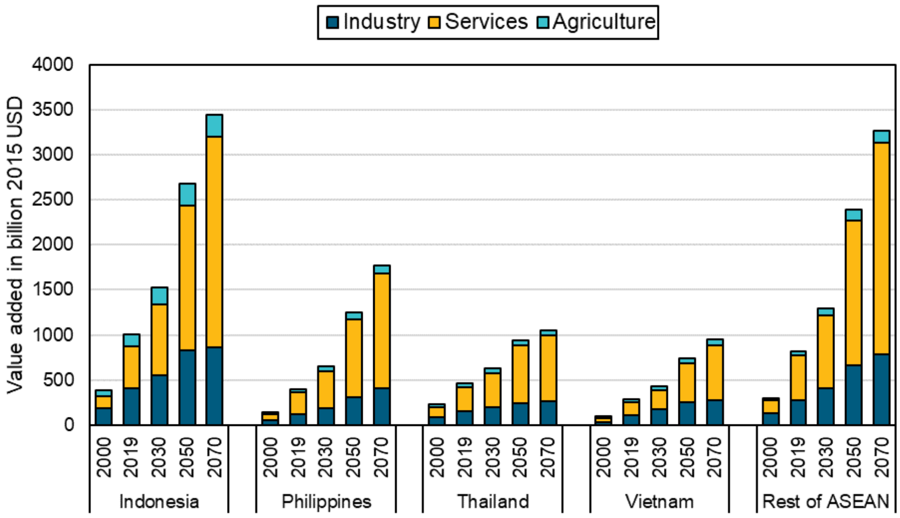


Source: Historical data from the World Bank (The World Bank 2022) and future projections based on the medium variant from UN Population Prospects (United Nations, Department of Economic and Social Affairs, Population Division 2022))

A look at the GDP of the individual countries in Figure 2 shows that Indonesia more than doubled its GDP from around 400 billion 2015 USD to over 1000 billion 2015 USD. Assuming per capita GDP growth rates between one and three percent and considering projected population trends, this sustained economic development could lead to a total GDP of nearly 3500 billion 2015 USD in 2070. However, such long-term GDP projections should be treated with great caution, as they are subject to a wide range of uncertainties. Similar to population, the other CASE countries are smaller than Indonesia by more than a factor of two in terms of GDP. All countries are expected to continue their historical trend of economic growth. Driven by its rapidly growing population and assumed GDP per capita growth rates of up to 3 % per year until 2030 and still 2 % in 2050, the Philippines could become the second largest CASE economy between 2030 and 2050, currently the position taken by Thailand, which is seeing a population decline in the same period. A look at the other ASEAN countries shows that they account for a significant share of GDP despite their small populations. The combined economic output of the six countries was around 850 billion 2015 USD in 2019, not far behind Indonesia and well above the figures for Thailand, Vietnam and the Philippines.

The breakdown of GDP among the three sectors of industry, services and agriculture shows that Indonesia and Vietnam today have a relatively high share of industrial value added compared to the Philippines and the aggregated six ASEAN countries, while Thailand lies in between. In all countries, the services sector have grown strongly between 2000 and 2019, while agriculture contributes only a small share to national GDP. This trend is expected to continue, and must be considered when forecasting future final energy demand. The services sector is less labour- and resource-intensive compared to industry, and a high proportion is already electrified today, which means that growing GDP that comes primarily from value added in the services sector does not have the same effect on energy demand and emissions as increasing industrial production would. However, the economic growth of the service sector leads, albeit to a lesser extent, to an increase in energy demand, which in this case is mainly met by electricity, underlining the importance of decarbonising the power sector.

Figure 2: **Evolution of the GDP split by sectoral value added for the four CASE countries and the rest of ASEAN**

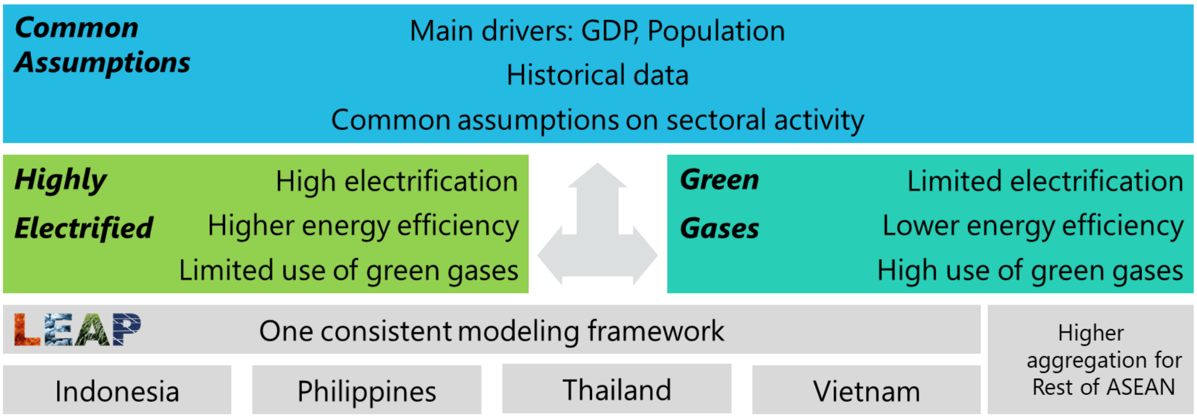


Source: Historical data from the World Bank (The World Bank 2022) and future projections based on own assumptions

2.4 Modelling approach

The Low Emissions Analysis Platform (LEAP) software is used for modelling. LEAP was developed by the Stockholm Environment Institute and has been used for many years by various institutions around the world for energy modelling and policy analysis and evaluation (SEI 2023b). One of its main features is its flexibility, allowing the level of detail of the modelling to be adjusted according to the objectives. Uniform models are developed for the four CASE countries: Indonesia, the Philippines, Thailand, and Vietnam. The base year of all models is 2019 and the time horizon extends to 2070, with results presented for every 10 years. The approach is briefly introduced here, while further details on the structure of the country models as well as information on the methodology for the aggregated modelling of the remaining six ASEAN countries can be found in chapter 5.1. Figure 3 shows a graphic representation of the modelling approach.

Figure 3: **Schematic representation of the modelling approach for the two scenarios**



Source: Own representation, LEAP is has been developed by Stockholm Environment Institute and is the modelling platform used in this project, see (SEI 2023b) for details.

2.4.1 Demand side modelling

A combination of bottom-up and top-down approaches is used to project the future demand of the different sectors. This allows for a high level of sectoral detail to be represented in the model despite limited data availability in some cases. The choice of technology shares is closely linked to the decarbonisation options described in Chapter 3 of the technical background report. Therefore, the description here is limited to some key points and puts a special focus on the sectors where the scenarios differ.

- In **industry**, hydrogen will be used in the future in the steel sector to produce primary steel through direct reduction. While this applies to both scenarios as there are currently no suitable commercial alternatives in sight, the decarbonisation pathways diverge on the use of hydrogen for heat generation. While this is minimal in the “Highly Electrified” scenario, it plays a greater role in the “Green Gases” scenario. For **non-energy uses**, we assume the same shares of renewable energy sources (biomass, hydrogen, synthetic hydrocarbons) in both scenarios.
- In the **transport** sector, the two scenarios differ on the role of fuel cell vehicles in road transport. Particularly, for heavy duty trucks, a technology share of up to 60% is assumed in the long term in the "Green Gases" scenario, compared to just 10% in the "Highly Electrified" scenario where battery electric vehicles dominate freight transport. In passenger transport, the share of fuel cell vehicles (30%) remains well below battery vehicles (70%) in the “Green Gases” scenario and plays no role in the "Highly Electrified" scenario due to the lower efficiency. Similar assumptions apply to rail transport in the long term, while national air traffic continues to rely on liquid hydrocarbons (substitution by biofuels and e-fuels). Depending on the scenario, only a small part of the flight kilometres will be directly electrified or operated by hydrogen planes.
- In the **residential** sector, no distinction is made between the scenarios. Strong direct electrification in combination with a small share of biomass use is assumed in both cases. Hydrogen and other gases play no role in the sector modelling, as other technologies (such as electric stoves and heat pumps) have clear efficiency and cost advantages.
- Like in the residential sector, hydrogen is assumed to play no role in the **services** sector due to the clear efficiency and cost advantages posed by electrification. No technology distinctions are made in this sector.
- In the **agricultural** sector, a mix of direct electricity use, hydrogen and biomass is assumed. The use of hydrogen differs in the two scenarios and ranges between 10% and 30% in the long term, with electricity dominating even in the "Green Gases" scenario.
- For '**international bunker** fuels' which typically include international (air and ship) transport, fossil liquid fuels are assumed in both scenarios to be replaced in the long-run by synthetic fuels and biofuels. Hydrogen (15%) and direct use of electricity (1%) play a subordinate role.

2.4.2 Estimation of renewable energy potentials

The renewable energy potentials for ASEAN countries was calculated in the scope of the HYPAT[4] project using the Renewable Potential Calculator 2.0 from Enertile(Kleinschmitt et al. 2022). The results for onshore wind and utility scale PV were used in this project. Offshore wind was calculated as part of HYPAT, but the calculation is limited to a water depth of 50m, which severely limits the potential in the ASEAN region. Therefore, the offshore wind potential was not considered in this project. The same applies to rooftop photovoltaics and concentrated solar power (CSP).

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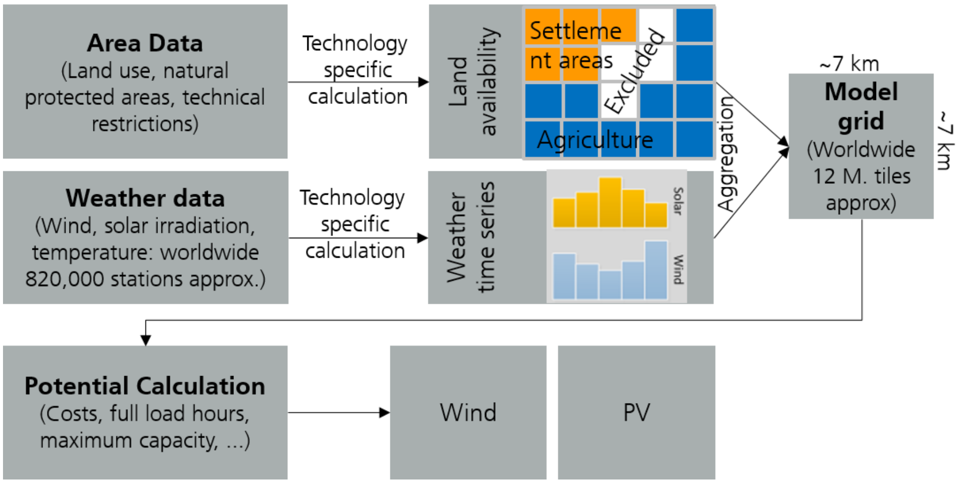
[4] Global Hydrogen Potential Atlas, see https://www.hypat.de/ for details

Figure 4: Schematic of the renewable potential calculation in Enertile



Source: (Kleinschmitt et al. 2022)

Figure 4 shows the schematic of Renewable Potential Calculator 2.0. The model is based on approximately 12 million 6.5 x 6.5 km^2 tiles worldwide. Each of these tiles is assigned land use criteria according to the GlobCover 2009 dataset (ESA 2010). Then, a factor is assigned to each land use per technology, which determines the amount of land available for renewable energy installation. The land use criteria used for wind onshore and utility scale PV are shown in Table 2. Areas classified as Ia, Ib and II protected areas by the International Union for Conservation of Nature and Natural Resources (IUCN) were excluded from the calculation of potential (IUCN 2019)

Table 2: Usage factors for different land use categories

Factors	Utility-scale PV	Wind
Barren	20%	50%
Cropland natural	2%	20%
Croplands	1%	10%
Forrest	0%	10%
Grassland	10%	40%
Savanna	5%	20%
Shrubland	5%	20%
Snow and ice	0	0
Urban	0	0
Water	0	0
Wetlands	0	0
Excluded	0	0

The largest factors are assigned to barren land because it has no other economic use and limited ecological impact. For utility-scale PV, small factors are given to both natural and regular croplands. The factors take into account the mixed use of the land for PV and agricultural activities (Agrivoltaics). The mixed composition of natural cropland allows a higher use factor to be used. Forest is not feasible for PV installations. Urban areas could be suitable for rooftop PV, while water bodies could be used for floating PV. However, these two technologies were not considered in detail in this project and the areas were therefore not included in the calculation of potential. Grassland, because of its lower ecological impact, has twice the factor of savanna and scrubland. Wind technologies have a higher assigned factor, because the distance between turbines allows mixed use of the land.

Besides the land use data, the model uses global weather data, ERA5 for the year 2010 (ECMWF 2020). The weather data is used to perform technologically specific calculations to determine the availability of the technology (Sensfuß et al. 2023). Further details on this calculation can be found in (Kleinschmitt et al. 2022; Pieton et al. 2023).

To effectively assess the energy generation potential, the potentials are grouped into different steps based on their full load hours (FLH). The initial step, denoted as Step 0, comprises the potentials with the highest FLH values, while subsequent steps contain potentials with progressively lower values. Within each step, the hourly time series data is collected and averaged for all the tiles within that step. This approach allows for a comprehensive analysis of the energy potential across various time periods and locations.

2.4.3 Supply side approach

On the supply side, the electricity sector is examined in detail. For each of the four CASE countries, the existing power plant fleet and its age structure are integrated as inputs into the energy system model. After reaching the end of their technical lifetime, the existing power plants are removed from the system. Future expansion planning is based on cost optimisation using the NEMO framework (SEI 2023a) available in LEAP. Under the given constraints, the model plans the expansion and operation of different types of power plants with the goal of meeting electricity demand at all times while minimising total system costs in each scenario. Besides power plants for electricity generation, there is also the option to install different technologies for energy storage. These include batteries for short term storage and hydrogen for seasonal storage. The hydrogen storage module considers the roundtrip efficiency of converting and reconverting electricity into hydrogen and vice versa. In countries where there is some potential for pumped hydro storage this is also considered with given capacity restrictions based on country specific literature values.

Hydrogen and e-fuels are imported in both scenarios, except for the hydrogen generated for energy storage, which is assumed to be produced domestically via renewable energy. This split of imported hydrogen and locally produced electricity allows to study the effects on the energy system in a stepwise manner (see also Chapter 3.1 in the technical background report).

In addition to the two main scenarios, we consider two sensitivity analyses, for which results are presented in chapter 3.3:

- Highly Electrified - BEV charging (HE BEV): This sensitivity is based on the "Highly Electrified" scenario. It assumes that battery electric vehicle (BEV) charging shifts more to midday when the availability of solar electricity is highest. This allows to analyse the effect of demand side flexibility using the example of BEV charging.
- Green Gases - Domestic H2 Production (GG H2): This sensitivity is based on the "Green Gases" scenario. It is assumed that one-third of domestic hydrogen demand is produced locally and fueled by solar electricity, while the remainder continues to be imported. This allows to analyse the effect of increased electricity demand for hydrogen production.

2.4.4 Data sources

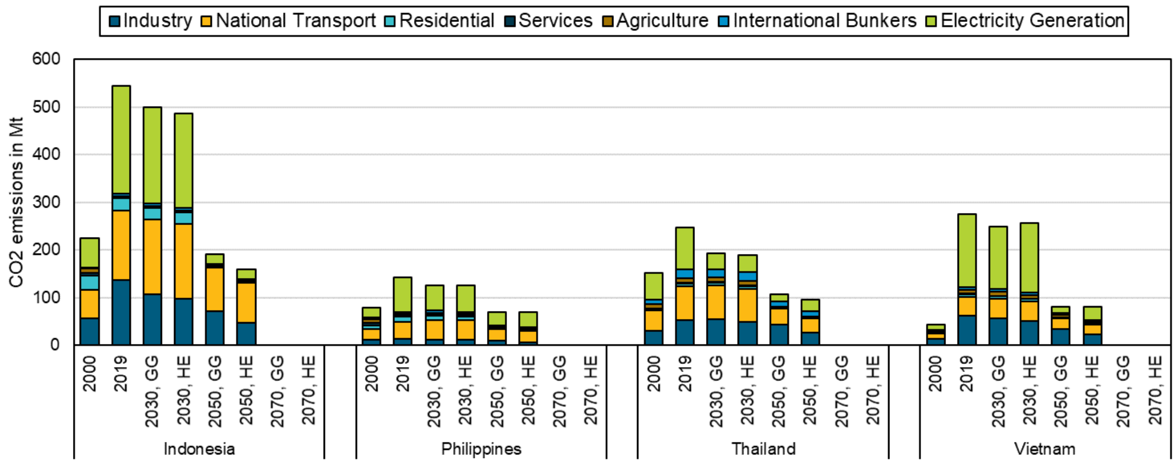
A variety of international data sources combined with national data were used to feed the models. For the demand side, historical demand data were taken from the Enerdata database (Enerdata 2023a) and the Global Energy Monitor (Global Energy Monitor 2022). For the different sectors, energy intensity and techno-economic parameters are our own assumptions based on expert opinion and internal data from Fraunhofer projects with European modelling. For the supply side, the data sources for renewable potentials are described in detail in the respective section above. Historical data on power generation are based on data from the International Energy Agency (IEA 2023), and historical data on power capacity are taken from the Enerdata database (Enerdata 2023b) as well as from national sources from the countries studied. The costs used in the supply modelling follow the techno-economic parameters of the Danish Energy Agency (Directorate General of Electricity et al. 2021). No CO_2 pricing is assumed in the scenarios.

3 Modelling results: Country comparison

3.1 CO_2 Emissions

Figure 5 shows the development of CO_2 emissions by sector for the different CASE countries. It shows that emissions from all countries have increased significantly between 2000 and 2019. This is particularly true for emissions from electricity generation, which increased by a factor of 1.6 (THA), 3.2 (PHL), 3.6 (IDN), and 13.6 (VNM) during this period (IEA 2023). Other major contributors were industry and national transport, while the other sectors accounted for only small shares of total CO_2 emissions. In the future projections, emissions decrease slightly by 2030 for all countries and scenarios, mainly due to reductions in the power sector and industry, while emissions in transport increase moderately. However, the largest reductions are achieved after 2030, where emissions from electricity generation in particular decline rapidly due to the installation of renewable power plants. Between 2030 and 2050, the decline continues in industry and begins in transport as technology shifts to cleaner solutions such as heat pumps or battery electric vehicles. The decline is even more pronounced in the "Highly Electrified" scenario than in the "Green Gases" scenario, as it implies higher energy efficiency and faster adoption of clean technologies without relying on natural gas. By 2070 at the latest, emissions in all sectors in all countries become zero.

Figure 5: Evolution of the CO_2 emissions from final energy demand and electricity generation by sector for the four CASE countries



Note: (HE: Highly Electrified GG: Green Gases).

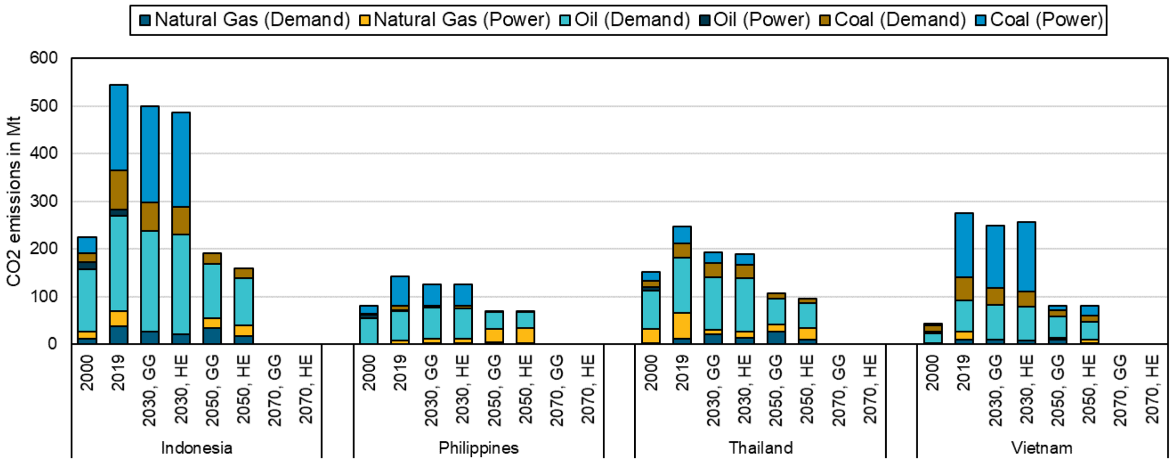
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios.

Figure 6 shows the development of CO_2 emissions by fuel for each CASE country. The increased use of coal, especially in the power sector, and in industry, has led to a sharp rise in energy-related CO_2 emissions in the past two decades. This also explains why the increase in CO_2 emissions from power generation was much higher in the Philippines, Indonesia, and especially Vietnam than in Thailand. While in the former three countries the share of coal in electricity generation increased from 36% to 59% (IDN), from 37% to 55% (PHL), and from 12% to 50% (VNM) between 2000 and 2019, in Thailand it remained almost constant at below 19% (IEA 2023). With a high share of electricity generated by natural gas-fired power plants (>60%), the Thai power sector thus differs from the other CASE countries, where natural gas plays only a minor role in electricity generation (around 20%). This difference can be explained by looking at the countries' natural energy resources. While Vietnam and especially Indonesia are large coal producers and have therefore met rising electricity demand in the past by expanding coal-fired power plants, Thailand and the Philippines have hardly any coal reserves and are hence dependent on imports. Thailand has been able to meet a large part of its natural gas demand, including electricity generation, domestically in the past. However, this will change in the future as proven natural gas reserves in Thailand are almost exhausted, which is currently leading to an expansion of import capacities for liquefied natural gas (LNG; see also Chapter 2 in the technical background report). Indonesia and Vietnam both have gas reserves as well, but have in the past used them mainly for their final energy needs and, in the case of Indonesia, exported some of it, but only to a lesser extent for power generation. The Philippines has very few fossil energy resources overall, although one domestic gas field was developed for power generation in the early 2000s. To meet the rising demand for electricity, additional coal-fired power plants have been built in recent years, which are mainly fuelled by imports from Indonesia.

Besides coal, oil is the main source of energy-related CO_2 emissions, especially in the transport sector. Here, electrification drives the sharp decline in emissions after 2030 in all countries and scenarios. Since the emission factor of natural gas is more than 40% lower than that of coal (JRC 2022), the total emissions of natural gas in all countries are low compared to those of coal and oil, especially in the demand sectors. Nevertheless, higher CO_2 emissions are projected in the "Green Gases" scenario due to the continued use of natural gas in industry, e.g., in Indonesia and Thailand in 2050. Since power generation is expected to be decarbonised faster than the demand sectors, oil used in the transport sector contributes most to energy-related CO_2 emissions in 2050.

The results clearly show the importance of addressing the power and demand sectors in concert. To decarbonise the demand sectors, it is crucial to replace fossil fuels such as coal in industry, for example for steel production, but also for process heat, and oil in the transport sector with CO_2-neutral energy sources. Electricity will play the key role here, regardless of the scenario, as it is often the most efficient and cheapest solution (see also chapter 3 in the technical background report for more details). To reduce overall emissions, it is therefore essential to transform electricity generation as quickly as possible and to replace fossil power plants with renewable ones and expand them even further.

Figure 6: **Evolution of the CO_2 emissions from final energy demand and electricity generation by fuel for the four CASE countries**



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios.

3.2 Final energy demand

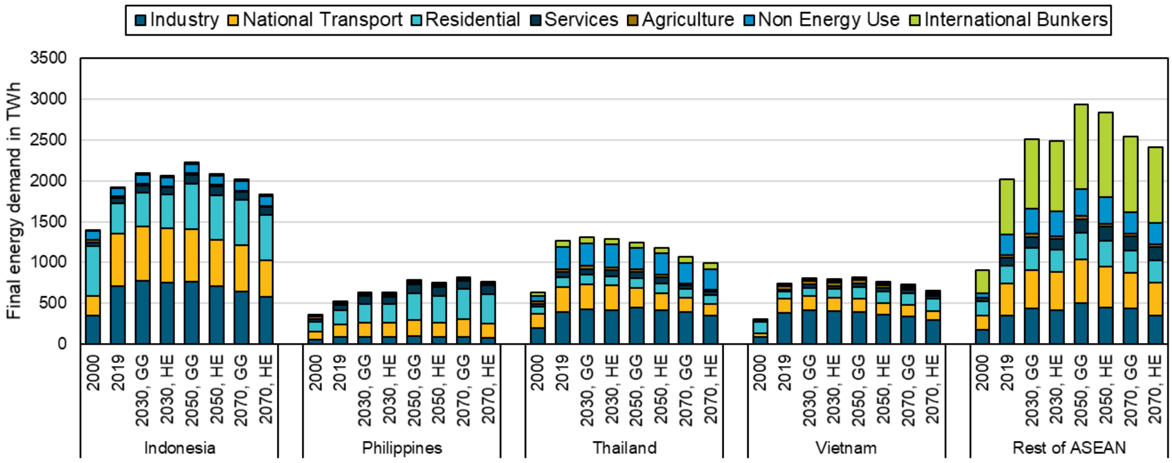
3.2.1 Total

Historically, energy demand has increased in all four CASE countries as well as the rest of ASEAN between 2000 and 2019. This trend is expected to continue but weaken by 2030 for all countries, as energy efficiency increases, and the population grows more slowly or even declines. As described in the technical background report (Chapter 3), direct electrification is often the more efficient decarbonisation option compared to the use of green gases, therefore the final energy demand in the "Green Gases" scenario is higher than in the "Highly Electrified" scenario. Examples are the use of battery vehicles compared to fuel cell vehicles or the application of heat pumps instead of hydrogen boilers for the provision of industrial process heat.

Figure 7 shows the final energy demand by sector for the ASEAN countries. Overall, Indonesia has the highest final energy demand among CASE countries, followed by Thailand, Vietnam and the Philippines. Based on the assumed development of the main factors of population and GDP, the energy demand of Thailand and Vietnam will decrease after 2030, while it will increase in Indonesia until 2050 and in the Philippines even until 2070.

Vietnam and Indonesia are among the largest steel and cement producers in the world, which explains their relatively high **industrial** energy demand. The strong petrochemical industry in Thailand (AIChE 2019) and the remaining ASEAN countries leads to comparatively large shares of **non-energy use**. Singapore as one of the main marine fuel suppliers in Asia (maritime gateway 2021) drives the high demand for **international bunkers** in the aggregated non-CASE countries. The higher population figures in the Philippines and Indonesia create a comparatively high demand in the **residential** sector. **National transport** accounts for a substantial share of final energy demand in all countries, while final demand for **services** and **agriculture** is rather low.

Figure 7: Evolution of final energy demand by sector and scenario for the four CASE countries and the rest of ASEAN



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios (HE: Highly Electrified GG: Green Gases).

The breakdown by fuel (Figure 8) shows that **oil** has historically accounted for a high share of final energy demand in all countries in the region, being used mainly in transport. To reduce this demand for oil and bring transport-related emissions to zero, the scenarios assume a switch to alternative powertrains, mainly electricity and to some extent hydrogen. This not only replaces oil, but also reduces overall energy demand due to efficiency gains that are particularly pronounced in the transport sector.

Due to the production of large quantities of steel and cement, **coal** is used as a prominent fuel in industry, mainly in Indonesia and Vietnam, and to a lesser extent also in Thailand. In these countries, the use of coal must be phased out as early as possible through fuel switching and a change in production processes, for example by transitioning primary steel production from the blast furnace route to direct reduction with hydrogen.

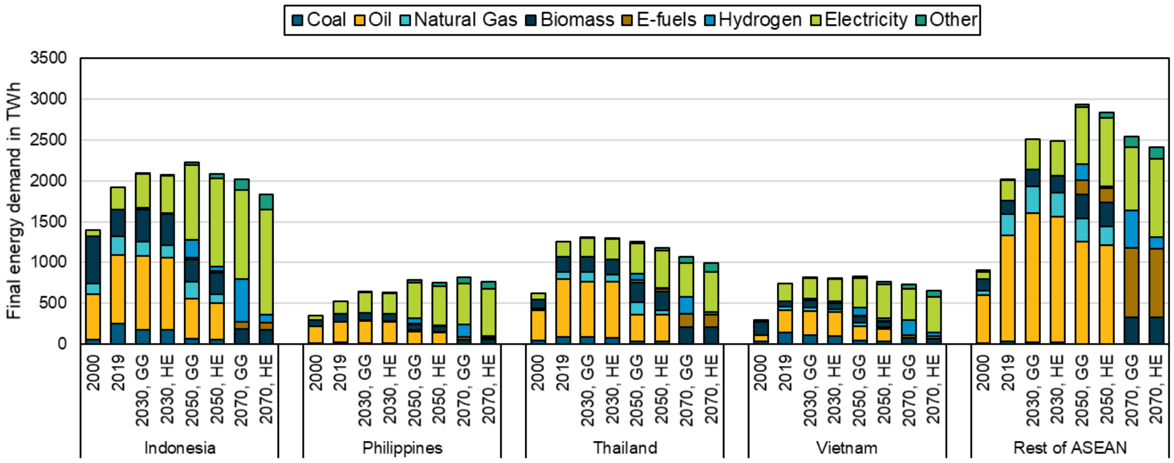
Natural gas has historically been used only in Indonesia, Thailand, and some of the aggregated non-CASE countries. Although gas has a lower emission factor compared to coal, these processes must also be converted by 2070 at the latest, or the remaining gas must be replaced by green hydrogen, in order to bring CO_2 emissions to zero and achieve the specified targets. An early switch to renewable processes away from fossil gas is therefore crucial to reduce costs and prevent lock-in effects. Among renewable fuels, biomass has historically had the highest share.

The overall use of **biomass** in the region is expected to remain stable in the future, but to shift partly between countries and sectors. In the long term, biomass is set to be used mainly for non-energy purposes and international bunkers, where carbon-based fuels will continue to be needed. These sectors are particularly strong in Thailand and the other aggregated ASEAN countries, resulting in more biomass use there than in the other modelled CASE countries.

Besides sustainable biomass, **e-fuels** are also likely to be needed in these sectors in the long run to become carbon neutral, which again is particularly relevant for the "Rest of ASEAN" countries and to a lesser extent for Thailand. Since e-fuels are assumed to be integrated into international transport sector on a larger scale only after 2050, there is a sharp increase in the share of e-fuels in total demand in the aggregated non-CASE countries between 2050 and 2070, while the share of oil decreases sharply over the same period.

Overall, the use of e-fuels should be kept as low as possible for efficiency and cost reasons. Wherever possible, priority should be given to energy efficiency measures and the direct use of electricity to replace fossil fuels. The different scenarios show that **hydrogen** is necessary for complete decarbonisation in certain applications (i.e., primary steel production), while its use in optional applications causes additional energy demand compared to **direct electrification**. Here, it should therefore be carefully examined whether it is beneficial from a system perspective.

Figure 8: **Evolution of final energy demand by fuel and scenario for the four CASE countries and the rest of ASEAN**



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios.

3.2.2 Transport

Figure 9 shows the final energy demand in the transport sector, categorised by fuel. Demand increased strongly in all cases between 2000 and 2019 due to the GDP and population growth. In 2000, oil is the most common fuel in all cases with a small share of electricity present in Vietnam, the Philippines and the rest of ASEAN.The small share of electric vehicles may be due to the limited charging infrastructure and "range anxiety"[5] (Thananusak et al. 2021). In 2019, oil remains the dominant fuel. The rest of the demand is supplied by biomass, natural gas and electricity.

In 2030, electrification of the vehicle fleet is still low, but it is increasing. Energy demand increases in all the regions for both scenarios. The "Highly Electrified" scenario exhibits a lower energy demand due to higher efficiency of electric vehicles.

Although the market share of diesel and gasoline cars declines sharply and falls behind alternative powertrains (BEVs or fuel cell vehicles) in terms of passenger-kilometres, oil still dominates transport energy demand in 2050 due to the lower energy efficiency of internal combustion engines. The share of electricity has increased to more than 30% in the "Highly Electrified" scenario across all countries, with only a small contribution of biofuels. Hydrogen and e-fuels are only beginning to be explored and remain marginal. For the "Green Gases" scenario the share of electricity is smaller approximately 15%. Hydrogen has a larger share between 20-25% in all regions. The highest share of electricity in the "Highly electrified" scenario leads to a smaller energy demand in the sector due to the higher efficiency of electric vehicles.

By 2070, the efficiency benefits of electrification are even more pronounced in the "Highly Electrified" scenario.The share of electricity increases between 67% and 82% in all regions. The rest of the demand is covered by Hydrogen biomass and e-fuels all of them with shares between 5-10%. In the "Green Gases" scenario, the electricity demand is lower in all cases as hydrogen takes a predominant role covering between 50% and 60% of the demand. In all cases, hydrogen and electricity are complemented by e-fuels and biomass at roughly equal amounts (5-10%).

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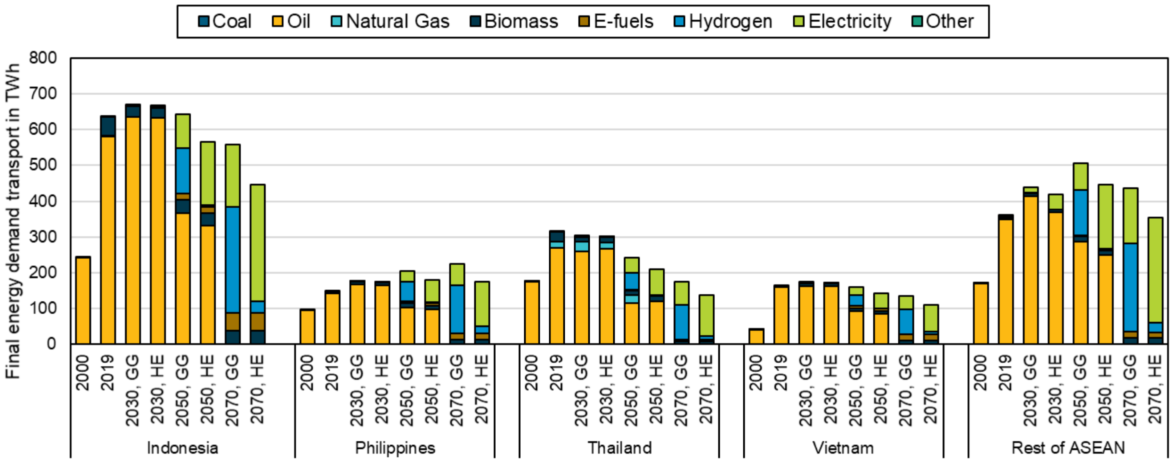
[5] Range anxiety is defined as the concern of drivers about the distance they can cover and the availability of charging points.

Figure 9: **Evolution of final energy demand in the transport sector by fuel and scenario for the four CASE countries and the rest of ASEAN**



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios.

3.2.3 Industry

Figure 10 shows the final energy demand in the industry sector categorised by fuel for both, historic and modeled values. Like for transport, industrial demand has increased drastically for all cases between 2000 and 2019. In 2000, coal, oil and gas made up more than 50% of final energy demand in all cases. By 2019, the share of electricity has increased and the use of natural has increased or started.

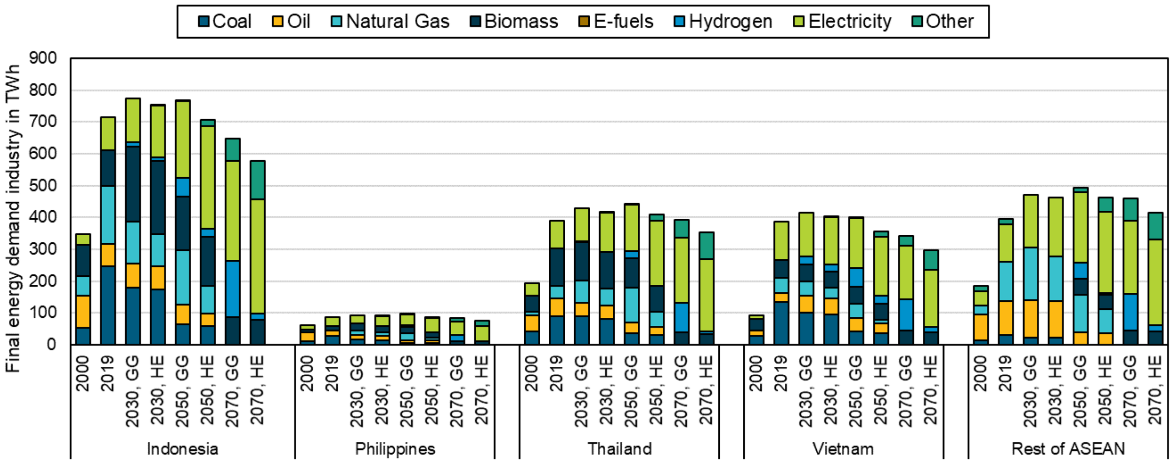
Moving towards 2030 in modeled values the industry sector continues to grow throughout the region, yet absolute growth is somewhat tempered by improvements in energy efficiency. The energy demand continues to decrease slightly also due to energy efficiency measures, most prominently further electrification and changes to process heat supply via heat pumps (classified here as Other, also see below), until 2070 in all countries. Heavy industries dominate energy use with non-metallic minerals (mainly cement), petrochemicals, and iron and steel making up more than 40% of energy demand in the ASEAN region. The extended annex shows the distribution between sectors.

Parallel to the increase in production, which is the main driver of demand, decarbonistion in the model is also achieved by a fuel and technology switch, which is also affecting energy intensity. The technical background report gives a detailed discussion of options to decarbonise the industry sector. There are certain sectors and applications where hydrogen as an energy carrier has limited current alternatives if complete decarbonisation is to be achieved, notably primary steel production and ammonia production. Mechanical energy demand can be decarbonised through electrification, while the energy carrier for process heat depends on the temperature level. Heat pumps using ambient heat can be used for lower temperature levels up to 150°C, while direct electrification can be used to decarbonise medium temperature levels. For temperatures above 1000°C, direct combustion of decarbonised fuels will increasingly be required. Process heat is required for a variety of different industrial purposes, while the often-discussed specific hydrogen applications, for example in the iron and steel or chemicals industries, account for a large proportion of energy requirements, but only affect a small number of installations.

In this study, all fossil fuels are phased out until 2070 and only biomass, hydrogen, electricity and ambient heat for use in heat pumps (classified here as Other) remain. Hydrogen is used in the "Highly Electrified" scenario only in sectors where electrification alternatives are not technologically viable (mainly steel and chemicals), while the "Green Gases" scenario makes more widespread use of hydrogen for high temperature heat.

While hydrogen supplies 25% - 29% of industrial final energy demand in the "Green Gases" scenario, it only reaches 3% - 6% in the "Highly Electrified" scenario by 2070. The "Highly Electrified" scenario applies more heat pumps, which increases the share of ambient heat in the energy mix ('Other' category; 20% - 24% for HE versus 9% - 15% in GG in 2070), but also decreases overall energy demand. Less biomass is used in 2070 compared to 2019 in all cases, as the heat is supplied by other, more energy efficient decarbonised options.

Figure 10: **Evolution of final energy demand in the industry sector by fuel and scenario for the four CASE countries and the rest of ASEAN**

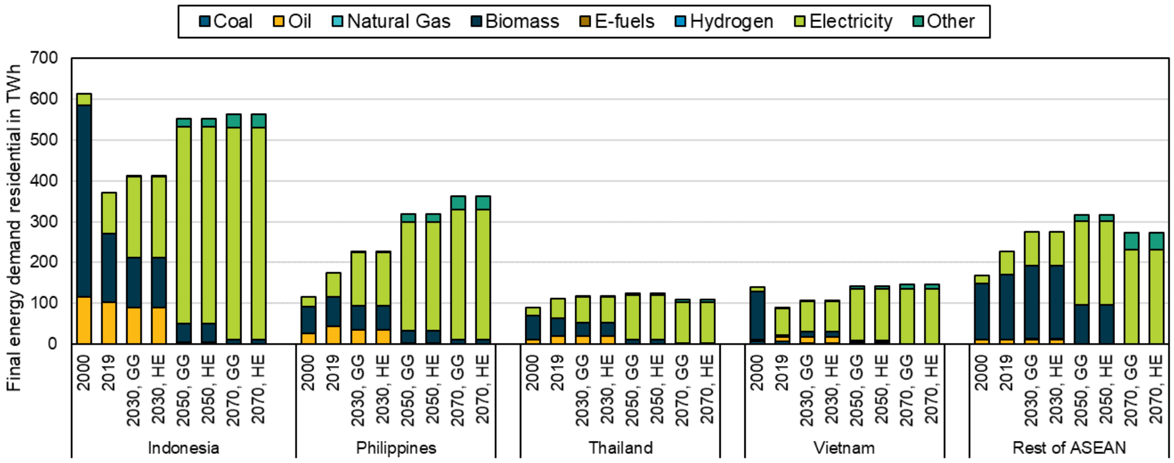


Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios.

3.2.4 Residential

The final energy demand in the residential sector, split by fuel, is shown in Figure 11. Historically, demand was dominated by biomass and mainly used for cooking and water heating. The use of biomass as given in national statistics decreased strongly between 2000 and 2019 for Indonesia and Vietnam, which also lead to an overall decrease of the sectoral final energy demand. This reflects the policy efforts related to electricity access and cleaner burning fuels that significantly reduce indoor and local air pollution and result in efficiency gains due to fuel switching. However, there were also changes in the calculation methodology for Vietnam in 2015, which led to a drop in the reported energy demand for residential biomass. Besides the reduced use of biomass for all countries, an increase in the use of electricity is visible. This trend is also expected to continue in the future. The main drivers for this are the increased use of space cooling and electrical appliances due to increasing population and wealth as well as the switch to electrical stoves for cooking and electrical water heating. As there is no future potential for the use of hydrogen or its derivatives in the residential sector, both scenarios assume the same pathways of residential demand until 2070. In the longterm, besides electricity, ambient and solar heat, which are aggregated as ‘Other’, also have a certain share for water heating.

Figure 11: **Evolution of final energy demand in the residential sector by fuel and scenario for the four CASE countries and the rest of ASEAN**



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios.

3.3 Power supply

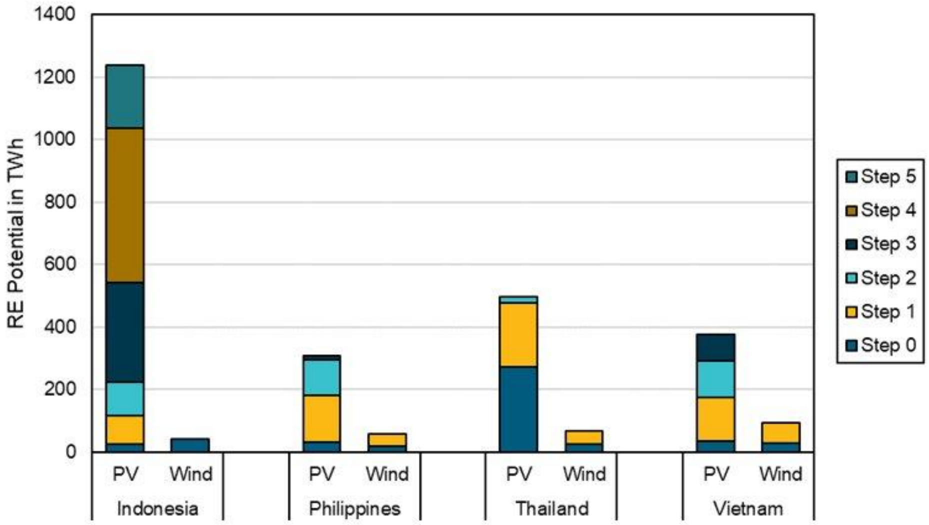
3.3.1 Renewable energy potentials

Harnessing renewable energy is key to decarbonising economies everywhere. Figure 12 shows the renewable energy potential for solar and onshore wind in the CASE countries. The potentials are divided into different levels representing different full load hours (FLH), where level 0 corresponds to the best sites. Each potential step has an availability curve that is used within the model. Only steps with FLH above 876 h (10% availability) are considered. The same potentials are used for both scenarios. The steps and their respective FLH are given in Table 3:

Table 3: **Full load hours for solar and onshore wind for the four CASE countries and their corresponding step**

Step	Indonesia		Philippines		Thailand		Vietnam	
	PV	Wind	PV	Wind	PV	Wind	PV	Wind
Step 0	1421	1303	1374	1770	1247	1348	1257	1774
Step 1	1309		1270	954	1185	889	1167	1058
Step 2	1189		1170		1075		1060	
Step 3	1079		1089				971	
Step 4	983							
Step 5	915							

Figure 12: **Renewable energy potential for solar and onshore wind for the four CASE countries split by steps according to full load hours and technology**

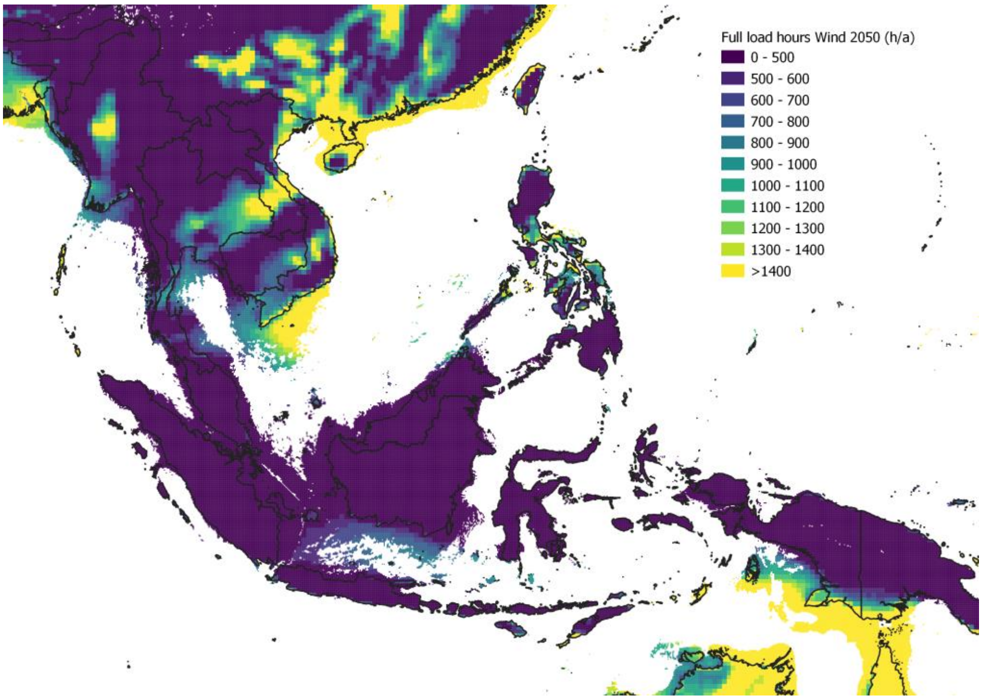


Source: own ellabouration

Figure 12 shows the electricity generation potential in terawatt hours (TWh) for both onshore wind and solar PV. Solar PV exceeds onshore wind potential throughout the region. Indonesia stands out with the highest PV potential of over 1200 TWh. However, it has the lowest wind potential in the region. Thailand has significant PV potential, all with full load hours (FLH) above 1000. The most favourable wind potential is found in Vietnam, where FLH exceeds 1700.

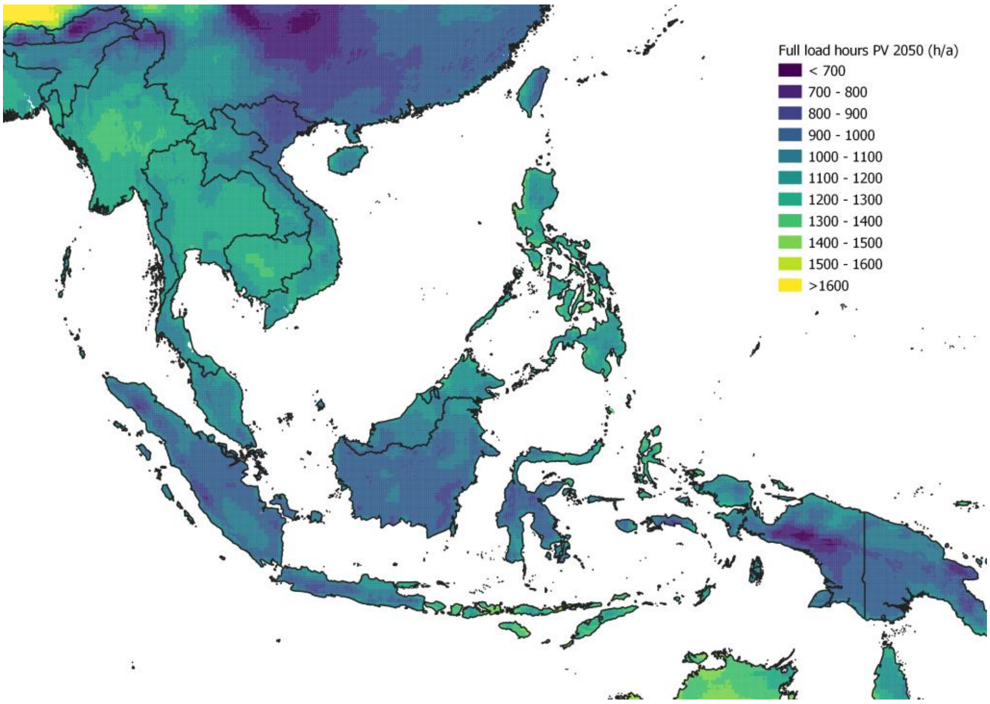
Figure 13 shows wind potential, which is largely dominated by low wind speeds and FLH below 600 (shaded in purple). It is estimated that only 1.5% of the total land area has an average wind speed greater than 7 m/s (Energy watch 2022). For further details please see section 5.2. Thailand and the Philippines both have some regions with higher FLH corresponding to step 0 with FLH above 1700. Figure 14 shows the photovoltaic (PV) potential across the region, showing a relatively even distribution with the majority of areas having full load hours (FLH) above 1000, as previously detailed in Table 3. Of particular note is the southern region of Indonesia, which has the most favourable PV areas, with FLH exceeding 1400, in line with the information presented in Table 3. Beyond Indonesia, other countries in the region also show regions with high FLH, consistently above 1300. This observation demonstrates the widespread and substantial PV potential across different geographical locations, and highlights the robust renewable energy resources available for electricity generation in these regions.

Figure 13: Full load hours of wind potential in the ASEAN region



Source: own elabouration with data from HYPAT

Figure 14: Full load hours of PV potential in the ASEAN region



Source: own elabouration with data from HYPAT

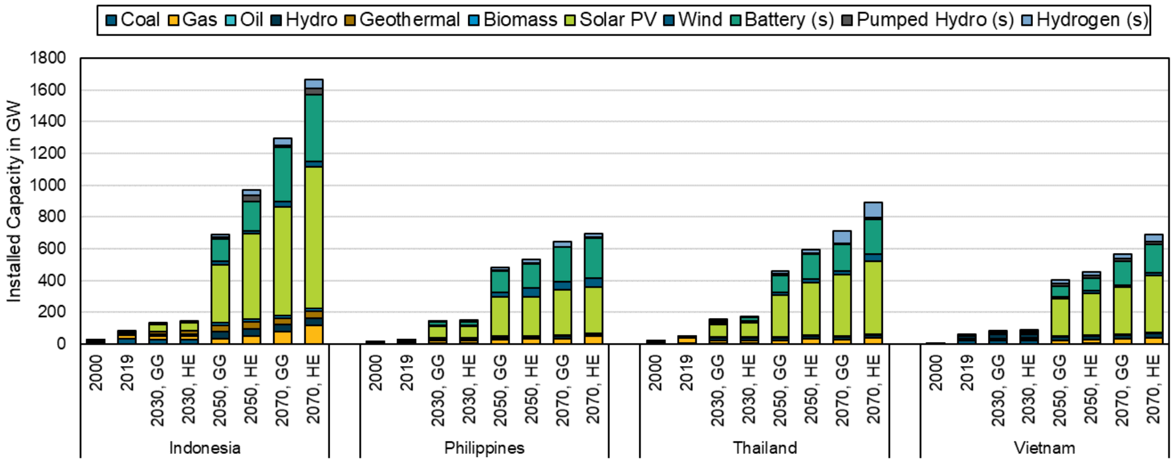
3.3.2 Capacities and electricity generation

Figure 15 and Figure 16 show the evolution of installed power generation capacity and electricity generation of the four CASE countries for the "Highly Electrified" (HE) and "Green Gases" (GG) scenarios, respectively. Historically, the CASE countries have either been highly dependent on coal (Indonesia, Philippines, Vietnam) or on natural gas (Thailand) for power generation. To reflect countries' carbon reduction targets, fossil fuel-fired coal, gas and oil power plants are phased out at the latest by a commonly assumed fossil-free target year of 2070 for all countries and scenarios.

To achieve full decarbonization, the remaining natural gas turbines will have to be replaced by hydrogen-ready turbines after 2050. Electricity generation capacity will need to meet growing demand. A power system based on lower capacity factor renewables requires relatively more installed capacity compared to a fossil-based system. However, the extent to which this happens depends partly on the specific technological choices in the demand sectors of each country. Below, the modelling results for the evolution of capacity growth are presented for scenarios where countries rely on a high degree of electrification ("Highly Electrified" scenario) and a high degree of hydrogen use ("Green Gases" scenario).

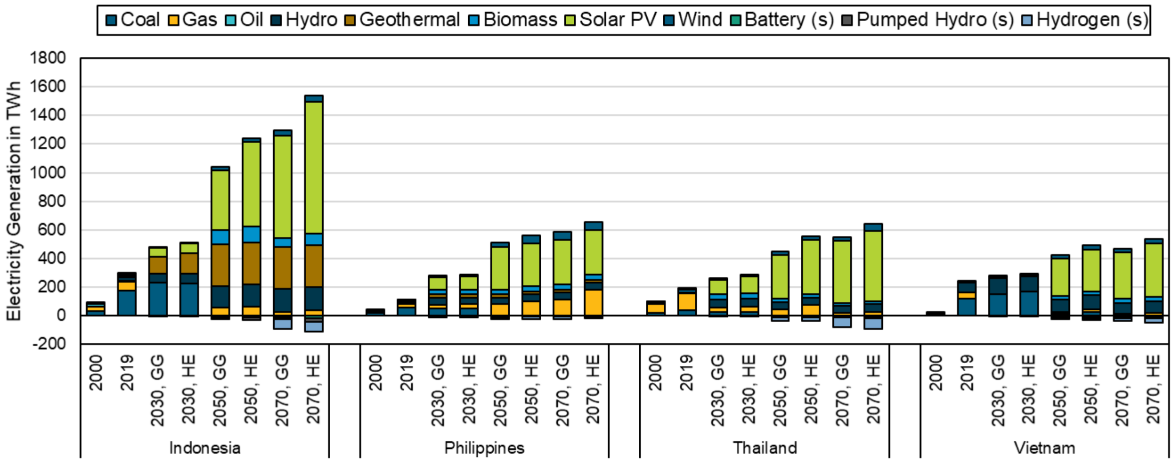
The transition to fossil free power systems requires high expansion rates of solar PV, wind and storage capacities (see Table 5). The rate of solar PV capacity expansion is highest in Indonesia in the "Highly Electrified" scenario, at 24 GW per year between 2030 and 2050, compared to 9 GW per year in the Philippines, 12 GW per year in Thailand, and 13 GW per year in Vietnam for the same period and scenario. The expansion of onshore wind power is limited due to its lower potential compared to the PV generation potential (see section 3.3.1), and ranges between 0 and 2.5 GW per year over all countries and scenarios. Biomass continues to contribute to electricity generation. In Indonesia, biomass capacity rises to 18 GW in 2050 and remains at this level in the energy system thereafter. In the Philippines, Thailand and Vietnam, biomass contributes 4-5 GW from 2030, less than one percent of total installed capacity.

Figure 15: **Evolution of installed power capacity by scenario for the four CASE countries**



Note: (HE: Highly Electrified GG: Green Gases; "s" denotes storage capacities).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 16: Evolution of electricity generation by scenario for the four CASE countries



Note: (HE: Highly Electrified GG: Green Gases); “s” denotes storage capacities and is therefore negative).
Source: Historical data from enerdata (Enerdata 2023b), future projections based on own scenarios

Table 4: Installed solar PV and onshore wind capacity and power generation in 2070 by scenario for the four CASE countries

	Indonesia		Philippines		Thailand		Vietnam	
Scenario	**GG**	**HE**	**GG**	**HE**	**GG**	**HE**	**GG**	**HE**
Solar PV capacity (GW)	682	896	284	292	388	459	293	357
Onshore wind capacity (GW)	31	31	53	53	20	45	16	17
Solar PV generation (TWh)	716	926	307	307	435	494	323	376
Onshore wind generation (TWh)	41	41	59	59	26	49	27	30

Note: (HE: Highly Electrified GG: Green Gases)

In Indonesia, large geothermal and hydropower potentials with high full load hours contribute also in the long term with high shares to the electricity mix (19% and 10% respectively in the HE scenario and 23% and 12% respectively in the GG scenario in 2070).

In the Philippines, there is a high dependency on gas for electricity generation in all scenarios after coal phases-out until 2050. This includes gas turbines fired by natural gas in short and medium term and hydrogen fired gas turbines after 2050 (28% of electricity production in 2070 in the HE scenario and 19% in the GG scenario). However, we have made certain simplifications in our analyses. For example, the potential of offshore wind, rooftop and floating PV has not been considered. In addition, the spatial and temporal resolution of the model is limited. Both may have a significant impact on the results and should be taken into account when analyzing and interpreting the figures.

In Thailand, new fossil gas turbines are still installed until 2050 but fossil gas phases out by 2065 and gas turbines remain in a CO_2 emission free electricity system in 2070, then fired by hydrogen (4 % of electricity production in 2070 in the HE scenario and 3 % in the GG scenario).

Vietnam's current dependence on coal-fired power plants has only been built up in recent years, and the optimisation results suggest that it will remain strong in the next years until 2030, but will decrease by 2050. In addition, hydropower will remain an important part of the electricity system as a cost-effective base-load source (16% of electricity production in 2070 in both scenarios). The recent build-up of large overcapacities in the fossil fleet poses a significant challenge to the transition to a decarbonised energy system. Financial mechanisms for the fossil phase out and efforts for a just transition are therefore crucial. An early expansion of renewables would allow coal to be phased out more quickly.

In Indonesia, electricity demand is growing much faster than the other CASE countries, more than doubling between 2030 and 2050 (110 % in the GG scenario and 140 % in the HE scenario, while only between 40 and 80% for the other countries). The development of large and low-cost geothermal and hydropower potentials will support the integration of volatile renewables into the electricity generation system, as a massive expansion of photovoltaics with high annual growth rates is inevitable. Increased reliance on renewable electricity brings with it the need for electricity storage, i.e., battery, hydrogen, and to a limited extent pumped storage.

Note that electricity demand for electrolysis to cover the hydrogen demand in transport, industry and residential sectors is not included here. In this analysis, electrolysis to produce hydrogen serves only for long-term storage via power-to-hydrogen-to-power. In Southeast Asia, seasonal storage seeks to make up for shortfalls, for example, in solar PV generation during the monsoon seasons. Partially domestic hydrogen production for the demand sectors is considered in a sensitivity analysis below (see section 3.4.2). The large-scale expansion of solar energy requires high storage capacities in times when no renewable electricity is generated. This is particularly true in areas where there are limited renewable energy technologies available to complement the use of solar energy. Interconnections between electricity systems, which would allow electricity to be transferred from regions of surplus generation to regions of high electricity demand, are not considered in this study.

In general, the HE scenario requires far more domestic storage capacity as flexibility option than the GG scenario. This is because the HE scenario relies on more electricity that is produced and stored domestically. Hydrogen, on the other hand, which plays a greater role in the GG scenario, is imported flexibly over time in this analysis. Battery storage capacities are built for short-term storage to shift the midday peak of solar power to the evening hours. The rates of battery storage capacity expansion for each of the four CASE countries are listed in Table 6. The contribution of pumped storage varies according to geographical potential. In addition, large hydrogen storage capacities are used as an option for inter-seasonal flexibility. During periods of high solar irradiation and high wind energy, additional electricity is generated and used to produce hydrogen by electrolysis. The hydrogen is stored and converted back to electricity via a hydrogen turbine during periods of low renewable electricity generation. In the HE scenario, the higher demand for electricity also means that more hydrogen is needed for storage and to cover peak loads. As described above, the hydrogen required is either produced domestically or imported. The proportions of local production and imports differ depending on the country.

Table 5: **Average annual addition rates of solar PV and battery storage capacities (GW) by scenario for the four CASE countries**

		Indonesia		Philippines		Thailand		Vietnam	
Time period within scenario		**Solar PV**	**Battery Storage**	**Solar PV**	**Battery Storage**	**Solar PV**	**Battery Storage**	**Solar PV**	**Battery Storage**
2019-2030	**GG**	2.9	0.1	6.3	1.9	7.1	1.0	0.4	0.0
	HE	3.3	0.0	6.5	2.1	8.2	1.8	0.4	0.0
2030-2050	**GG**	16.0	6.9	8.8	5.7	9.1	4.8	11.2	3.3
	HE	24.4	9.3	8.7	6.5	12.1	6.8	12.8	3.9
2050-2070	**GG**	15.9	10.4	1.9	3.9	6.3	3.0	3.0	4.3
	HE	18.0	11.8	2.2	5.1	6.2	3.3	4.6	5.1

Note: (HE: Highly Electrified GG: Green Gases)
Source: future projections based on own scenarios

3.4 Deep dives

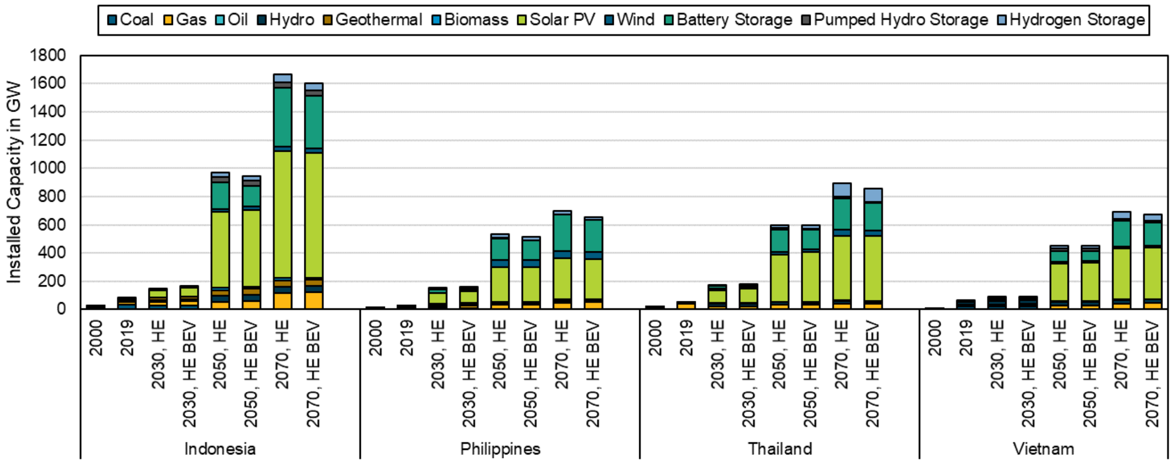
3.4.1 Sensitivity analysis: BEV Charging as example of load shifting

The electrification of the entire energy system means higher electricity demand and could push the limits of a country's renewable energy potential. The energy transition also implies a paradigm shift towards system flexibility. Sector coupling helps to unlock the flexibility potential in demand sectors and can lower peak capacity needs by reducing net-load impacts. To explore how enabling demand flexibility can benefit supply-side generation, we investigate the impact of shifting BEV charging to renewable peak load periods. As a sensitivity to the Highly Electrified scenario (referred to as "HE BEV"), shifting BEV charging to midday hours can help reduce the amount of power plant and storage capacity needed in the system.

The impacts of dynamic BEV charging on power plant capacity and electricity generation is shown in Figure 17 and Figure 18. By 2070, dynamic BEV charging would reduce the required capacity for short-term battery storage by 10-13% across the CASE countries. Depending on the countries' electricity mix and storage requirements, long-term hydrogen storage capacity would also be reduced by 4% in Thailand to 10% in the Philippines. Renewable energy capacity expansion also decreases slightly requiring 2-3% less solar PV capacity in Indonesia and the Philippines, and 7-8% less wind capacity in Thailand and Vietnam. Other renewable capacities are left mainly unaffected.

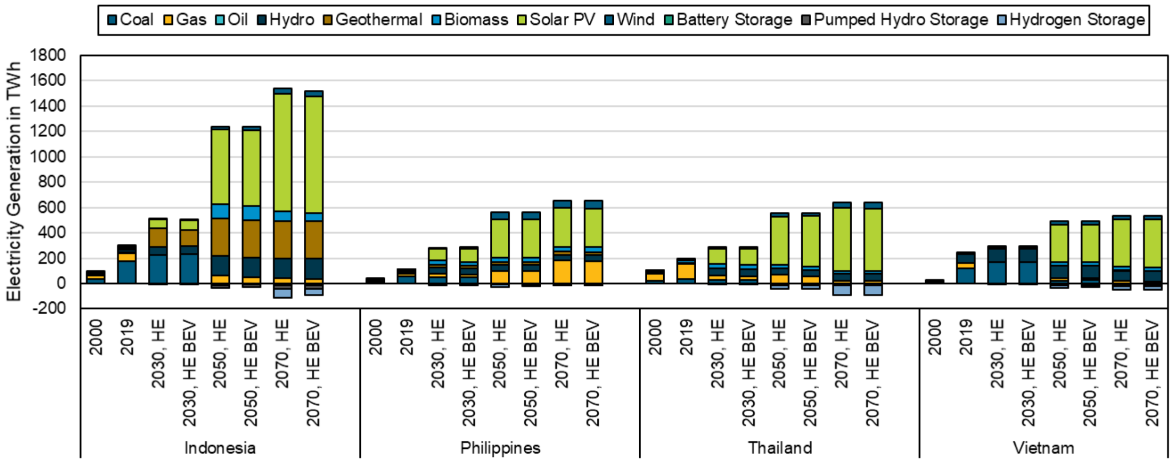
Dynamic BEV charging supports the power system because shifting demand, rather than supply reduces storage capacity requirements. Unlocking load shifting potential in the building and industry sectors can amplify this benefit. The scale of the benefit depends on the trade offs between the higher costs of adjusting demand and is difficult to quantify. Similarly, quantifying the impacts of demand flexibility in the residential sector is difficult as electrical appliances have different load characteristics. Nevertheless, electricity demand the residential sector is higher than BEVs, with the largest shares in space cooling. In general, the impact of flexibility options also depends strongly on the generation profile. In wind-dominated or interconnected systems that enable affordable power imports, the supply curve over time is flatter. In PV-dominated systems, such as those in the ASEAN focus countries, there is a pronounced mid-day peak in the supply curve, which usually leads to a greater potential for load shifting and thus a reduction in the required generation, grid and storage capacity.

Figure 17: **Evolution of installed capacity for the four CASE countries in the "Highly Electrified" scenario with BEV charging load variation**



Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 18: **Evolution of electricity generation for the four CASE countries in the "Highly Electrified" scenario with BEV charging load variation for the four CASE countries**



Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from enerdata (IEA 2023), future projections based on own scenarios

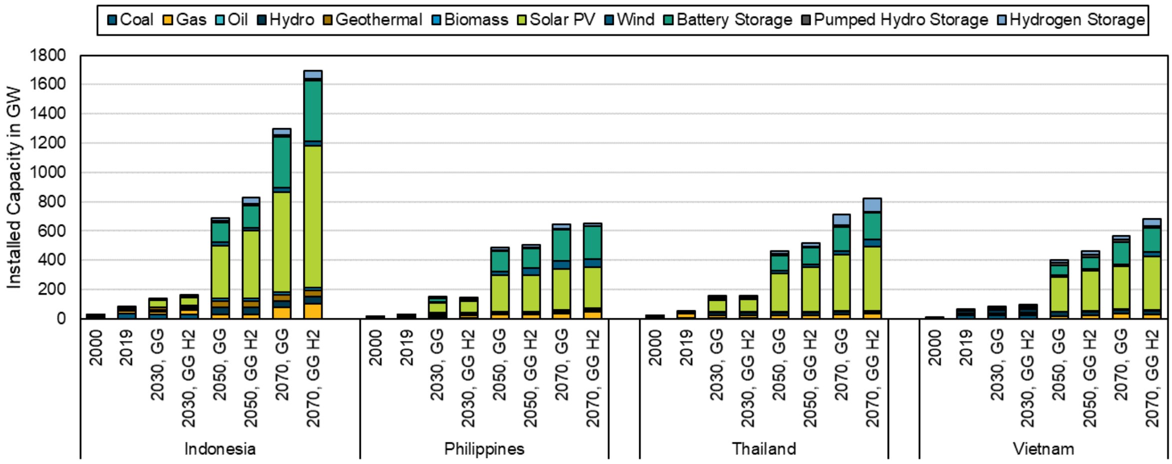
3.4.2 Sensitivity analysis: Domestic H2 Production

In the two base scenarios, we assume all hydrogen for the transport, industry and residential sectors are imported, for example from Australia, which has large areas and good renewable potential for hydrogen production. In the following, we examine partial domestic hydrogen production for the demand sectors (33% of final energy demand) as a sensitivity to the "Green Gases" scenario, with a load curve following the PV availability. This case shown in Figure 19 and Figure 20 (denoted as "GG H2") therefore assumes one third of the national hydrogen demand to be produced domestically and two thirds continued to be imported. This sensitivity analyses the effect, in 2070, of increased power capacity installation and electricity generation for hydrogen production.

In Indonesia, domestically supplying one-third of sectoral hydrogen demand would require a 42% increase in solar PV installations (292 GW), a 19% increase in battery storage capacity, and a 25% increase in hydrogen storage capacity for seasonal storage. In Philippines, this scenario does not lead to a reasonable solution, as within the assumed land use factors for electricity generation, no further domestic renewable potentials can be harnessed for additional hydrogen electrolysis. In Thailand, the additional domestic hydrogen production would require 155% more wind, as solar PV increase reaches the limits of the considered PV potentials within this scenario. In addition, existing biomass plants are operated at higher FLH increasing the overall use of biomass. Storage is relatively little affected, as domestic electrolysis can be well supplied by the additional biomass baseload and wind capacities. In Vietnam, like in Thailand, domestic hydrogen is supplied by additional solar PV capacities, and additional onshore wind power, albeit at low FLH. Battery storage capacity would increase by only 10%, but seasonal hydrogen storage capacity would increase by 82%.

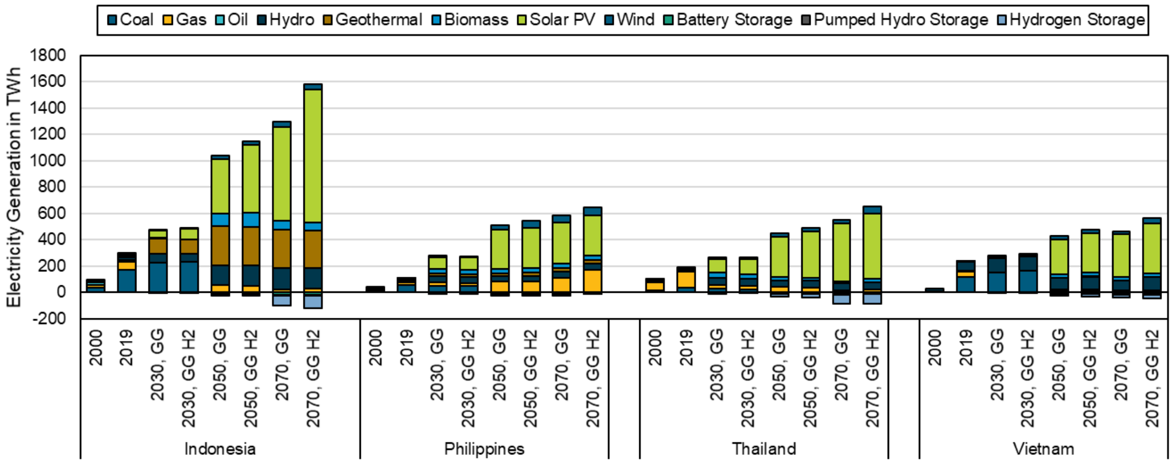
In summary, Indonesia's partially domestic hydrogen production would increase its installed solar PV capacity. Thailand and Vietnam, on the other hand, would push the exploitation of their solar and wind potentials to the assumed limits, while the model finds no solution for the Philippines. However, we have not considered the potential of offshore wind, rooftop and floating PV in this analysis. This would of course increase the available potential and could therefore change the results to some degree. The extent to which storage capacities expansion would be required depends on the countries' demand load compared to the electricity supply curve by the generation mix. Pushing towards higher price segments of the renewable energy potential curve means higher generation costs for theses capacities, which would likely lead to higher prices for electricity. Resulting prices for domestically produced hydrogen then need to be contrasted with uncertain, but potentially lower, prices of imported hydrogen.

Figure 19: Evolution of installed capacity for the four CASE countries in the "Green Gases" scenario with and without partial domestic hydrogen production



Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 20: **Evolution of electricity generation for the four CASE countries in the "Green Gases" scenario with and without partial domestic hydrogen production**



Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from enerdata (IEA 2023), future projections based on own scenarios)

3.4.3 Comparison of hydrogen and natural gas imports

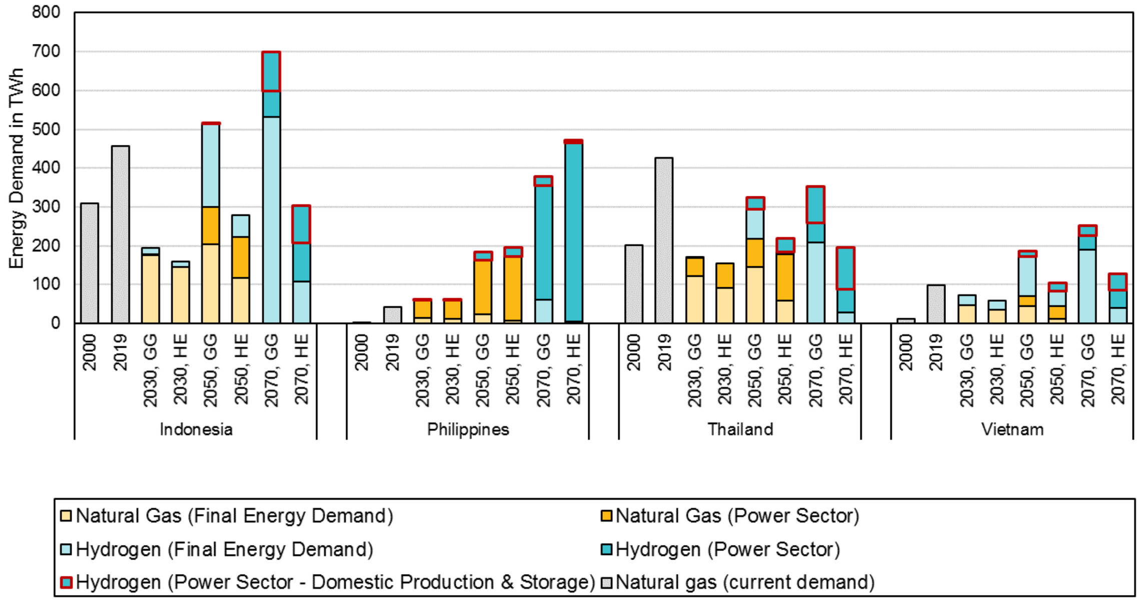
Renewable energies increase energy sovereignty and reduce import dependency. As discussed in the previous deep dive section, the supply with hydrogen is challenging to meet by domestic supply. Figure 21 shows future hydrogen demand as a final energy carrier and in the power sector, the latter split into demand for long-term electricity storage and direct use, and compares this to current and projected natural gas demand. In this study, we assume that hydrogen is imported except for long-term electricity storage.

Natural gas use declines in both scenarios, while the use of hydrogen increases, and is of course more pronounced in the "Green Gases" Scenario. In the scenarios, all countries require a certain amount of imported hydrogen for use in the power sector on top of what is imported to supply demand sectors. Until 2050, the use of hydrogen plays only a small role in the power sector, while it is used as a storage medium in 2070 in all countries and scenarios. Note that natural gas is not replaced by hydrogen in all its applications, but is rather shown here only for comparison purposes.

As results from the scenarios show, the future demand for hydrogen may well exceed the current use of natural gas. Natural gas is currently completely domestically produced, except for Thailand. In contrast, however, hydrogen is imported in the scenarios, except for the small amount produced for long-term electricity storage. By exploiting further renewable resources, the domestic supply with hydrogen could potentially be increased. If this is accomplished, the demand in the power sector could have a chance of being met by local resources, except for the Philippines. However, this is unlikely for the demand sector, particularly for the "Green Gases" scenario, which makes extended use of hydrogen as a final energy carrier. In all cases, the imported amount of hydrogen in the "Green Gases" scenario is a multiple of the amount in the "Highly Electrified" scenario. This underlines the substantial need for imports and the new import dependency arising from an extensive use of hydrogen in the demand sectors.

While energy sovereignty may increase in the future as the demand for oil (and coal) imports declines, it will not be complete. A demand for imported hydrogen remains. The higher demand for imports of hydrogen in the "Green Gases" scenario can be reduced if renewable energy potentials are exploited more heavily and electrification is prioritised, as under the "Highly Electirifed" scenario.

Figure 21: Natural gas and hydrogen demand for the four CASE countries



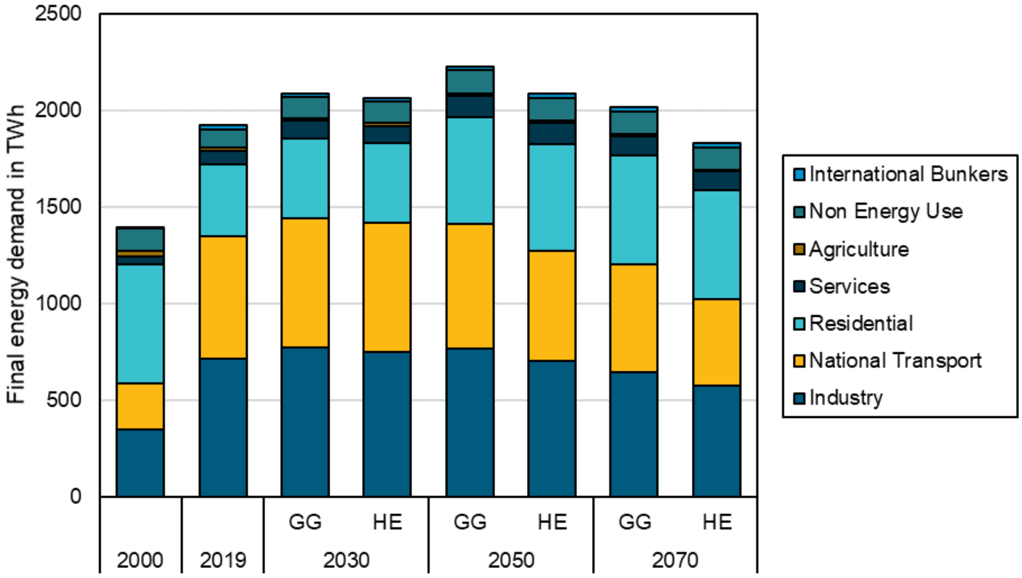
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

4 Extended Annex (country-specific figures)

4.1 Indonesia

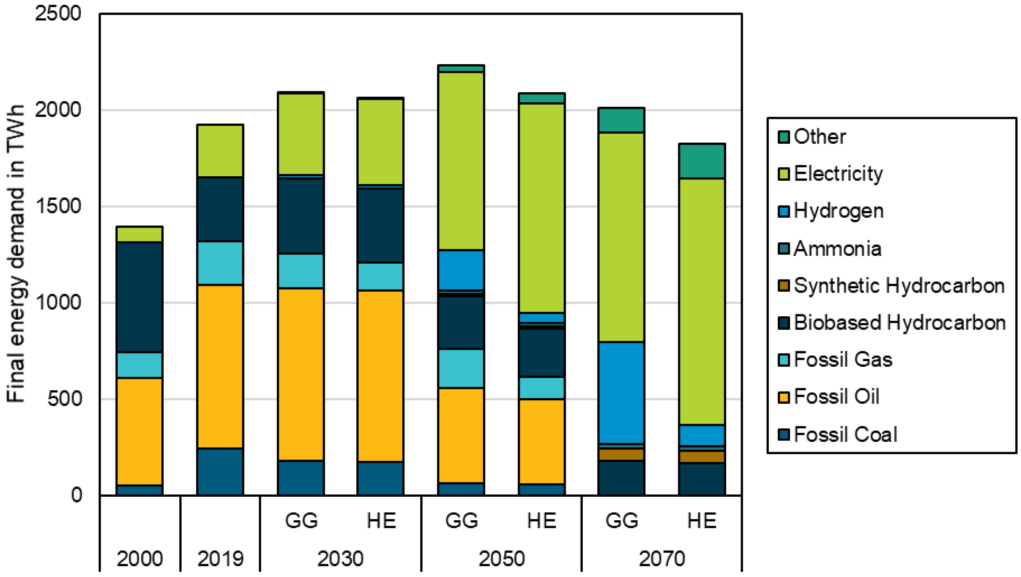
Demand side

Figure 22: Evolution of Indonesia's final energy demand by sector and scenario



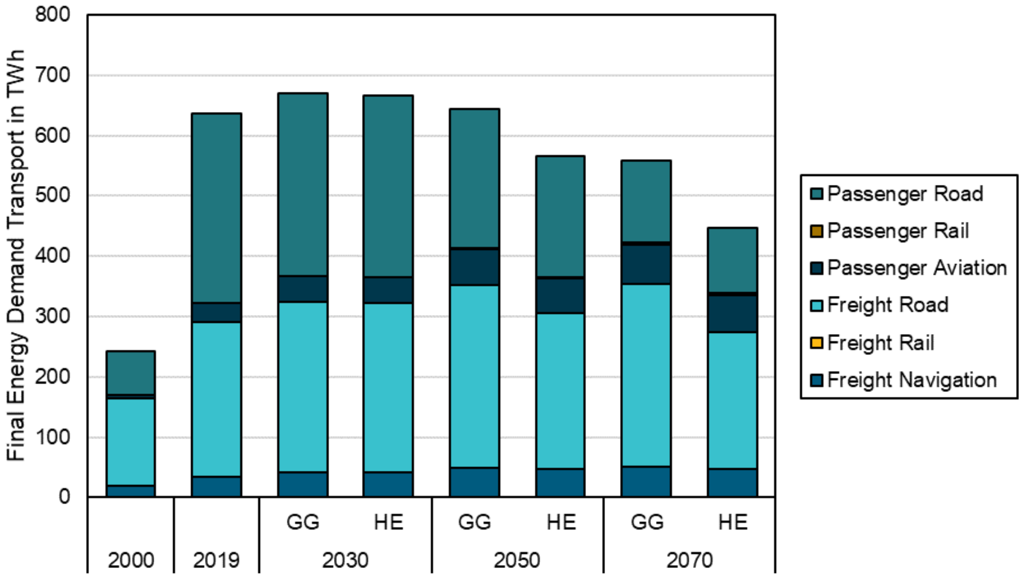
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 23: Evolution of Indonesia's final energy demand by fuel and scenario



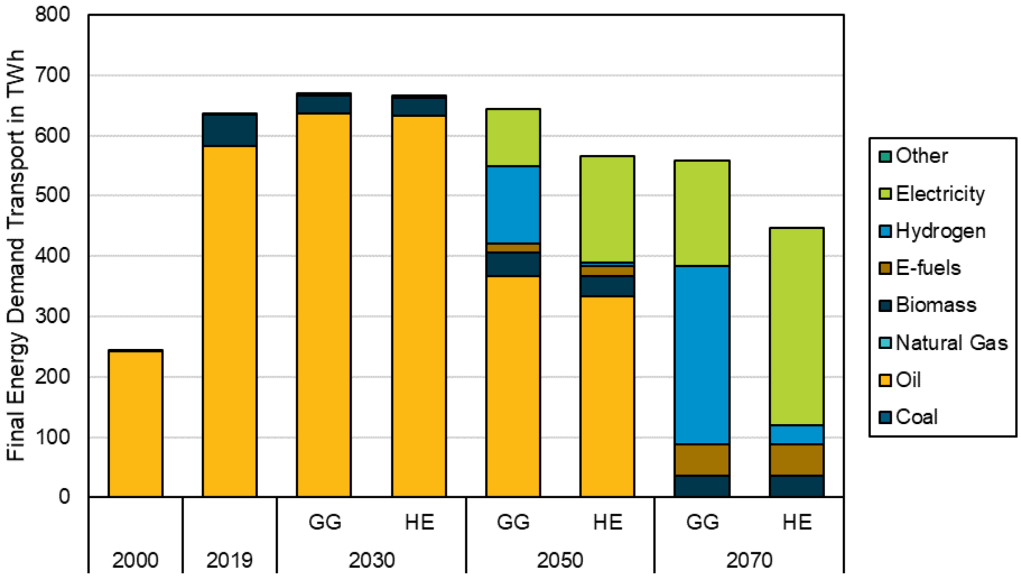
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 24: **Evolution of Inodnesia's final energy demand in national transport by sub-sector and scenario**



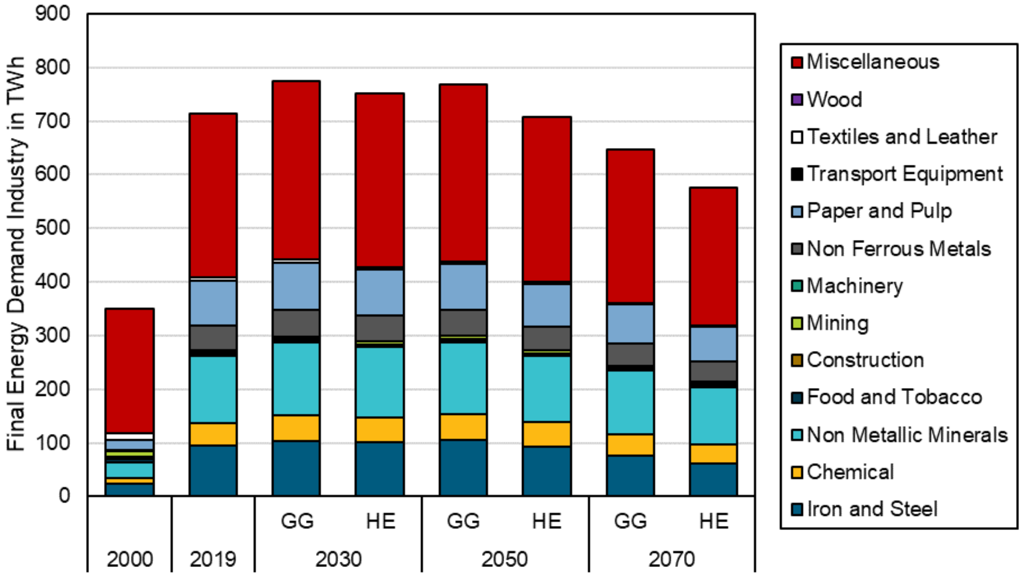
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 25: **Evolution of Indonesia's final energy demand in national transport by fuel and scenario**



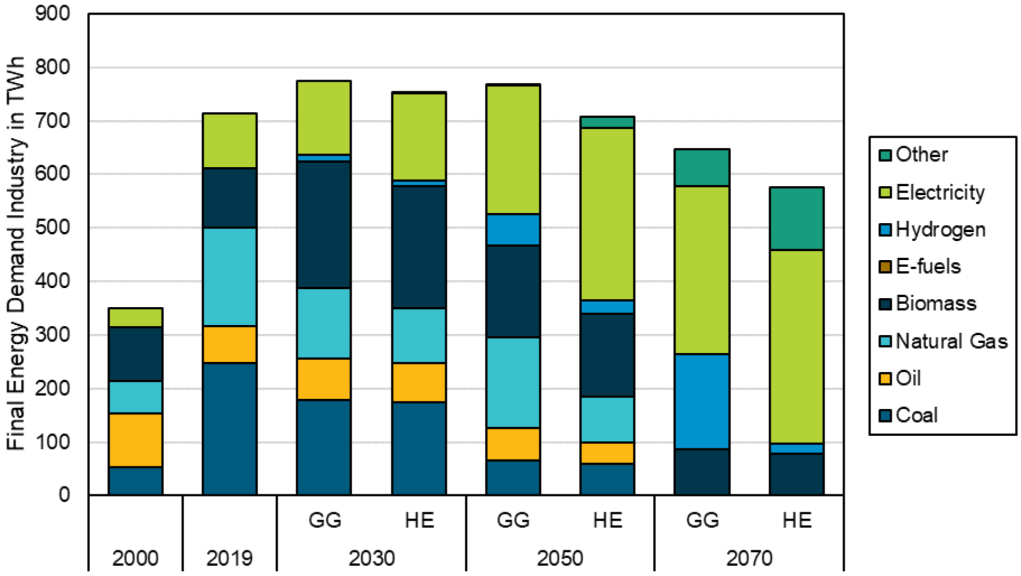
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 26: Evolution of Indonesia's final energy demand in industry by subsector and scenario



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

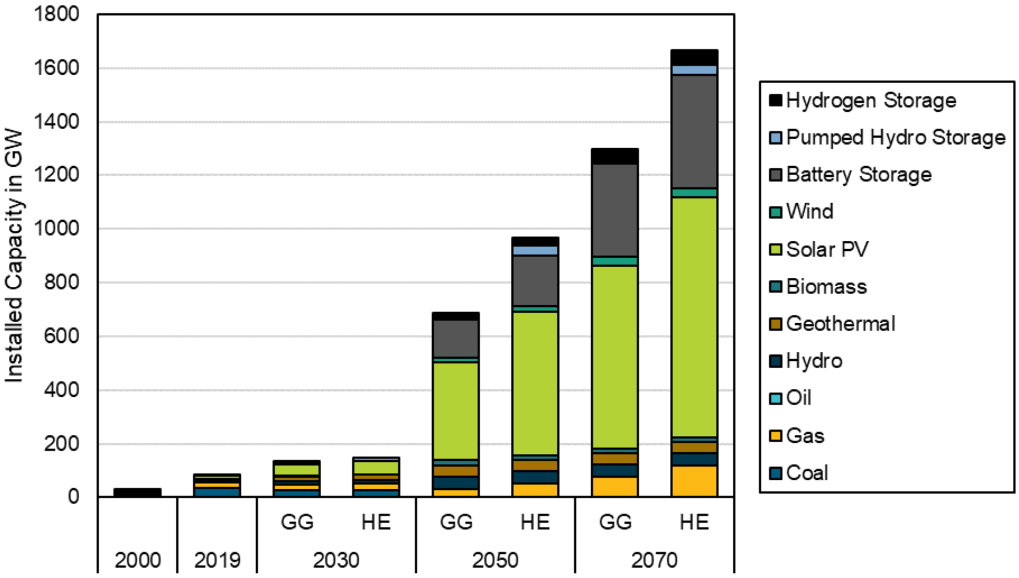
Figure 27: Evolution of Indonesia's final energy demand in industry by fuel and scenario



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

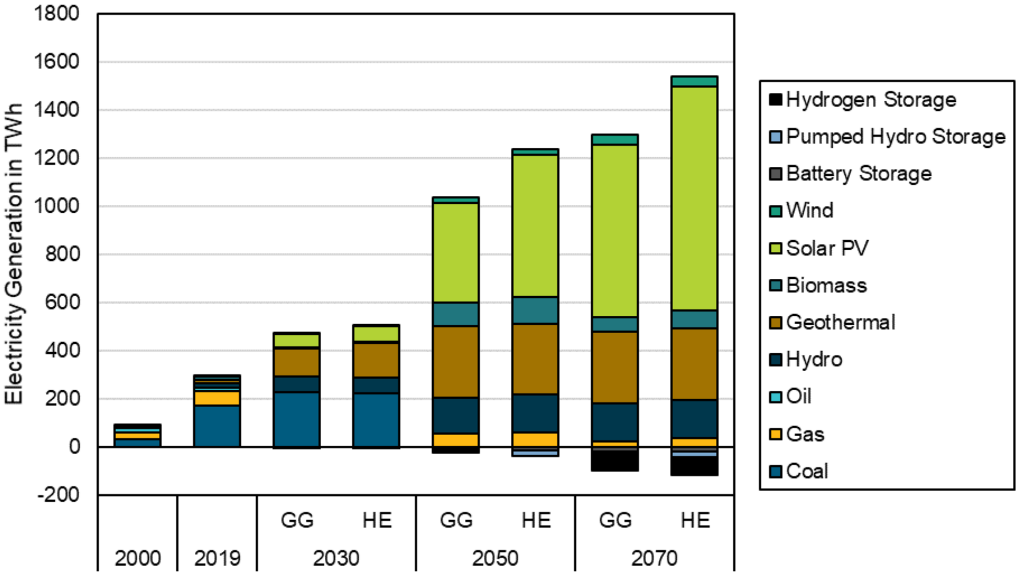
Supply side

Figure 28: Evolution of Indonesia’s installed capacity by scenario



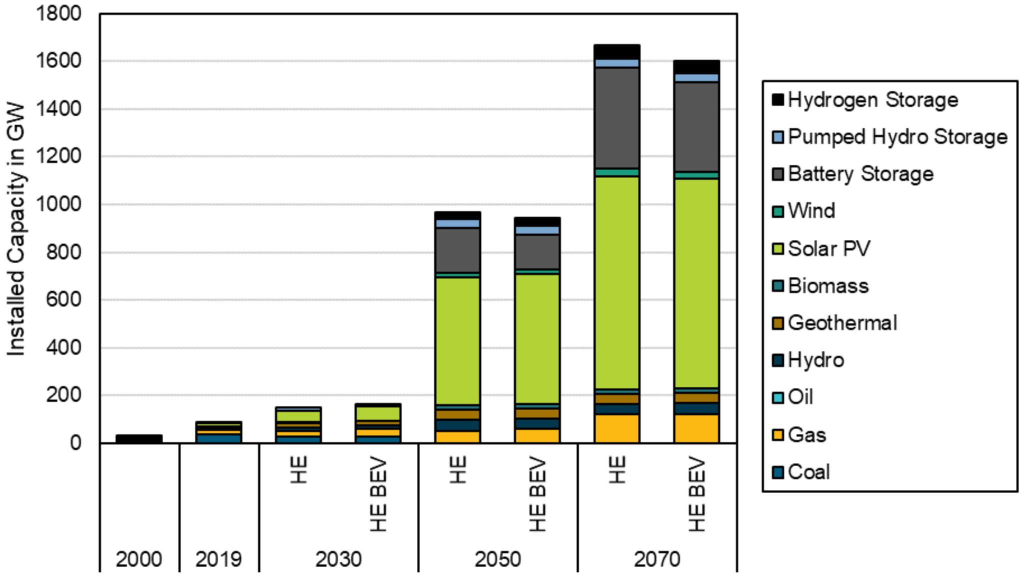
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 29: Evolution of Indonesia’s electricity generation by scenario



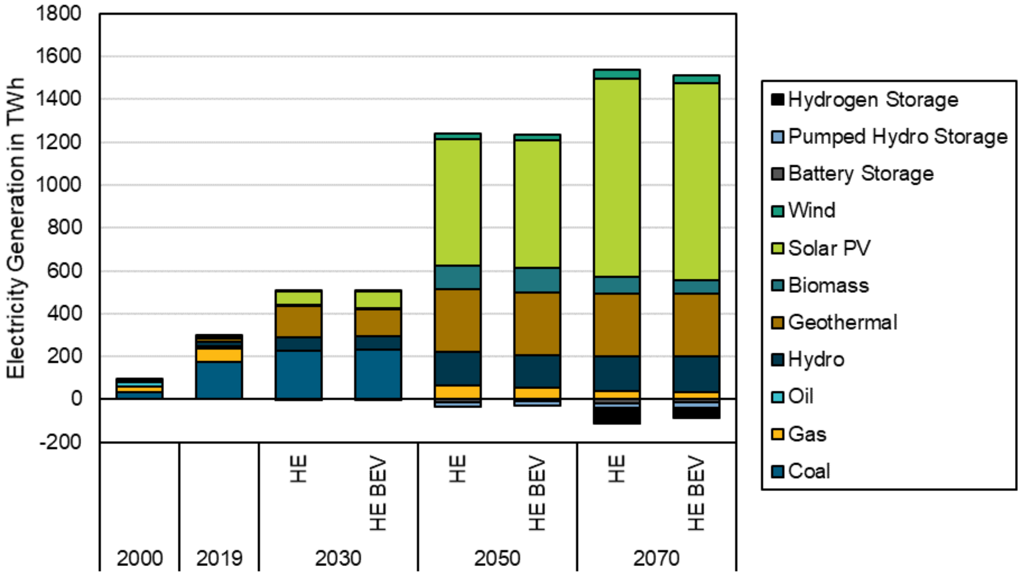
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

Figure 30: Impact of shifted demand for BEV charging on the evolution of Indonesia's installed capacity



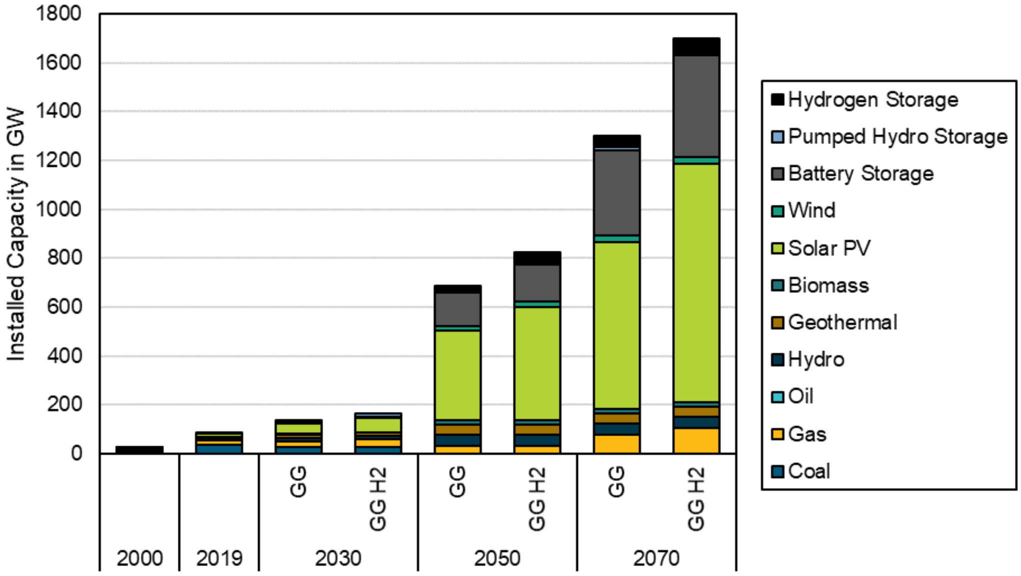
Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 31: Impact of shifted demand for BEV charging on the evolution of Indonesia's electricity generation



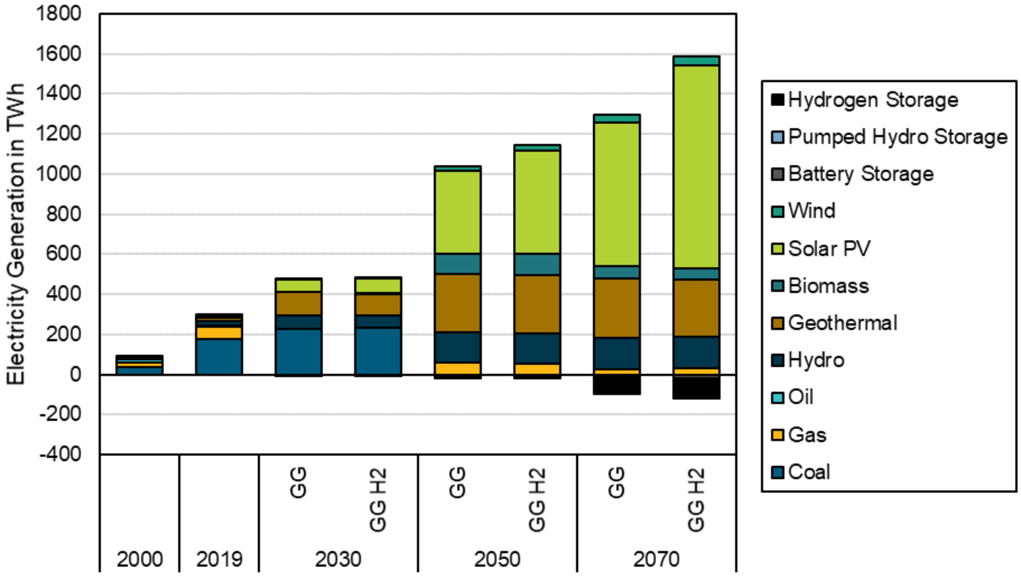
Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

Figure 32: **Impact of domestic green hydrogen production on the evolution of Indonesia's installed capacity**



Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 33: **Impact of domestic green hydrogen production on the evolution of Indonesia's electricity generation**

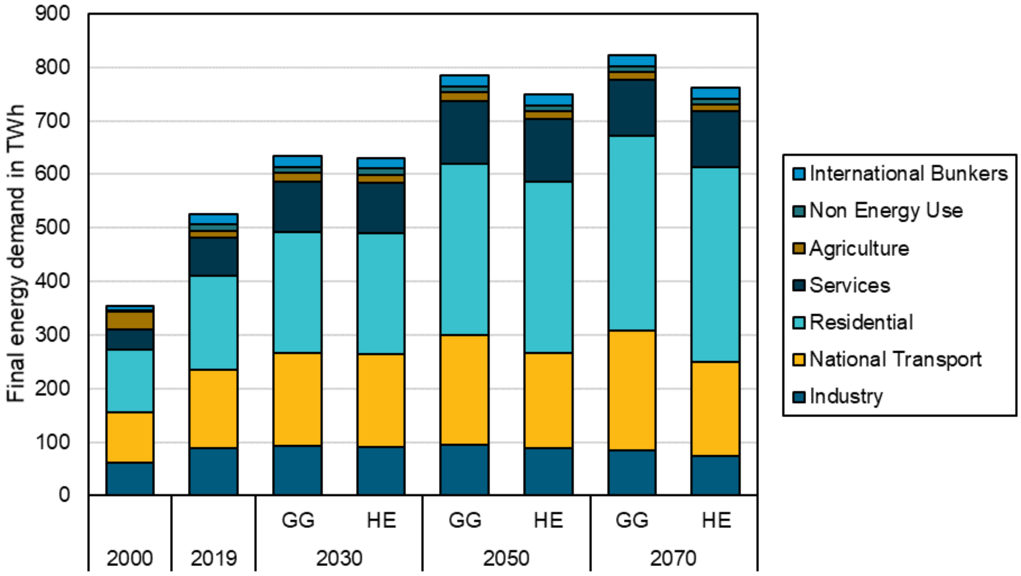


Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

4.2 Philippines

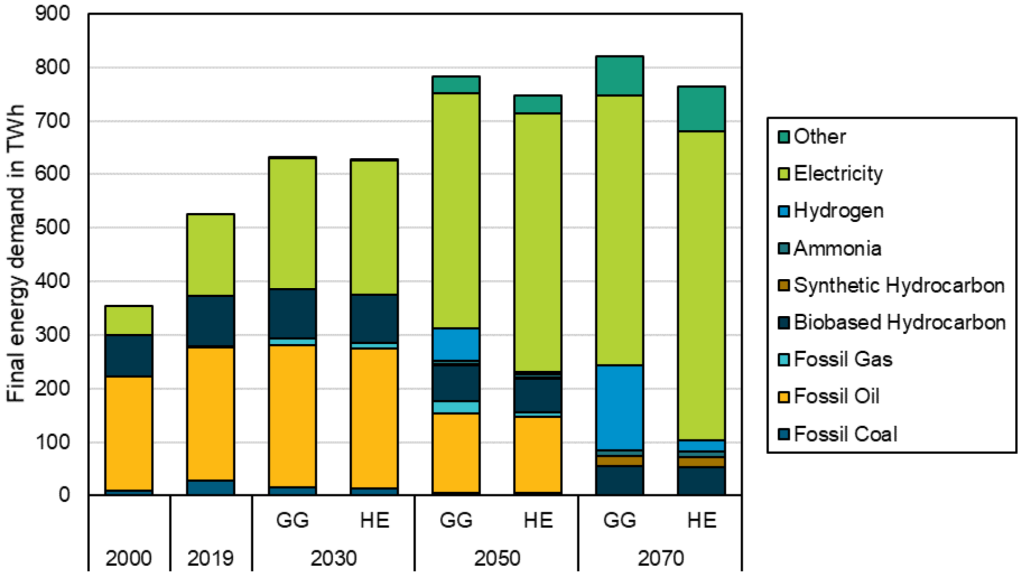
Demand side

Figure 34: Evolution of the Philippines' final energy demand by sector and scenario



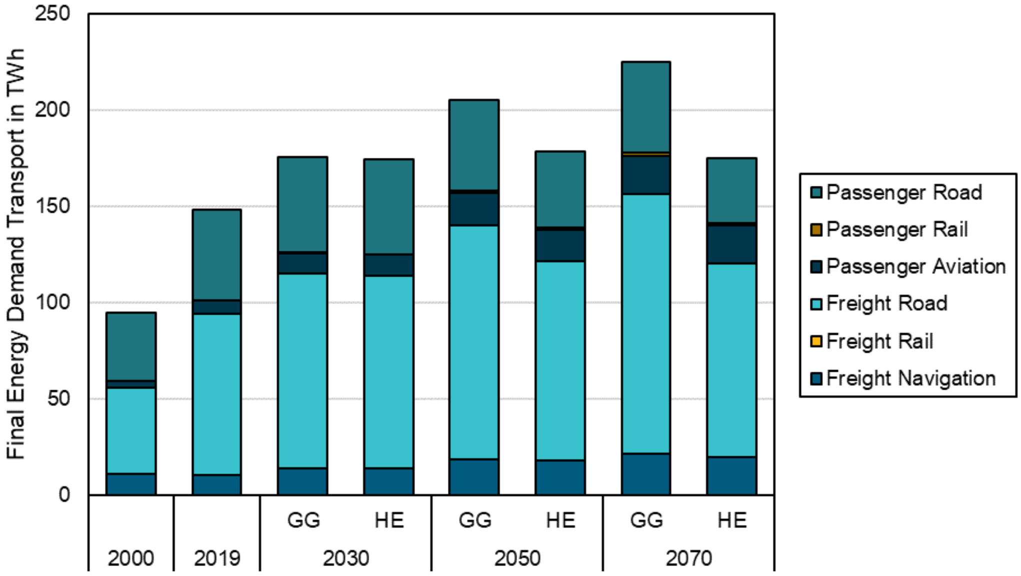
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 35: Evolution of the Philippines' final energy demand by fuel and scenario



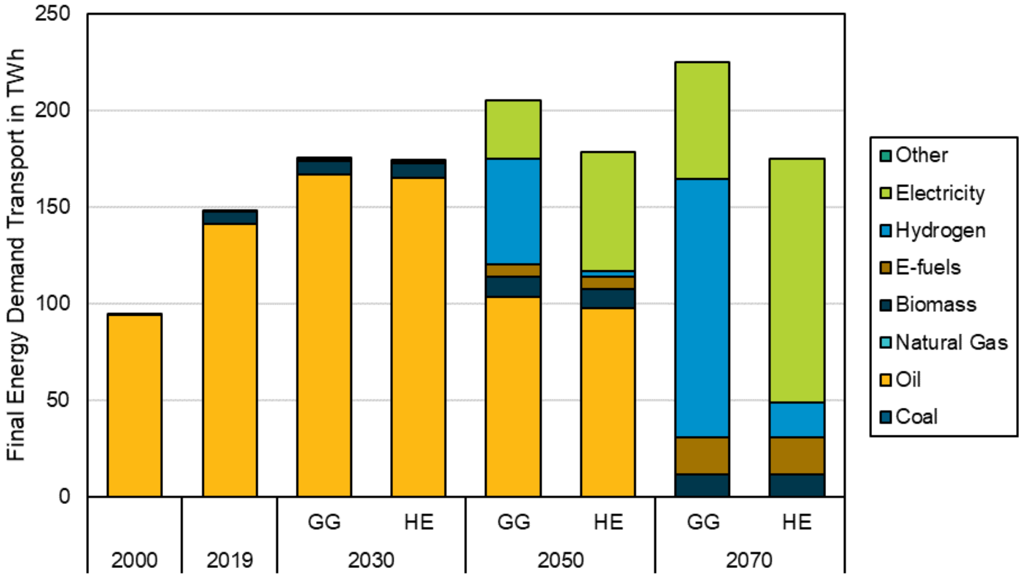
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 36: **Evolution of the Philippines' final energy demand in national transport by subsector and scenario**



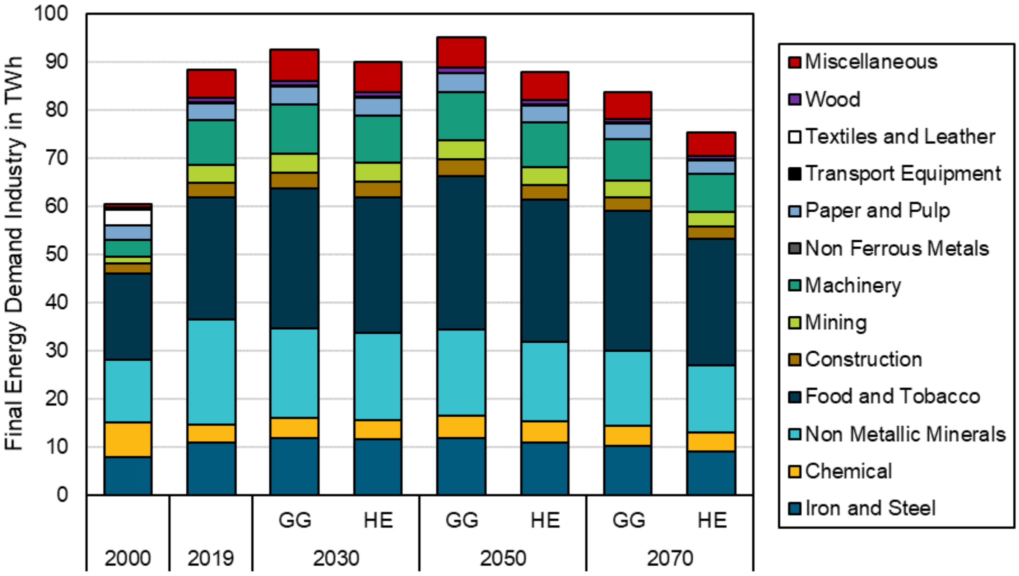
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 37: **Evolution of the Philippines' final energy demand in national transport by fuel and scenario**



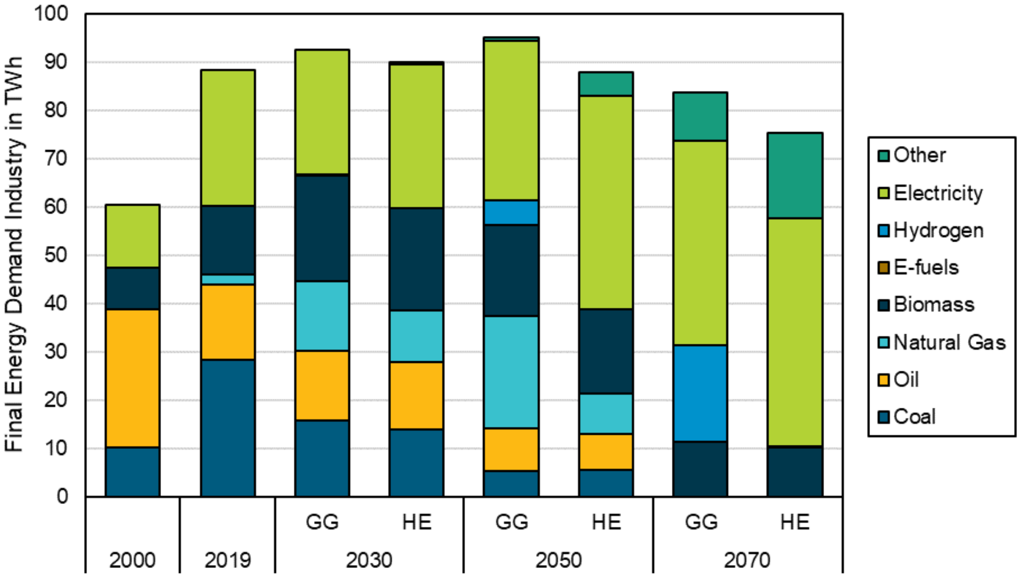
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 38: **Evolution of the Philippines' final energy demand in industry by subsector and scenario**



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

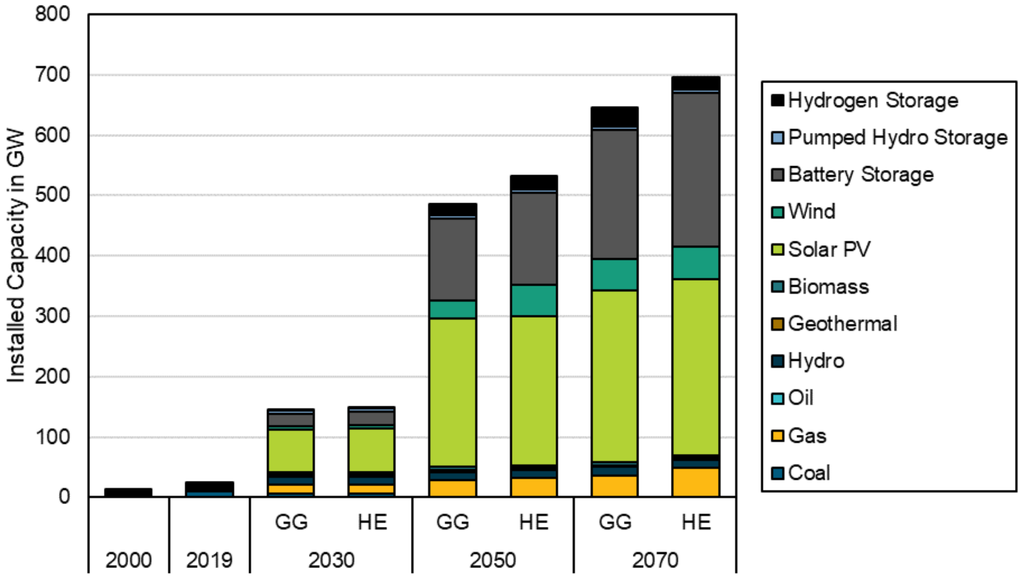
Figure 39: **Evolution of the Philippines' final energy demand in industry by fuel and scenario**



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

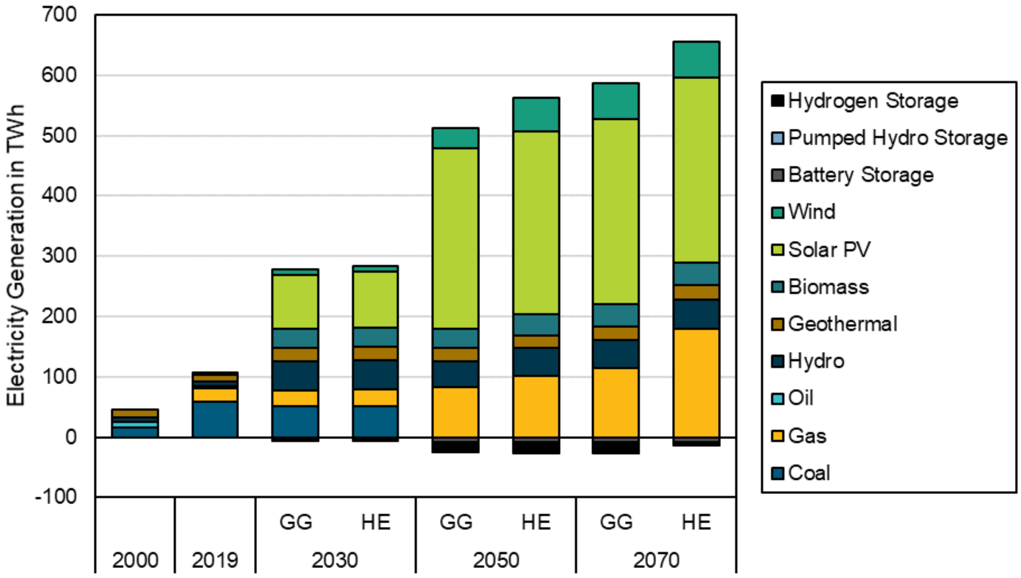
Supply side

Figure 40: Evolution of the Philippines' installed capacity by scenario



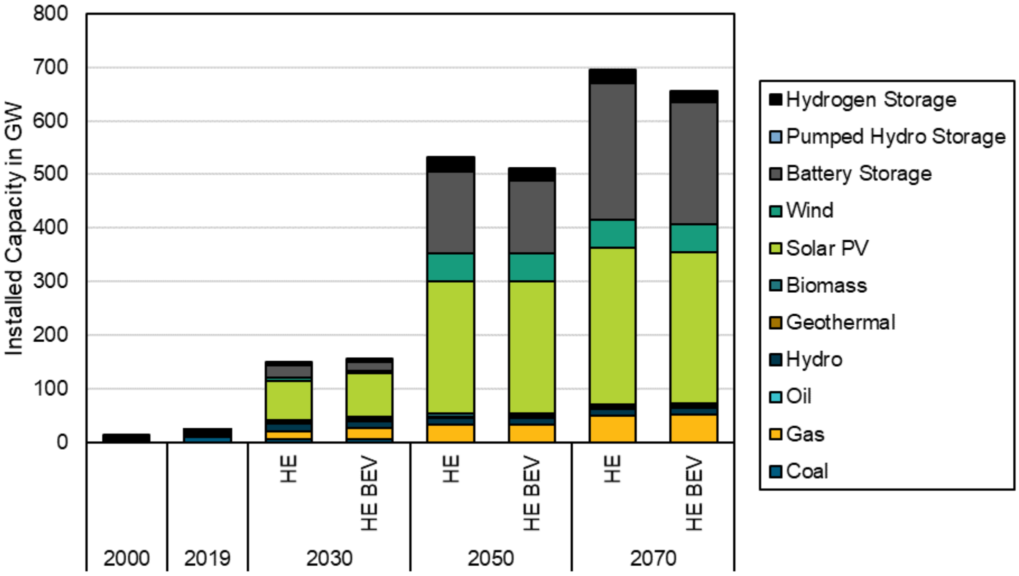
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 41: Evolution of the Philippines' electricity generation by scenario



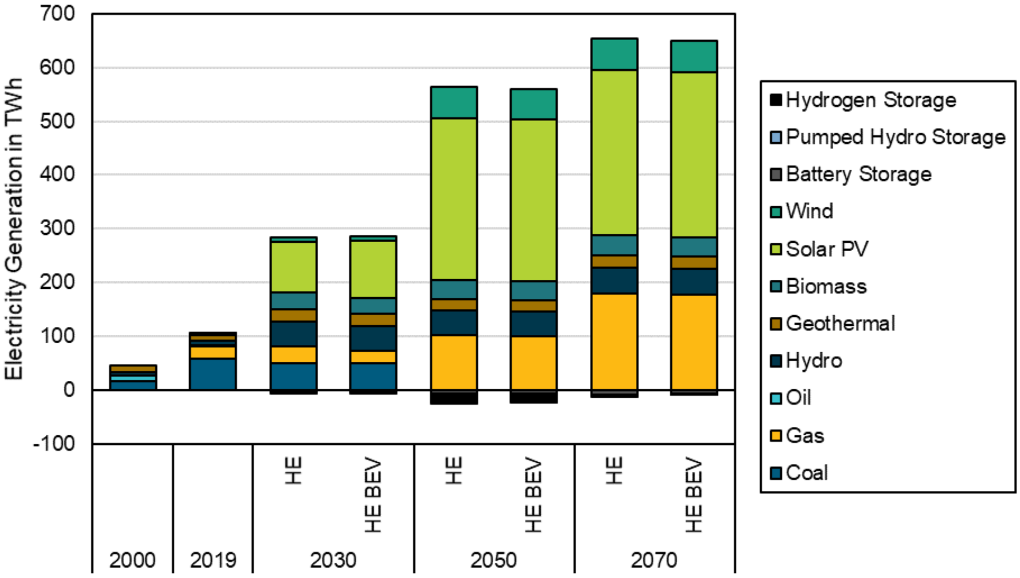
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

Figure 42: **Impact of shifted demand for BEV charging on the evolution of the Philippines' installed capacity**



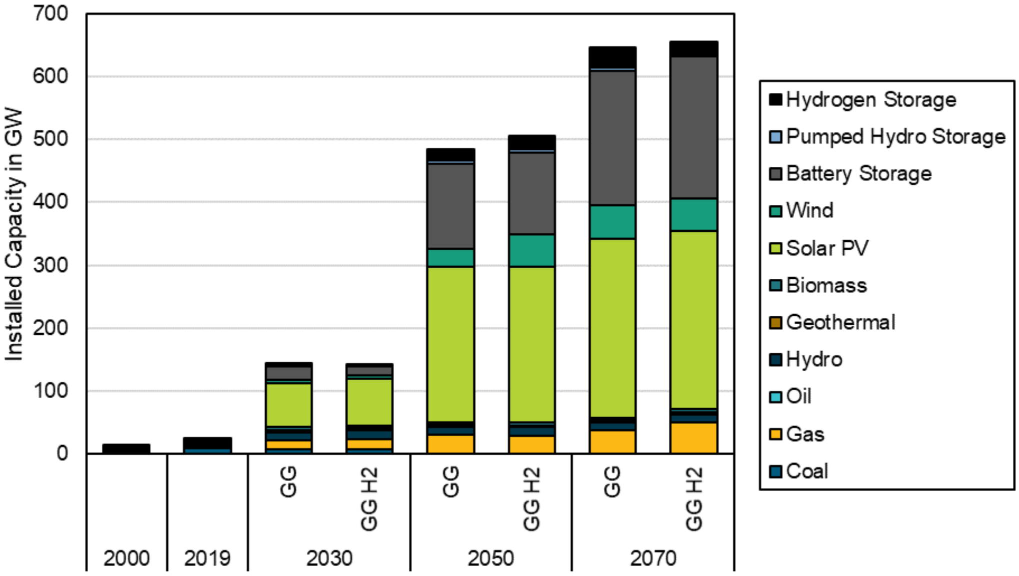
Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 43: **Impact of shifted demand for BEV charging on the evolution of the Philippines' electricity generation**



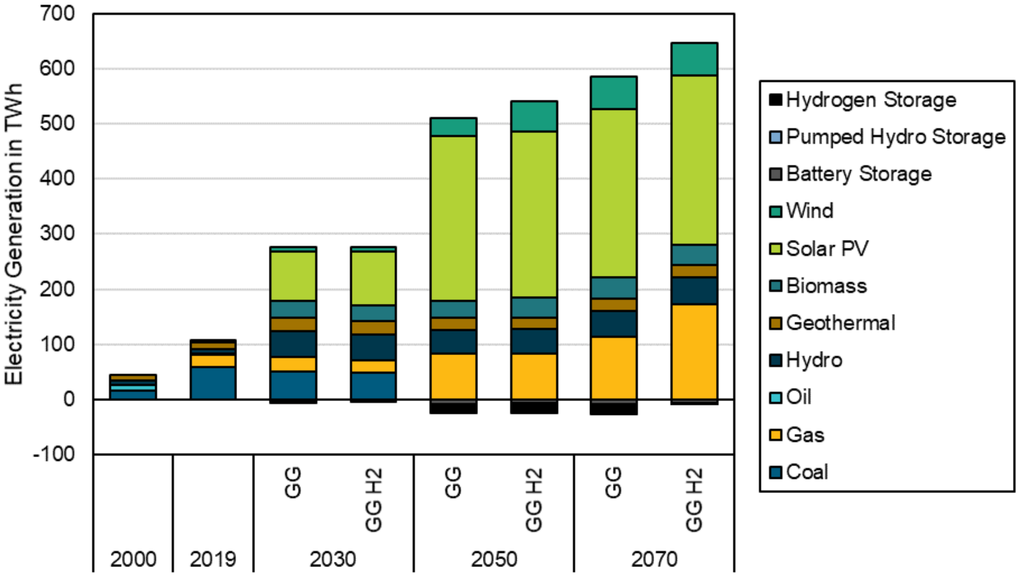
Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

Figure 44: **Impact of domestic green hydrogen production on the evolution of the Philippines' installed capacity**



Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 45: **Impact of domestic green hydrogen production on the evolution of the Philippines' electricity generation**

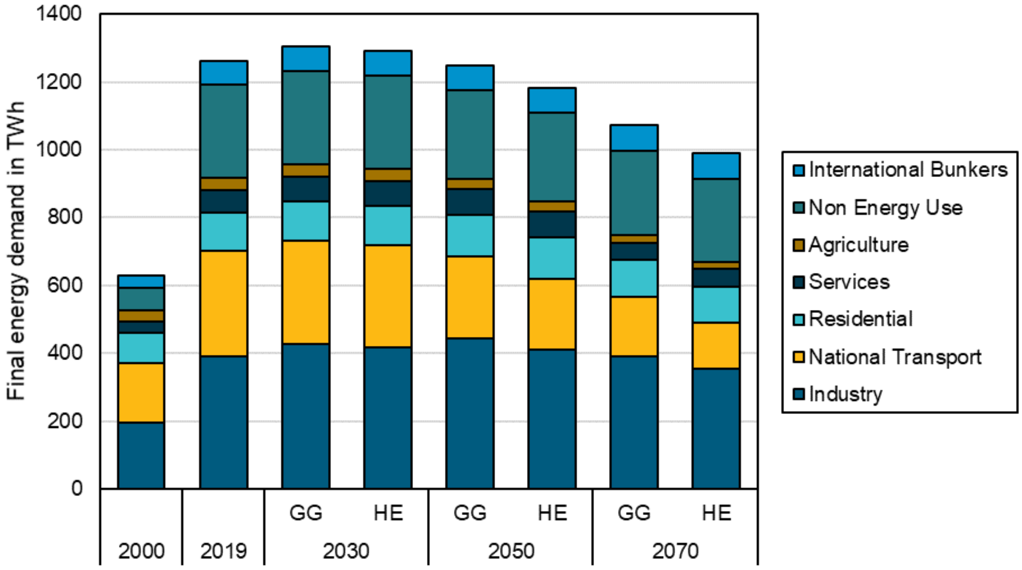


Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

4.3 Thailand

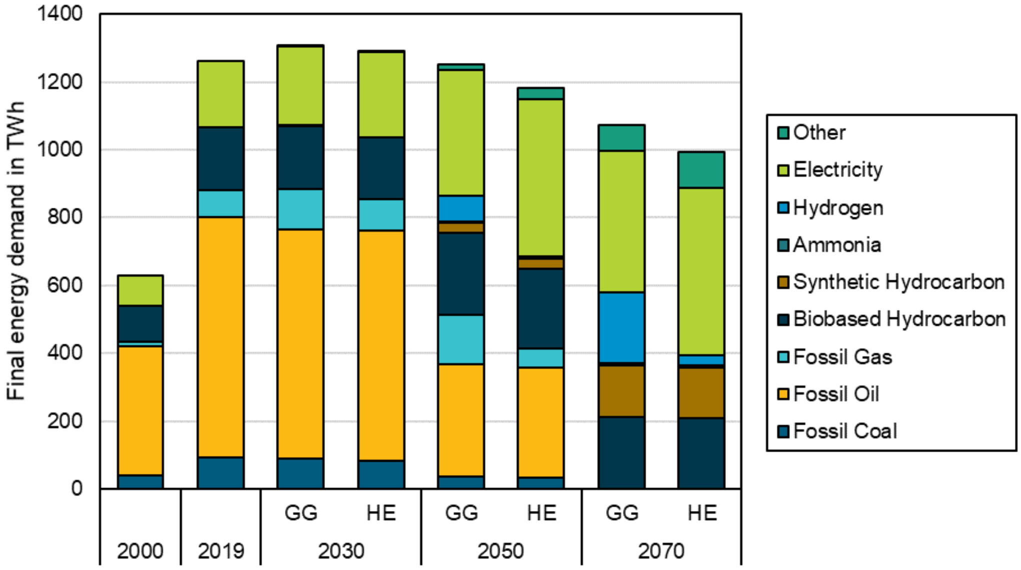
Demand side

Figure 46: Evolution of Thailand's final energy demand by sector and scenario



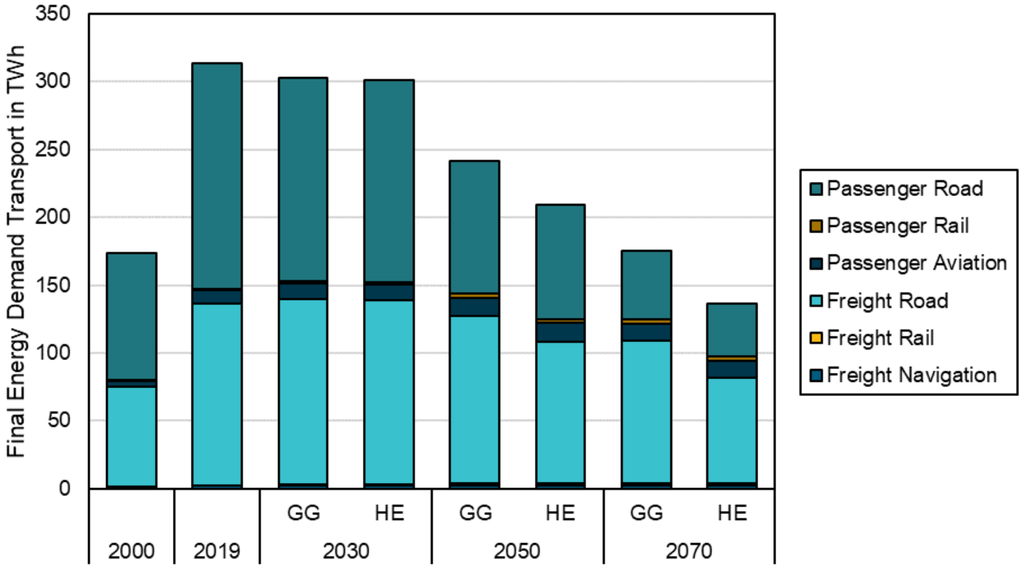
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 47: Evolution of Thailand's final energy demand by fuel and scenario



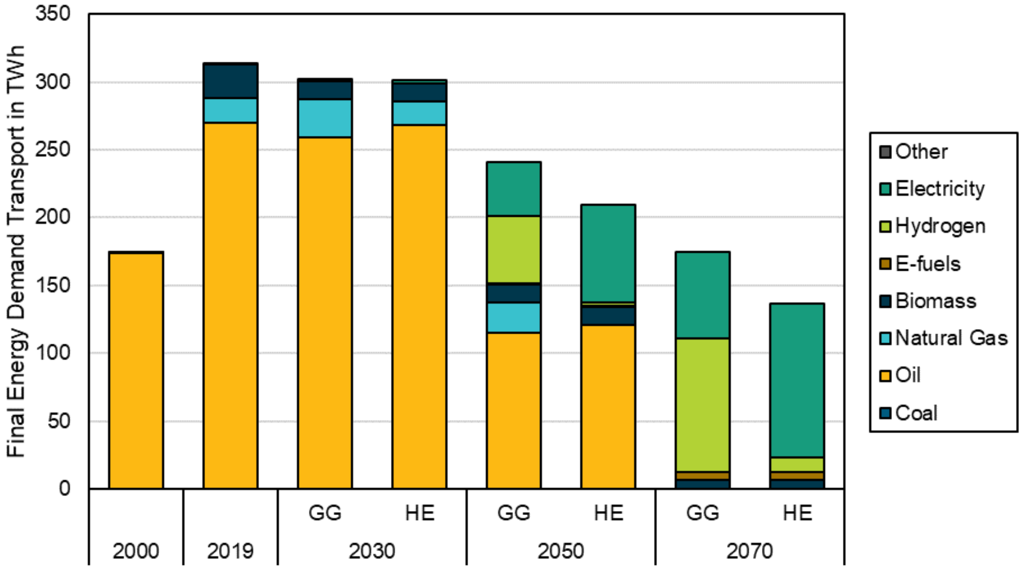
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 48: Evolution of Thailand’s final energy demand in national transport by sub-sector and scenario



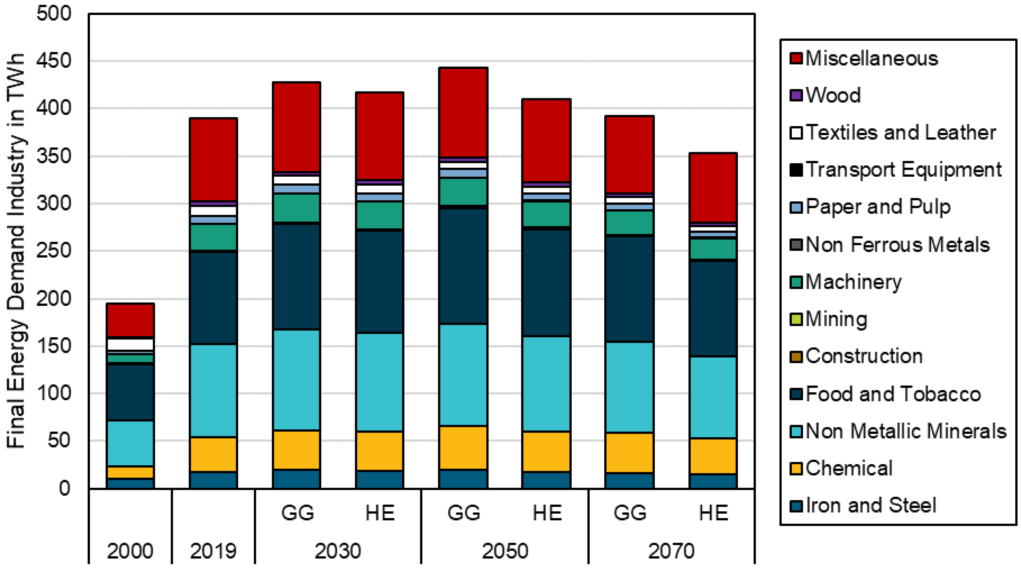
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 49: Evolution of Thailand’s final energy demand in national transport by fuel and scenario



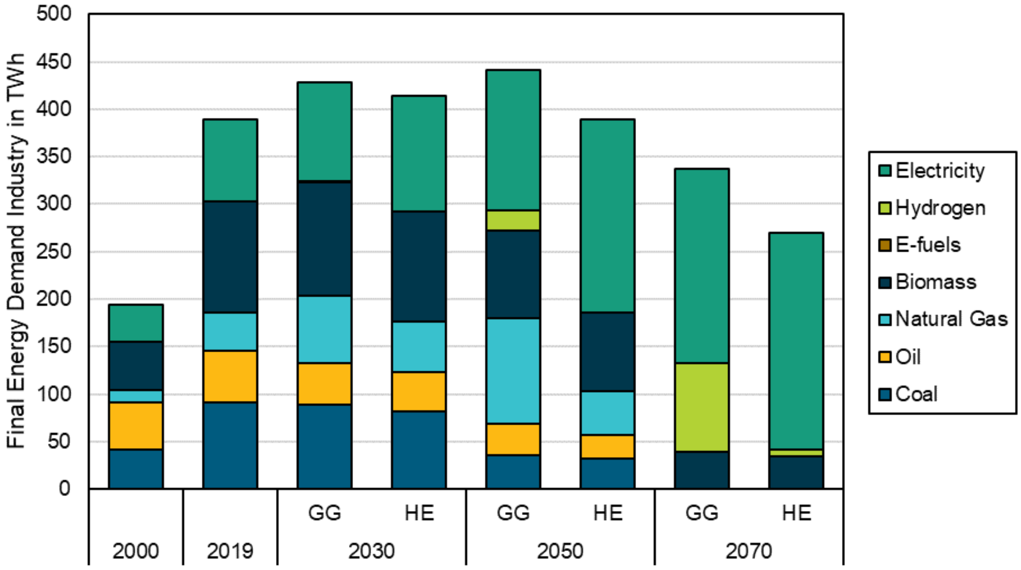
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 50: **Evolution of Thailand's final energy demand in industry by subsector and scenario**



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

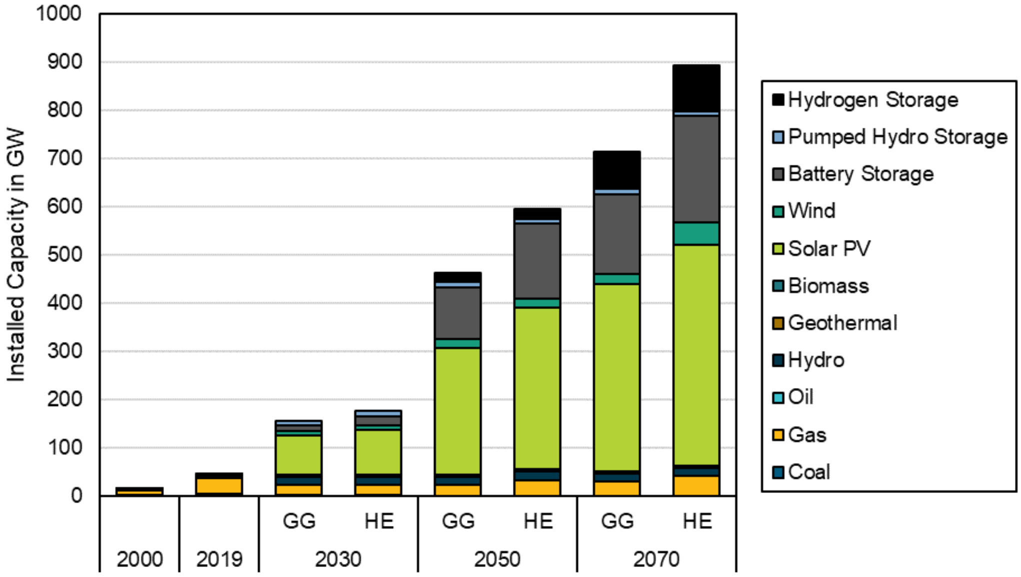
Figure 51: **Evolution of Thailand's final energy demand in industry by fuel and scenario**



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

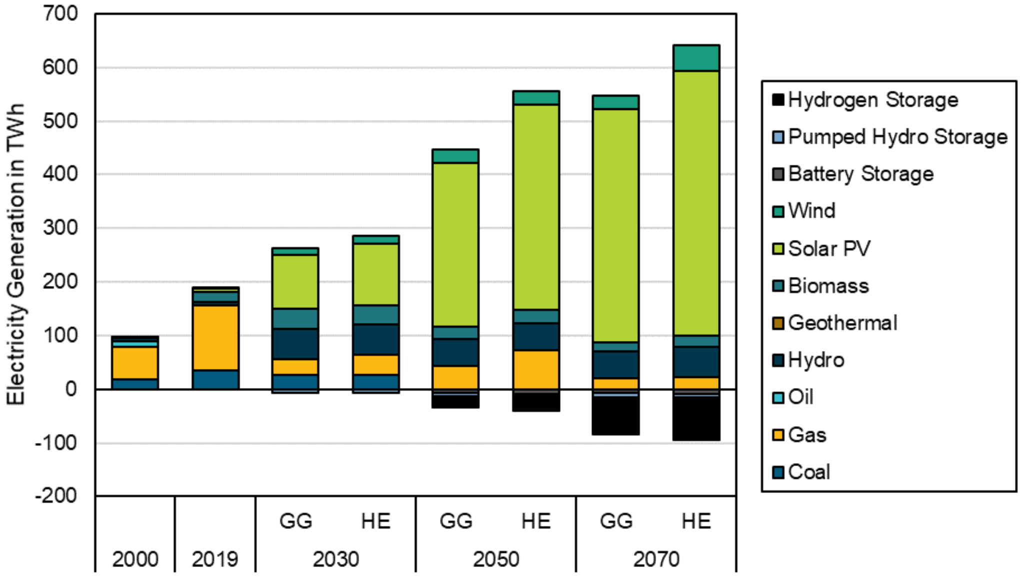
Supply side

Figure 52: Evolution of Thailand's installed capacity by scenario



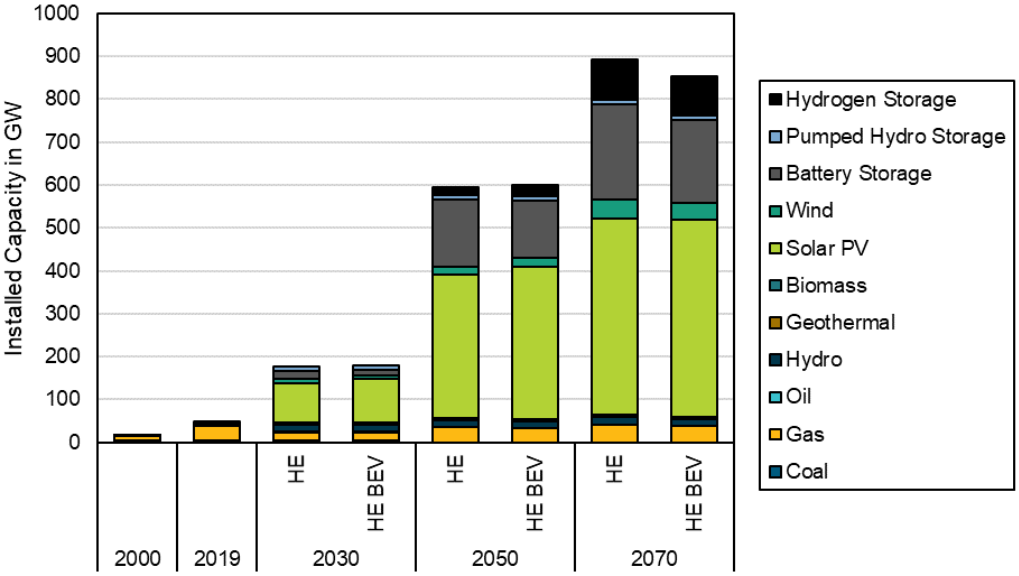
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 53: Evolution of Thailand's electricity generation by scenario



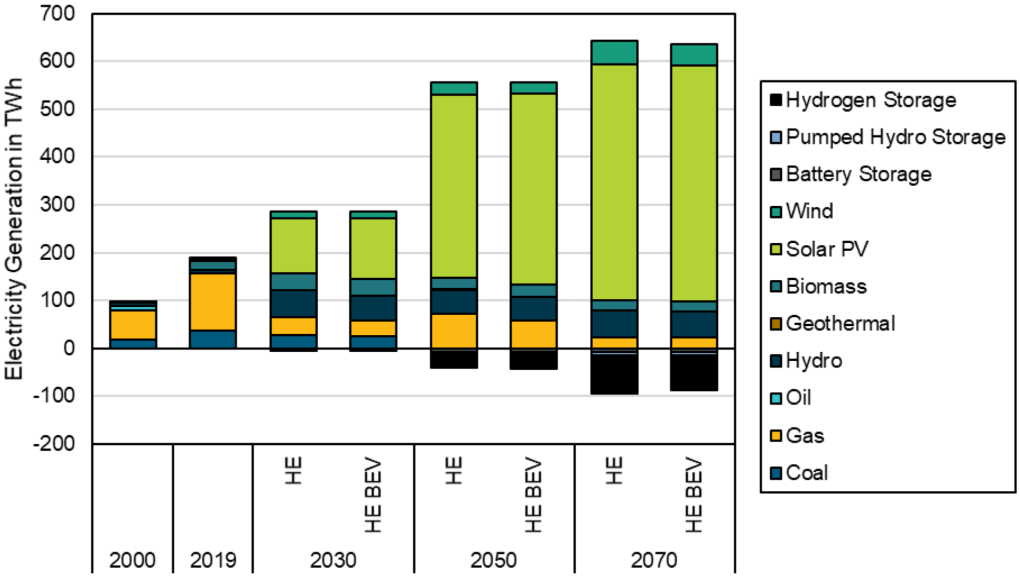
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

Figure 54: **Impact of shifted demand for BEV charging on the evolution of Thailand's installed capacity**



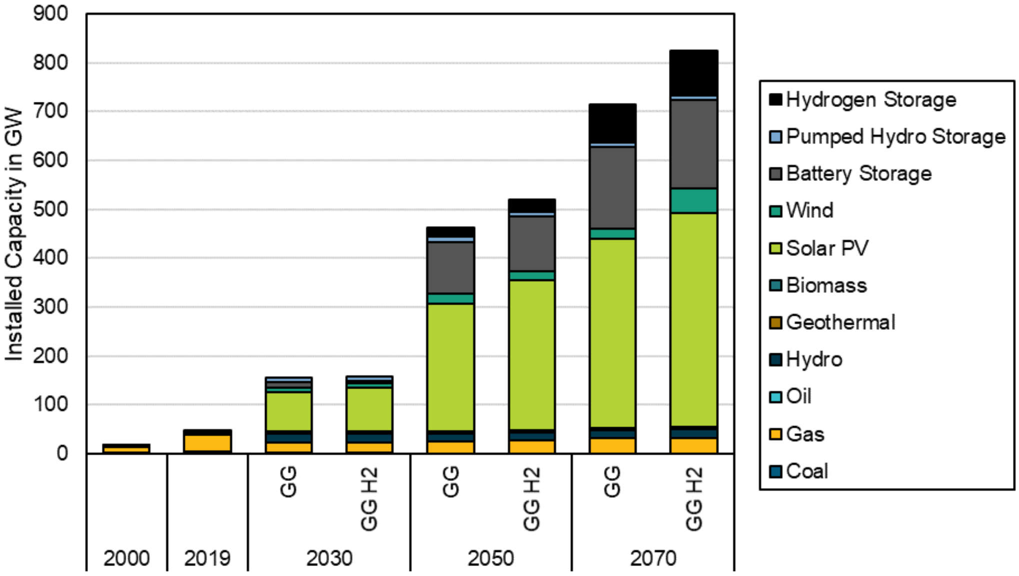
Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 55: **Impact of shifted demand for BEV charging on the evolution of Thailand's electricity generation**



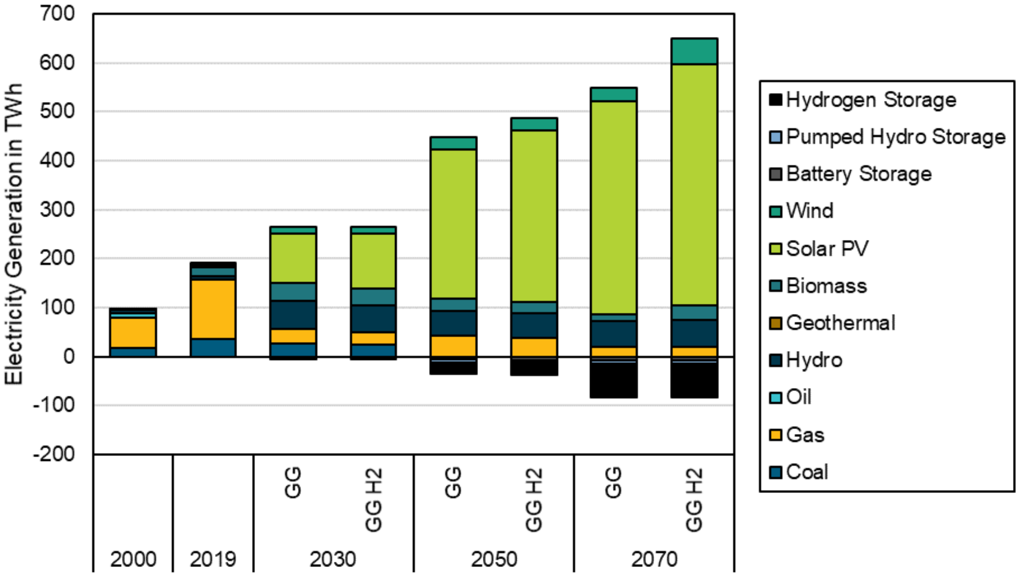
Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

Figure 56: **Impact of domestic green hydrogen production on the evolution of Thailand's installed capacity**



Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 57: **Impact of domestic green hydrogen production on the evolution of Thailand's electricity generation**

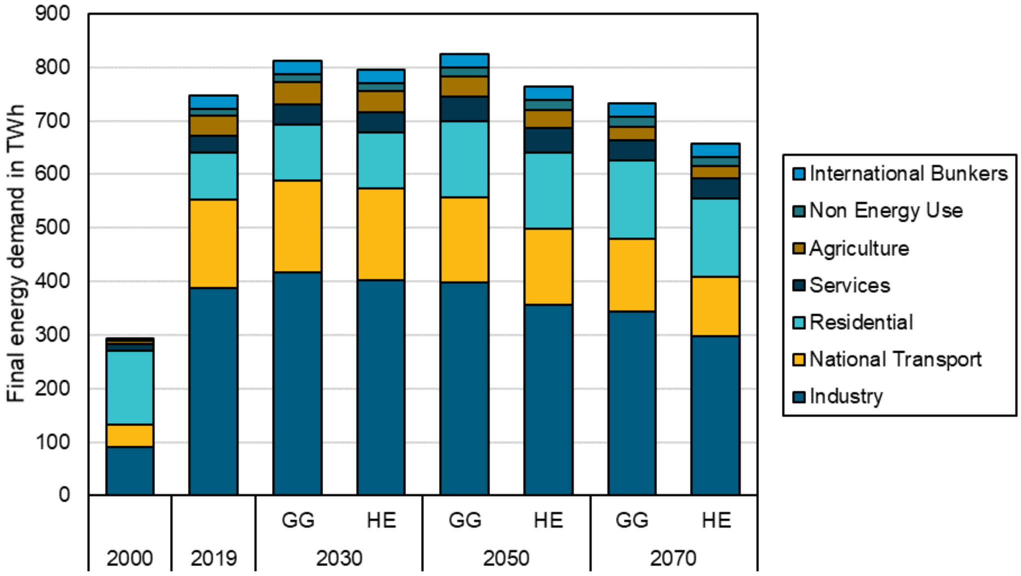


Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

4.4 Vietnam

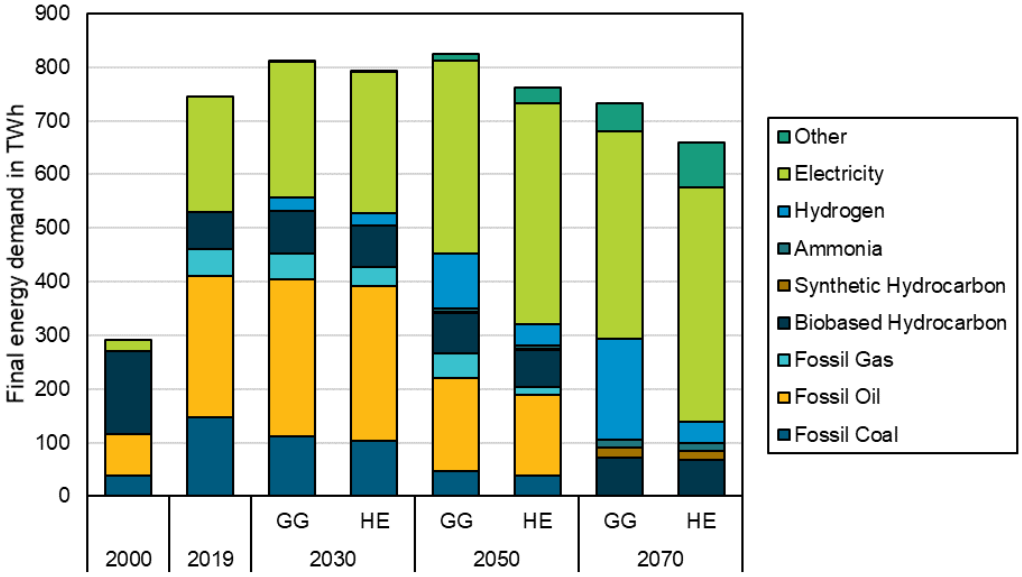
Demand side

Figure 58: Evolution of Vietnam's final energy demand by sector and scenario



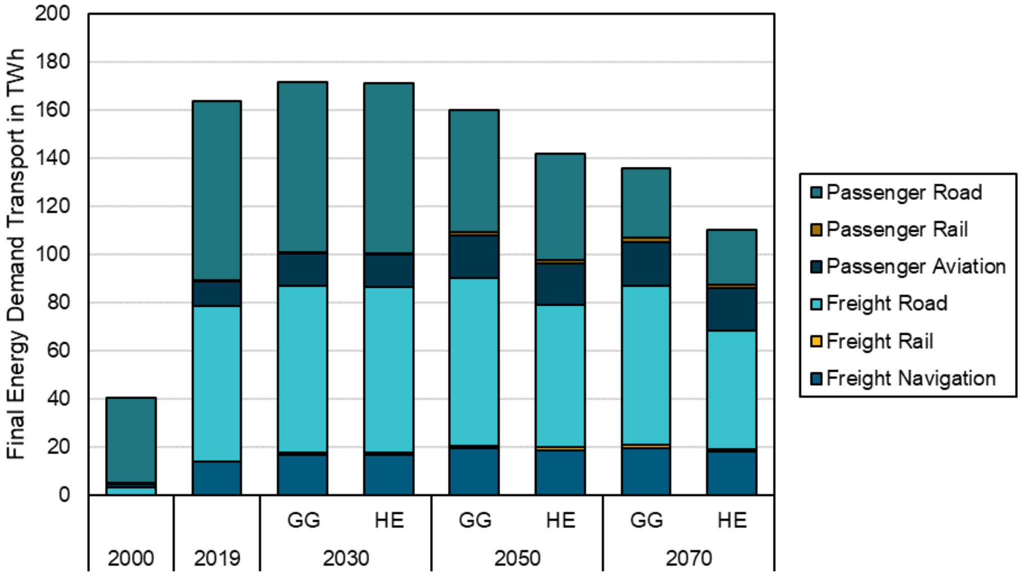
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 59: Evolution of Vietnam's final energy demand by fuel and scenario



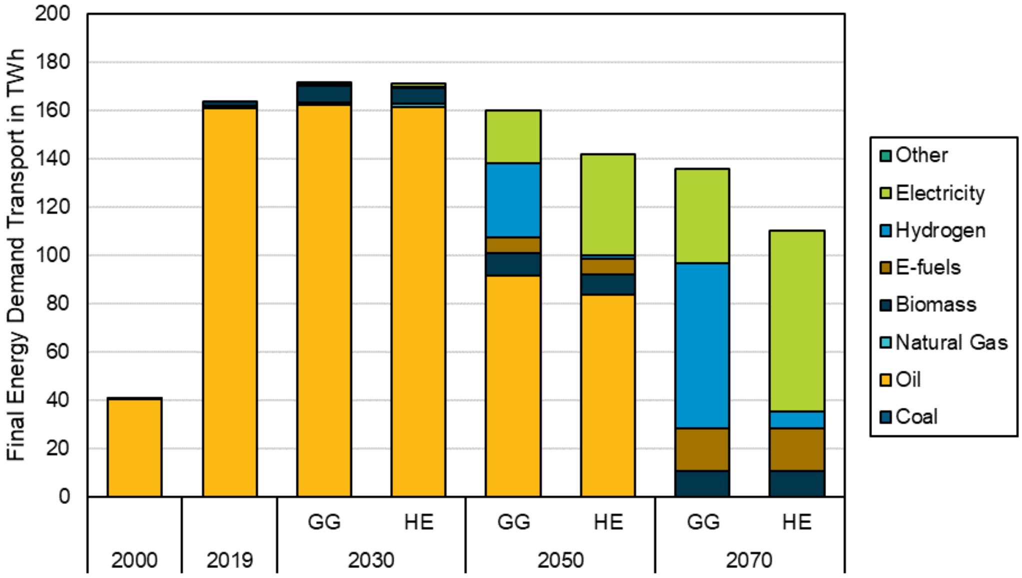
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 60: **Evolution of Vietnam's final energy demand in national transport by sub-sector and scenario**



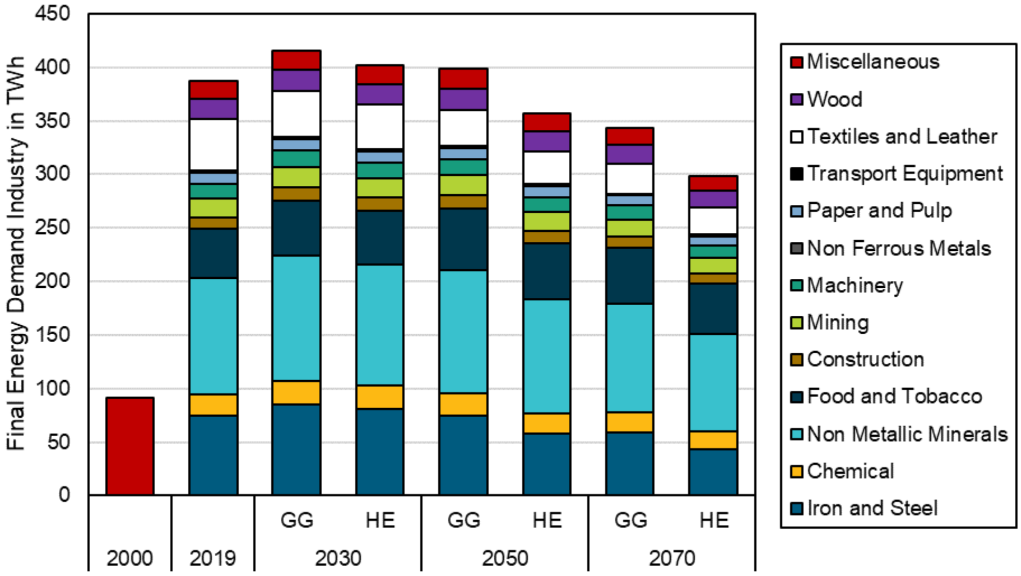
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 61: **Evolution of Vietnam's final energy demand in national transport by fuel and scenario**



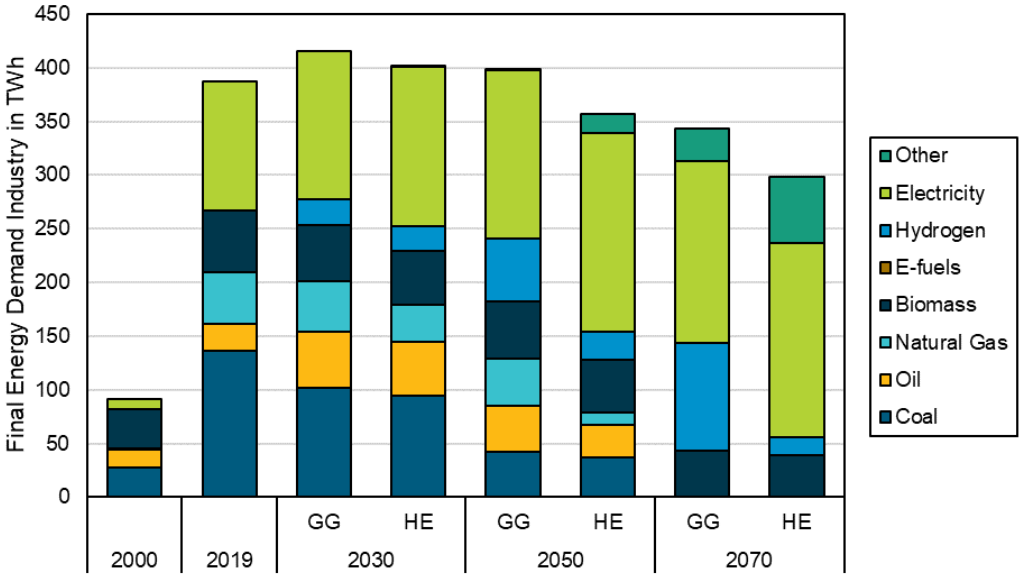
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

Figure 62: Evolution of Vietnam's final energy demand in industry by subsector and scenario



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

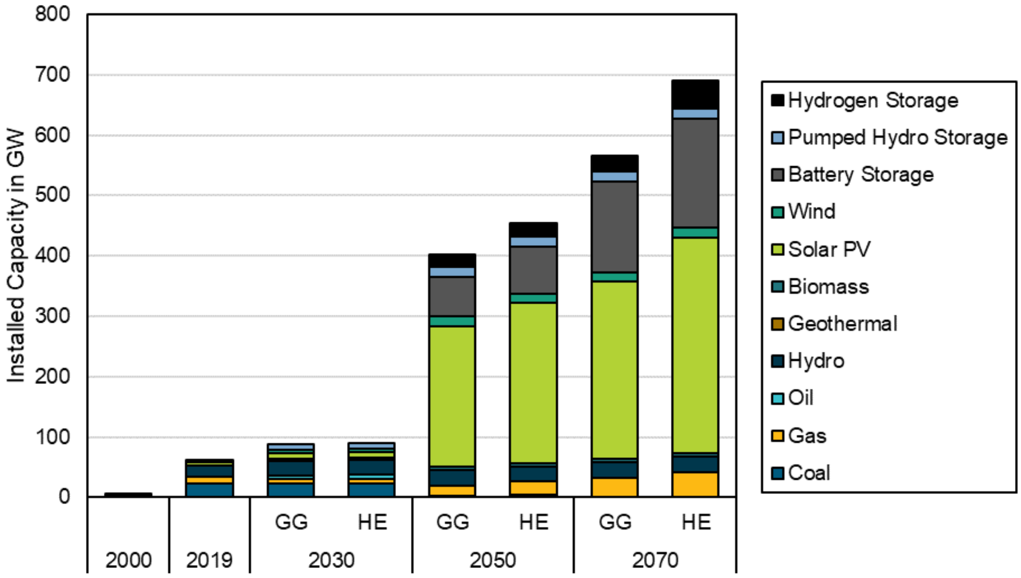
Figure 63: Evolution of Vietnam's final energy demand in industry by fuel and scenario



Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023a) and future projections based on own scenarios

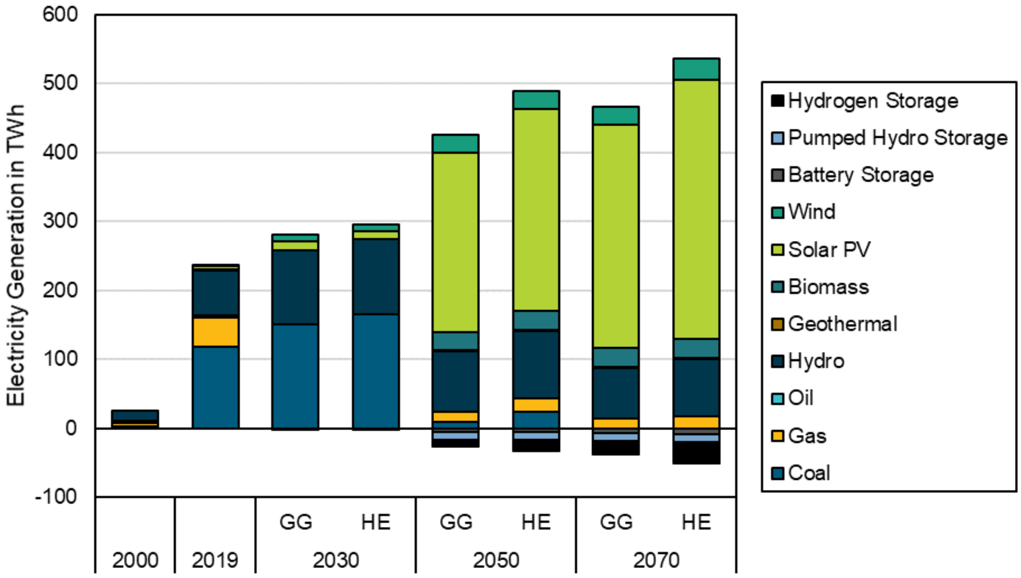
Supply side

Figure 64: Evolution of Vietnam's installed capacity by scenario



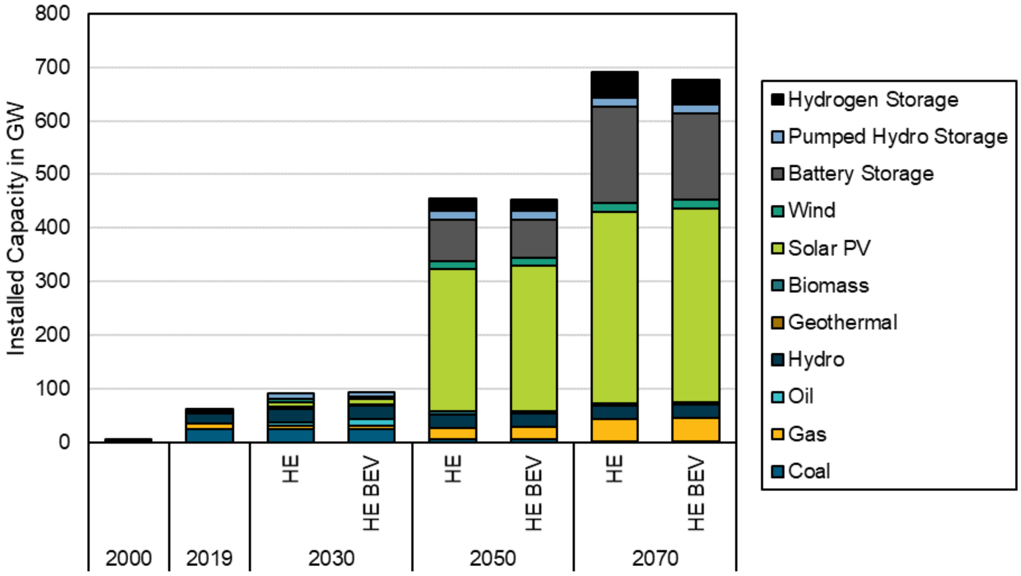
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 65: Evolution of Vietnam's electricity generation by scenario



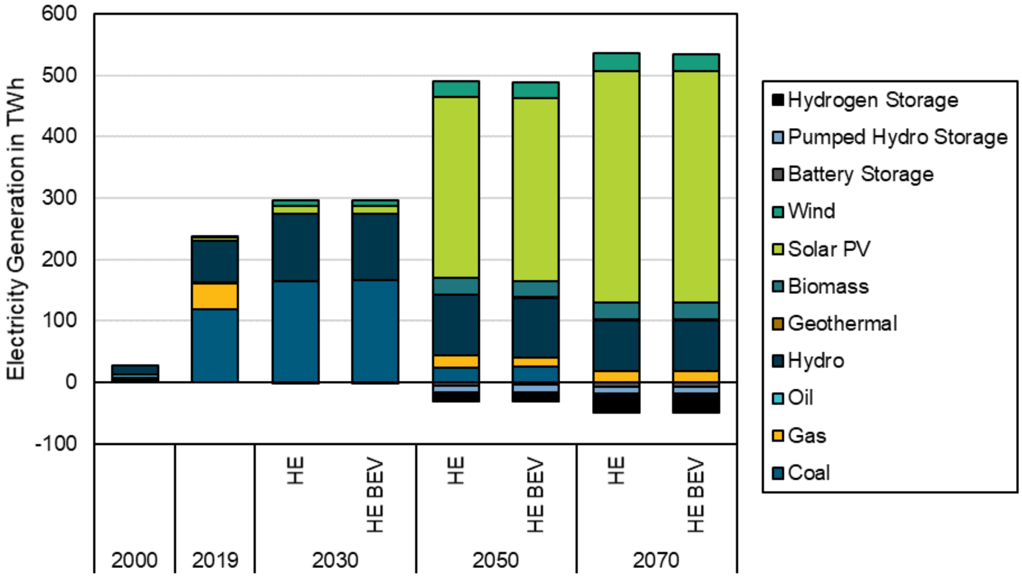
Note: (HE: Highly Electrified GG: Green Gases).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

Figure 66: **Impact of shifted demand for BEV charging on the evolution of Vietnam's installed capacity**



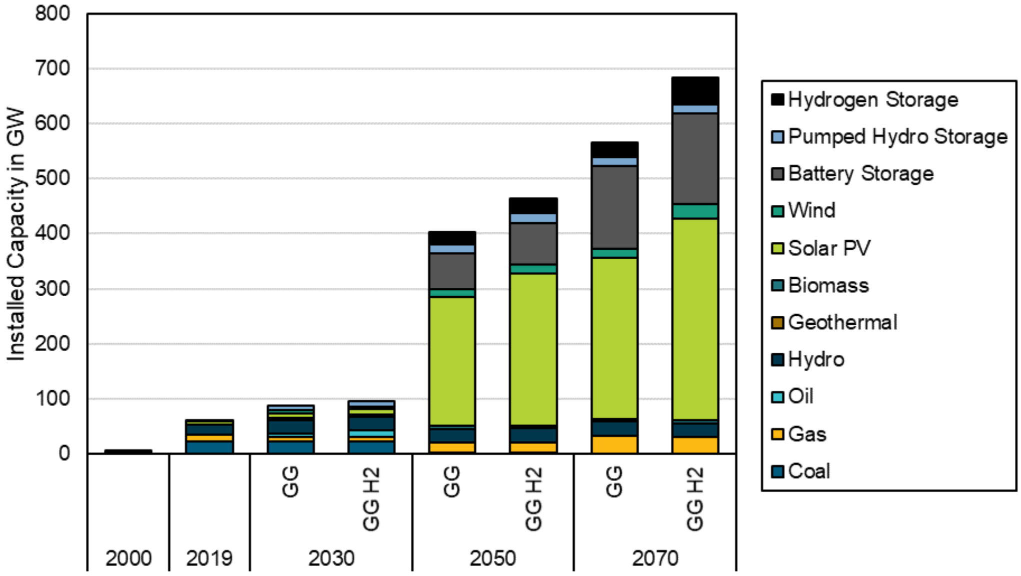
Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 67: **Impact of shifted demand for BEV charging on the evolution of Vietnam's electricity generation**



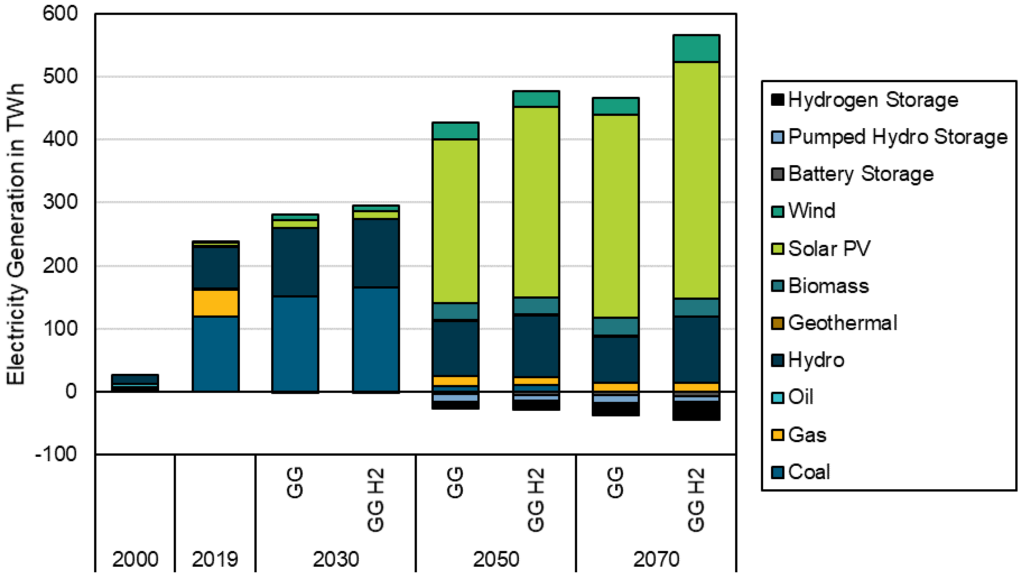
Note: (HE: Highly Electrified HE BEV: Highly Electrified - BEV charging).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

Figure 68: **Impact of domestic green hydrogen production on the evolution of Vietnam's installed capacity**



Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from enerdata (Enerdata 2023b) and local sources, future projections based on own scenarios

Figure 69: **Impact of domestic green hydrogen production on the evolution of Vietnam's electricity generation**



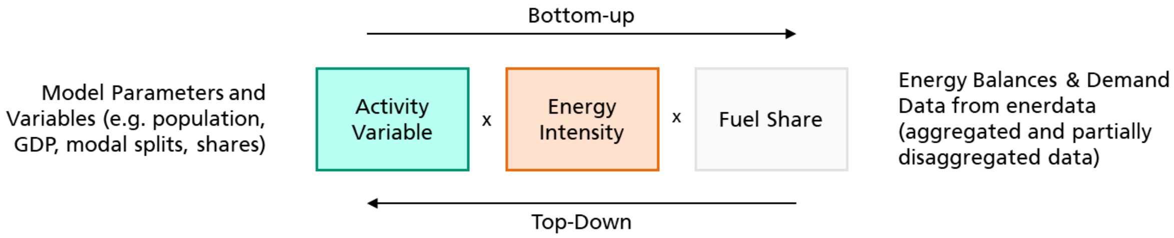
Note: (GG: Green Gases GG H2: Green Gases - Domestic H2 Production).
Source: Historical data from International Energy Agency (IEA 2023), future projections based on own scenarios

5 Technical details

5.1 Demand side modelling

Specific bottom-up input data such as population, production statistics, modal splits, and technology-specific energy intensities are collected as input data, and national energy balances are used as top-down reference data. Based on this, the historical energy demand from the energy balances is decomposed into the structure to be represented in the model. Since not all necessary factors are available for all countries and sectors, missing parameters are estimated and adjusted to the total demand from the energy balances. These parameters do not necessarily all represent real values, but can be considered as "meaningful tuning variables" that can be influenced for future projections. This approach is particularly useful for sectors where fundamental technological changes are expected in the course of the energy transition. Examples include the road transport sector, which could switch from combustion engines to battery-electric or fuel-cell vehicles, or the steel industry, where coal-fired blast furnaces may be replaced by direct reduction using hydrogen or secondary electric steelmaking.

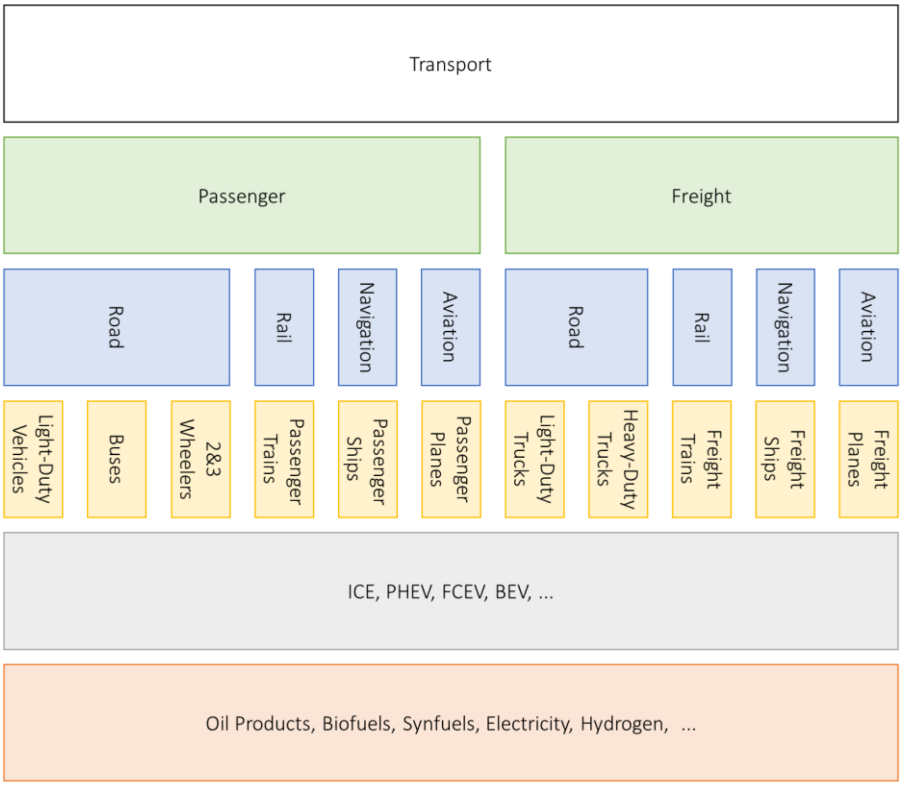
Figure 70: Schematic of the modelling approach using a mix of bottom-up and top-down techniques



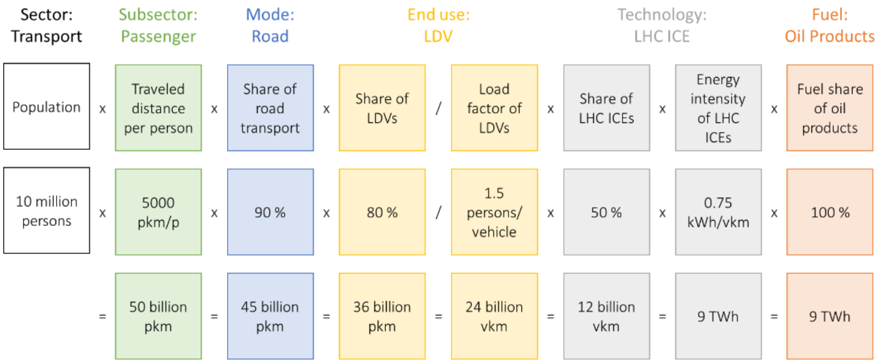
Approach to regional model (six other countries)

For the regional model that covers the remaining six countries of the ASEAN region, the final energy demand of the different sectors is projected using the GDP respectively sectoral value added as driver. The sectoral activity variable is then multiplied with the corresponding energy intensity and fuel share in each year to get the final energy demand of each fuel in each sector. Historical data from the World Bank (The World Bank 2022) and enerdata (Enerdata 2023a) are used as basis. The assumed future changes in GDP and energy intensity are covered by annual growth rates. As for the detailed country models, the fuel shares depend on the scenario. While one considers are really strong direct electrification and higher energy efficiency the other entails a rather high share of green gases such as hydrogen in the long-term and natural gas as a transition fuel.

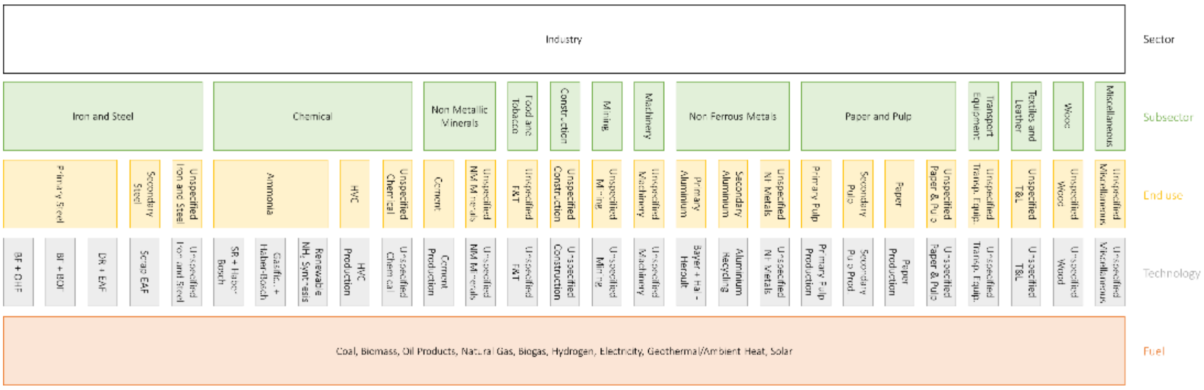
CASE models sectoral split and exemplary calculations

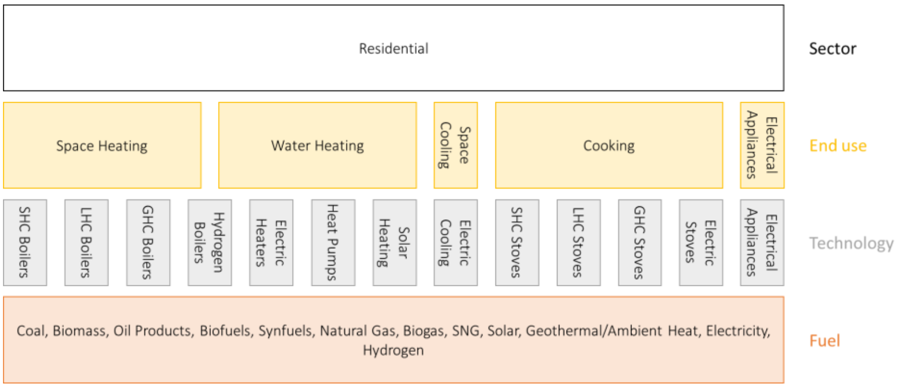


Example – Transport – Passenger – Road – LDV – LHC ICE – Oil Products



Sector: Transport		Subsector: Passenger		Mode: Road		End use: LDV				Technology: LHC ICE				Fuel: Oil Products
Population	x	Traveled distance per person	x	Share of road transport	x	Share of LDVs	/	Load factor of LDVs	x	Share of LHC ICEs	x	Energy intensity of LHC ICEs	x	Fuel share of oil products
10 million persons	x	5000 pkm/p	x	90 %	x	80 %	/	1.5 persons/ vehicle	x	50 %	x	0.75 kWh/vkm	x	100 %
	=	50 billion pkm	=	45 billion pkm	=	36 billion pkm	=	24 billion vkm	=	12 billion vkm	=	9 TWh	=	9 TWh





5.2 Renewable energy potentials

The renewable potential in the ASEAN region is mainly composed by utility-scale PV. The wind onshore potential is modest, according to the calculation made using the Enertile Renewable Potential Calculator 2.0 from Enertile. All the Enertile calculations are for the year 2050. A comparison of the Enertile results with the literature is presented below. Table 6 and Table 7 present the PV potential literature review in terms of generation (TWh) or capacity (GW). Table 8 presents the wind onshore capacity literature review in GW.

Table 6: Solar PV generation potential literature review

	Generation (TWh)				
Source	**Indonesia**	**Thailand**	**Vietnam**	**Philippines**	**Comment**
Enertile	1238	495	496	307	Please refer to section 2.4.2
Siala et al. (2016) conservative scenario	108	64.5	61.4	20	10% of barren land, grassland and scrubland is considered available for rural PV projects. In addi-tion, 5% of urban areas can be covered with rooftop PV.
Siala et al. (2016) realistic scenario	1416.9	600	361.7	144.2	The factor for barren land, grassland and scrubland is increased to 50%. In addition, a factor of 1% for forests, savannahs, croplands and natural vegetation is available for rural PV installations.
IESR-A Scenario 1 (Tampubolon et al. 2021)	26,972				Scenario excludes protected areas, forests, water, wetland, airports and seaports + areas with slope (>10%)
IESR-A Scenario 2	10,508				S1+croplands and plantation forests
IESR-A Scenario 3	8,541				S2+transmigration and settlements
IESR-A Scenario 4	4,705				S3+dry shrub
Vidinopoulos et al. (2020)	24,789	9,023			Forest urban and 50% of agricultural land is excluded. No other factors are given for other land uses. A fraction of 15% of the systems consider tracking devices.

Table 7: Solar PV capacity potential literature review

Source	Capacity (GW)				
	Indonesia	**Thailand**	**Vietnam**	**Philip-pines**	**Comment**
Enertile	1,210	408	484	249	Please refer to section 2.4.2
Siala et al. (2016) conservative scenario	82	51	49	16	10% of barren land, grassland and scrubland is considered available for rural PV projects. In addi-tion, 5% of urban areas can be covered with rooftop PV.
Siala et al. (2016) realistic scenario	1,078	476	291	116	The factor for barren land, grassland and scrubland is increased to 50%. In addition, a factor of 1% for forests, savannahs, croplands and natural vegetation is available for rural PV installations.
Langer et al. (2021)	98,650				Forests, water and protected areas are excluded. No factors are given to the other land uses.
IRENA - Gielen et al. (2017)	532				It consider resource and land availability constraints. No further details are given.
IRENA (2022)	3000				Analysis using geographic information system. No data about exclusion factors.
IESR-A Scenario 1 (Tampubolon et al. 2021)	19,385				Scenario excludes protected areas, forests, water, wetland, airports and seaports + areas with slope (>10%)
IESR-A Scenario 2	7,700				S1+croplands and plantation forests
IESR-A Scenario 3	6,310				S2+transmigration and settlements
IESR-A Scenario 4	3,397				S3+dry shrub
IESR-B Scenario 1 (Tumiya et al. 2021)	7,714				Includes shrubs, savannah, bare land, residential, area, mining, transmigration and dam
IESR-B Scenario 2	6,749				Like S1 but restricts residential to just 27% and dam to 5%
CASE (Rolland et al. 2022)		300			Only high irradiance sites are considered (>1,850 KWH/m^2)
EREA & DEA (2019)			380		Limited by land use availability. A factor of 1.1-1-2 ha/MW is used
International trade administration (2022)			386		No details are given

Table 8: Wind onshore capacity potential literature review

	Capacity (GW)				
Source	**Indonesia**	**Thailand**	**Vietnam**	**Philippines**	**Comment**
Enertile	31	66.7	77.7	51.9	Please refer to section 2.4.2
IRENA- Gielen et al. (2017)	9.3				It considers resource and land availability constraints. No further details are given.
IRENA (2022)	61				No details are given
Manomaiphiboon et al. (2017)(low)		50-250			2 MW turbines consider. They use different map layers to exclude areas and calculate wind resource
Manomaiphiboon et al. (2017) (high)		100-500			No land exclusion is considered
EREA & DEA (2019)			217		Considers a minimum wind speed of 4.5 m/s and height of 80 m.
Elliott (2000)				76	No details are given

6 List of Figures and Tables

7 Literature

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