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Towards a collective vision of Thai energy transition: National long-term scenarios and socioeconomic implications

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Table of Contents

4 Summary and recommendations

15 Introduction

23 Developing an inclusive long-term energy scenario framework

33 The pathway towards carbon neutrality by 2050

41 Key findings and strategies to reach carbon neutrality

- 43 Increase of low-carbon electricity supply through domestic renewable supply
- 51 Increase of power system flexibility
- 58 Transformation of the transport sector
- 67 Transformation of the industry sector

75 Socioeconomic opportunities of the power system transition

83 Cross-sector collaborations

Summary and recommendations

Achieving Thailand's vision of carbon neutrality with a cost-efficient transition will depend on today's choices and policy actions, which will shape the energy system in the next decades.

CO2 emissions need to decrease immediately and drop by 30% in 2030, 50% in 2037 and 80% in 2050 compared to 2019 levels[1]. This is made possible by a fast scaling-up of renewables, improvement in energy efficiency, gradual phase-out of fossil fuels and electrification of other end-use sectors, such as transport and industry. In 2037, at least 50% of the total energy supply should come from renewables. As electricity becomes a major energy carrier, electricity is expected to supply 20% of transport energy demand and 60% of industrial heat demand in 2037. The energy transition needs to start immediately since it requires time, resources and technical and institutional capacity, but also to avoid the risks of technological lock-in that would jeopardise Thailand's climate, energy and broader economic goals.

The transition to a low-carbon energy system will benefit the Thai economy, increase energy security, reduce health impacts and improve the environment.

The significant construction of renewable generation capacity over the next eight years could create over a million new jobs. Building such an ambitious economic program will require time, resources and significant capacity-building efforts. In addition to creating new jobs in manufacturing, installation, operation and maintenance, establishing these renewable generation capacities could position Thailand as a front-runner in the region. Early actions could also act as a green-growth economic impetus post-Covid An increased share of indigenous renewable energy (RE) sources will reduce fossil fuel-import dependency, mitigating geopolitical and supply shock risks like those encountered in 2022. Thailand's transition to a low-carbon energy system will reduce air pollution in the energy sector, saving 27,000 lives over the next 30 years and reducing the risk of premature death from stroke, ischemic heart disease and lung cancer.

[1] It should be noted that this study took the year of 2019 (before the pandemic) as a reference year for emissions reduction, rather than taking a business as usual (BAU) approach as stated in Thailand's long-term strategy submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The BAU approach has often inflated emissions since it often refers to a decades-old economic growth assumption. It is important to note that reaching carbon neutrality in the presented pathway depends on the role of carbon sinks in Thailand.

The energy transition represents an opportunity to modernise the Thai energy system and will require a comprehensive program of investments.

The required annual investment to transform the power sector represents 2% to 5% of Thailand's GDP. These investments are relatively evenly distributed across cost-efficientand mature low-carbon technologies, such as solar photovoltaics (PV), batterystorage, electric vehicles (EV), etc. Total system costs remain comparable to the ones related to operating today's power system yet comprise additional economic benefits such as reducing exposure to fossil fuel price volatility.

The road to climate neutrality requires the transformation of all sectors, which in turn calls for cross-ministerial dialogue and integrated planning.

Cross-ministerial dialogue and integrated planning are necessary to ensure that all implementation plans are working towards the same goals. Multi-sectorial policy alignment will require stronger cooperation between line ministries to ensure a just and economically viable energy transition. Integrated planning of the energy system transformation requires new regulatory and market frameworks that spur technology cost reductions and unlock investments in renewables and other emerging technologies.

The Thai energy transition to a low-carbon energy system will benefit the Thai economy, increase energy security, reduce health impacts and improve the environment

Emissions

need to peak as early as the end of **2022**

drop by **30%** in **2030**

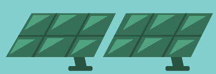
drop by **50%** in **2037**

drop by **77%** in **2050**

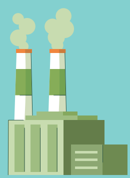
compared to 2019 levels

Action by 2030

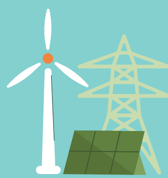
Solar booster program
(5GW per year until 2030)



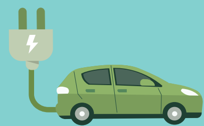
No new coal power plants



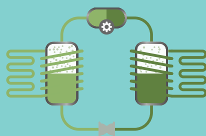
Flexible operation of power system



Increase sales of zero emission vehicles
(100% in 2035)



Increase heatpump in industry
(40% heat supply)



Benefit

Renewable energy technologies can create

1.2 million new jobs

until 2030, which could help revive the economy after the recession.

Reducing air pollution is estimated to

save 27,000 lives

over the next 30 years.

The energy transition will induce a total investment of

THB 8 trillion

in the power sector over 30 years.

How we created the pathway?

The pathway depicted here represents the outcome of several "what-if?" thought experiments, following these guiding principles:

The power sector is the key enabler
to decarbonise several other end-use sectors
(e.g., low temperature heat in industry, electric vehicles in transport, etc.)

Using the best technologies
available at decreasing costs over the transition,
following global trends (e.g., electric vehicles)

Thailand's pursuit of its vision to become
a front-runner in the energy transition

Carbon sinks are available to offset remaining emissions

The power and heat supply side are decarbonised solely under
cost-optimization constraints,
without additional climate constraints.

Sector specific strategies

A. Power sector transformation

A.1. Rapidly scale up renewables, particularly solar PV

Key findings:

- The power system will drive the decarbonisation of the entire Thai energy system through increased electrification of end-use sectors.
- The decarbonisation of the power sector is therefore the pre-condition, backbone and enabler to achieve carbon neutrality.
- Renewables-based electricity is already a cost-effective option in Thailand, particularly solar PV, given the high solar irradiation and sufficient available land.
- Renewables should cover 60% of power supply in 2030, 77% in 2037 and 85% in 2050.

Recommendations:

- **To be on track with its long-term net-zero commitment, Thailand should immediately launch a solar booster program with a yearly installation target of 5 GW per year.**
  A clear annual target in the PDP and a committed implementation plan will build trust among private investors, attract the necessary investments and provide technical certainty on system integration challenges.

- **Thailand should review renewables support mechanisms and remove existing market barriers.** Some regulatory and market barriers must be bypassed in order to facilitate investment and system integration of renewables. Key priorities include a new design of electricity transmission and distribution fees for third party access, a refinement of energy trading regulations, and a review of the grid code. Specific incentives need to be provided to accelerate the installation of small-scale RE such as rooftop solar PV.

A.2. Unlock and increase power system flexibility

Key findings:

- With increasing shares of variable renewable energy (VRE), the power system must be redesigned around the flexibility paradigm.
- Up to 15% VRE can be integrated into the power system without fundamental changes in the power system structure. However, existing thermal power plants will gradually need to operate more flexibly to facilitate the integration of renewables and limit curtailment.
- Other flexibility options exist to facilitate the integration challenge (e.g., transmission grid, interconnection with neighbors, demand-side response).
- After 2030, the rollout of battery storage will become a key measure to further support the expansion of solar technologies.
- The gradual electrification of end-use demand (in particular charging of electric vehicles) will provide an important source of additional flexibility to the system and contribute to reduced CO2 emissions.
- The security of the power supply will be ensured throughout the transition through the reliance on battery storage and gas peaking power plants. Gas peaking power plants will be required in seasons with low solar PV irradiance (typically in July) but their output will be reduced significantly, and in the long-run they should be climate-neutral ready (requiring a fuel-switch towards green hydrogen).

Recommendations:

- **Increase operational and contractual flexibility of thermal power plants.**
  Current power purchase agreements (PPAs) with minimum-take obligations and take-or-pay fuel supply contracts must be revised to facilitate increasing RE shares and minimizing total system costs. Possible options include creating more flexible fuel supply contracts through a portfolio procurement approach (fuel supply contracts with a mix of short-term and long-term products) and tendering new/restructured PPAs with more flexible terms.

- **Support the mid-term rollout of battery storage to facilitate solar integration.**
  Given the correlation of solar PV generation and demand profiles, installing battery storage from 2030 could significantly support the integration of high shares of VREs into the grid and reduce total system costs. In comparison, investments in transmission grid reinforcement will be relatively low. During days with high solar generation, battery storage (stationary or EV charging, in particular bi-directional) could help absorb excess peak generation in the middle of the day and discharge it to supply nighttime demand. Incentives and financing options must be designed to support the development of the battery storage market before the technology is expected to be cost-competitive (in the 2030s).

- **Promote other decentralized solutions (e.g., distributed energy resources and demand response) in enhancing system flexibility.**
  Supporting the deployment of decentralized solutions on both the supply and demand sides will require a comprehensive modernization investment programme. These investments should be relatively evenly distributed across cost-efficient and mature low-carbon technologies.

A.3. Phase-out fossil fuels and reassess the role of gas power during the transition

Key findings:

- No new coal power plants must be built, as they are incompatible with climate objectives and bear energy security and economic risks. In addition, coal power plants must be retired more quickly in line with the uptake of renewables.
- By 2050, the amount of thermal power plants required to ensure system adequacy will decrease significantly (from 39 GW in 2019 to 27 GW in 2050) despite a significant increase in power overall power consumption. Other technologies, such as storage and optimal EV charging, alleviate the need and provide additional flexibility to the system.
- Between now and 2050, the economics and operating structure of gas power plants will change progressively as renewables enter the system. The average utilization rate of existing gas power plants will decrease.
- New thermal generators will mostly operate as peaking plants during periods of low renewables output and high inflexible demand, especially in June and July. In order to be aligned with ambitious decarbonisation objectives, those thermal power plants should be ready to switch to zero-carbon fuels (green H2).

Recommendations:

- **Develop new cost-recovery mechanisms for gas power plants.**
  With the reduced utilization of existing gas power plants, their earnings and cost structure will change significantly over the transition. This situation requires the design of new contracts or other cost-recovery mechanisms for gas power plants that must consider flexibility requirements along the trajectories of renewables uptake.

- **Renegotiate existing long-term contracts of gas power plants.**
  The utilization of existing gas power plants will change as renewables enter the system. This requires a renegotiation of existing PPA contracts to minimize system costs and reduce renewables curtailment.

- **Develop a fossil fuel transition plan with all concerned stakeholders.**
  Achieving ambitious emissions reduction targets will require a fossil fuel transition plan involving all concerned stakeholders and including a just energy transition perspective to mitigate any social impacts. The natural gas policy of the Thai government should be assessed in greater detail, in particular in light of energy security and external price shocks, climate constraints and the optimal cost structure of the power plant mix.

- **Gradually switch fuels from natural gas to green hydrogen on the road to more ambitious climate objectives.**
  The speed of the transition away from natural gas towards green hydrogen will depend on the level of climate ambition. In particular, the transition will depend on the level of sinks dedicated to offset energy-related emissions, as well as carbon pricinginstruments and the long-term price evolution of fossil fuels. One key strategy to achieve this transition towards green hydrogen is to ensure that any new investments in gas power plants should be H2-ready.

B. Transport sector transition
B.1. Electrification of transport is key for driving down fossil fuel consumption

Key findings:
- By 2030, the renewables-based electrification of the transport sector will increase the annual electricity demand by 12 TWh, or less than 1 Mtoe, while reducing fossil fuel consumption by almost 6 Mtoe. This electricity demand will be mostly flexible, facilitating the integration of higher shares of variable renewables.
- By 2050, electricity demand in the transport sector will represent almost 20% of the total electricity demand, saving a total of 211 Mtoe of oil products during that year (compared to a scenario without deep electrification).
- Reaching ambitious electrification targets in the transport sector requires the rapid adoption of an infrastructure plan (charging infrastructure and power system integration) in the coming years.

Recommendations:
- **Support EV deployment with both demand- and supply-side policy measures to accelerate transport sector decarbonisation.**
  Examples of demand-side measures include tax incentives and price subsidies on the purchase of electric vehicles, charging infrastructure development, preferential lanes and city access/parking. On the supply side, examples of measures include subsidies to support the automotive and battery industries, R&D programs and mandating emissions reduction from production lines. In addition, improving fuel economy or vehicle standards will play an important role in reducing emissions and developing smart charging incentives will facilitate EV integration into the power system.

B.2. Emissions reduction in the transport sector requires a broader strategy than the deployment of electromobility

Key findings:

- While 100% EV sales by 2035 can result in up to 50% of emissions reduction in the transport sector in 2050, additional measures – such as fuel economy standards and CO2 limits for vehicles – are required to bring emissions down further.
- Modal shift and energy efficiency lead to faster emissions reduction in the mid- to long-term, reducing energy demand by 15% in 2030 and 40% in 2050.
- Accelerated turnover will be required to ensure rapid EV deployment. In addition, stricter emissions standards are required to minimize the emissions of combustion engine fleets, which will still represent a large share by 2050.

Recommendations:

- **Promoting modal shift is as important as the deployment of EVs.**
  Modal shift (including shifting from road to rail and from motorized to non-motorized, as well as scaling up mass public transport systems) should be stimulated to increase both carbon efficiency and energy efficiency of the transport sector. Since public transportation can be electrified faster than private transportation, modal shift that encourages the use of public transport and its electrification are the measures with highest impact to decarbonise the transport sector in the mid-term.

- **Promote faster turnover of more energy-efficient and less carbon-intensive vehicles.**
  Policies and regulations to support a faster turnover of vehicles should be implemented to encourage early retirement, limit the circulation of older vehicles and increase sales of new efficient vehicles. In addition to instruments promoting electromobility (EV tax credits or exemptions to make new vehicles more affordable), several additional measures must be implemented, such as taxation of combustion-engine vehicles, vehicle scrappage policy, stringent emissions standards for vehicles on the road and circular economy practices to receive older vehicles before the end of their lifetime.

C. Industry sector transformation

C.1. Energy efficiency and electrification will be key to decarbonise low-temperature heat in the industry

Key findings:

- Despite an expected increase in industrial activity in Thailand, the industrial energy demand can be reduced by more than 10% over the next 20 years through electrification of heat and energy efficiency measures.
- Since the current industry structure in Thailand is dominated by low-temperature heat (e.g in the food and tobacco industries), important CO2 savings can be provided now by the diffusion of readily available technologies powered by clean electricity (e.g., heat pumps).

Recommendations:

- **Develop incentive schemes for industry to accelerate the switch to electric heating technologies.** Maintaining low electricity costs will be a key driver for industry electrification. During the transition period, policymakers should develop programs to facilitate the diffusion of electric technologies while incentivizing the development of renewable electricity sources within industrial parks.

- **Accelerate the deployment of energy efficiency measures targeting energy-intensive industries.** The government should strictly enforce the Energy Conservation Promotion Act for energy-intensive industries, such as the cement, steel and plastic industries. Mandatory Minimum Energy Performance Standards (MEPS) should be considered to incentivize the use of energy-efficient equipment in all industrial sectors.

- **Energy Service Companies (ESCOs) can deliver energy efficiency gains financed through energy savings.** ESCOs are one of the most effective mechanisms for promoting energy efficiency in the public and industrial sectors, particularly in emerging countries. The government should strengthen the condition of ESCOs markets by promoting energy-saving performance contracting in the industrial sector. In addition, the operation of ESCOs can be encouraged using funds from the Energy Conservation Promotion Fund to increase the number of credit lines granted by the ESCO Fund.

C.2. Low-carbon fuel, such as biomass and green hydrogen, will become key for decarbonizing high temperature heat

Key findings:

- While low-temperature heat processes will be decarbonised through renewables-based electricity, high-tem perature heat processes, especially in the cement and steel industries, will be decarbonised through the use of clean fuels, such as biomass and green hydrogen.
- Sustainable biomass can provide a large share of high-temperature heat demand and should be reserved to those usages where its value is highest.
- Hydrogen produced from solar power will play a role in decarbonising some industrial sectors in the long run, but its role will likely remain relatively marginal in Thailand.
- In the long run, coal should be replaced by clean fuels, such as biomass or green hydrogen, for the provision of high-temperature heat in industry. Relying on CCUS to abate energy-related emissions is un certain given the high technology costs.

Recommendations:

- **Incentivize biomass reallocation to high-value use.**
  The government should prioritize the use of biomass in sectors where no other abatement technologies exist, for example in the cement industry. Biomass should phased out of the sectors in which it is currently used and the cascading principle should be followed to minimize negative impacts on the biomass market and on biodiversity.

- **A supportive policy framework will be required to promote the use of green hydrogen in the industry sector.**
  To accelerate the adoption of green hydrogen technologies, several measures must be implemented both on the supply side (e.g., Carbon Contract for Difference (CCfD), carbon pricing schemes, standardisation) and the demand side (e.g., green procurement policies).

CASE for Southeast Asia

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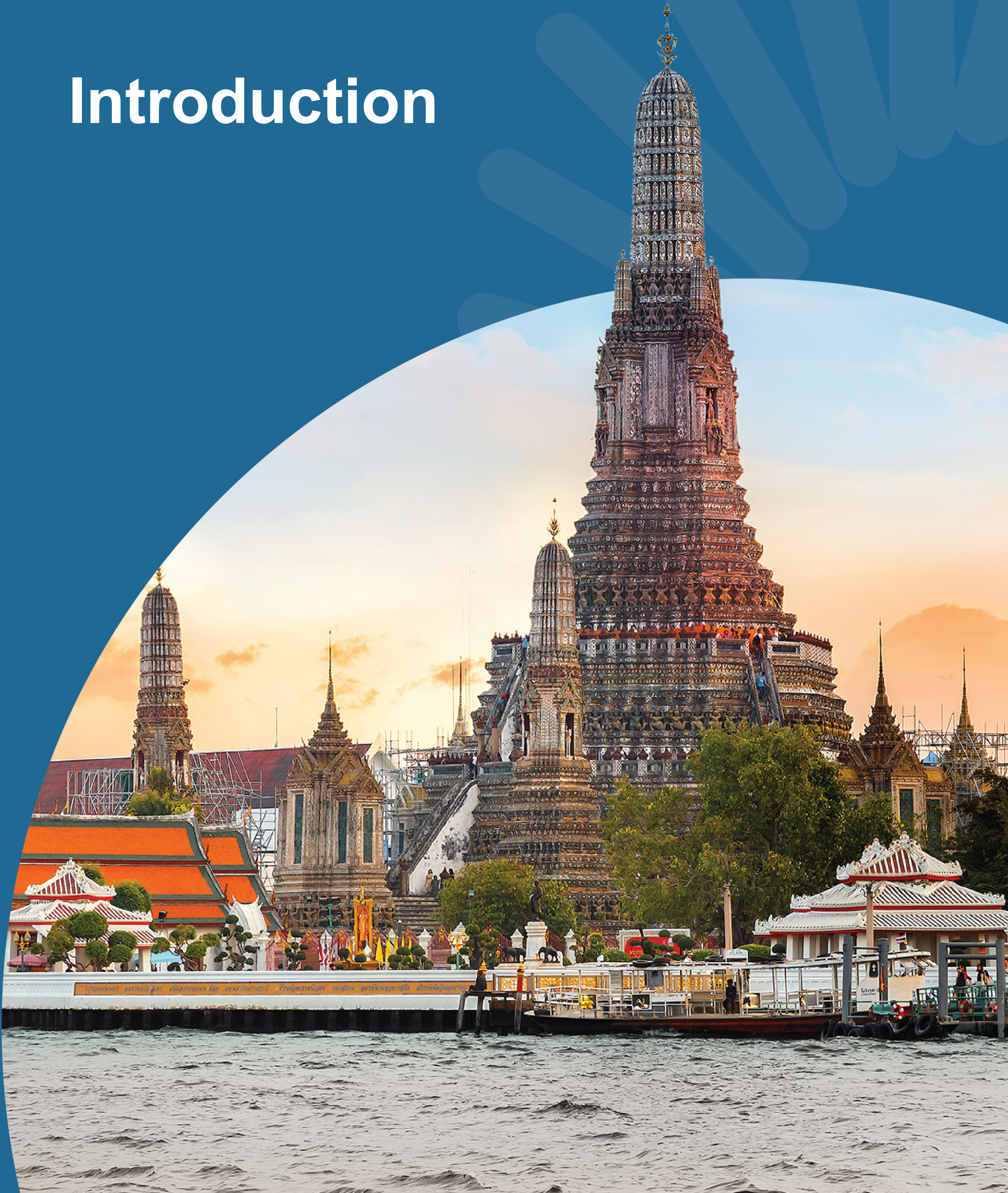
Introduction



Thailand has joined the global race towards reach ing net-zero emissions by mid-century

Thailand's greenhouse gas (GHG) emissions today represent less than 1% of global emissions and are lower than the world average. On 1 November 2021 at COP 26 in Glasgow, the Thai Prime Minister announced the country's aim to reach carbon neutrality by 2050, and net-zero greenhouse gas emissions by or before 2065 (Ministry of Foreign Affairs, 2021), embracing global trends (to date, 140 countries have announced or are considering net-zero targets covering almost 90% of global emissions).

With these new targets, Thailand is expected to review its long-term strategy for reducing GHG emissions. According to its Nationally Determined Contribution (NDC) Roadmap on Mitigation 2021–2030, Thailand is targeting a 20% to 25% GHG reduction by 2030, which will rise to a 40% reduction with international support such as technology transfers, international cooperation and financing facilities (Thai Government, 2021).

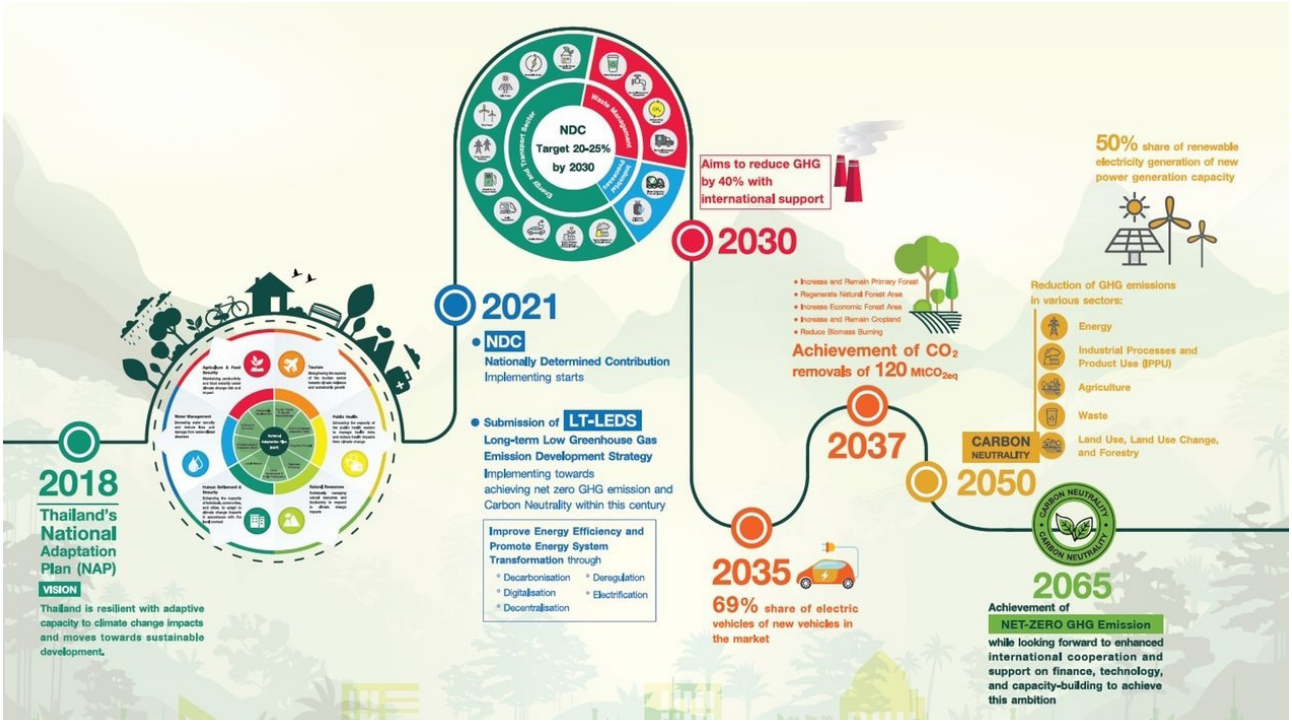


Figure 1.1: Carbon neutrality and net-zero GHG emissions pathway of Thailand.

In the past decade, net Thai GHG emissions have in creased annually by 2.3%, driven by the growth of the energy sector.

According to Thailand's Fourth National Communication, the total GHG emissions (excluding those from the Land Use and the Land-Use Change and Forestry sector) increased from 246 MtCO2eq in 2000 to 373 MtCO2eq in 2018, with an average annual increase of 2.3%. The net removal of CO2 increased from 45 MtCO2eq in 2000 to 86 MtCO2eq in 2018. The energy sector is the main contributor to net GHG emissions (257 MtCO2eq) followed by agriculture (58 MtCO2eq), industrial processes and product use (IPPU) (40 MtCO2eq) and waste (17 MtCO2eq).

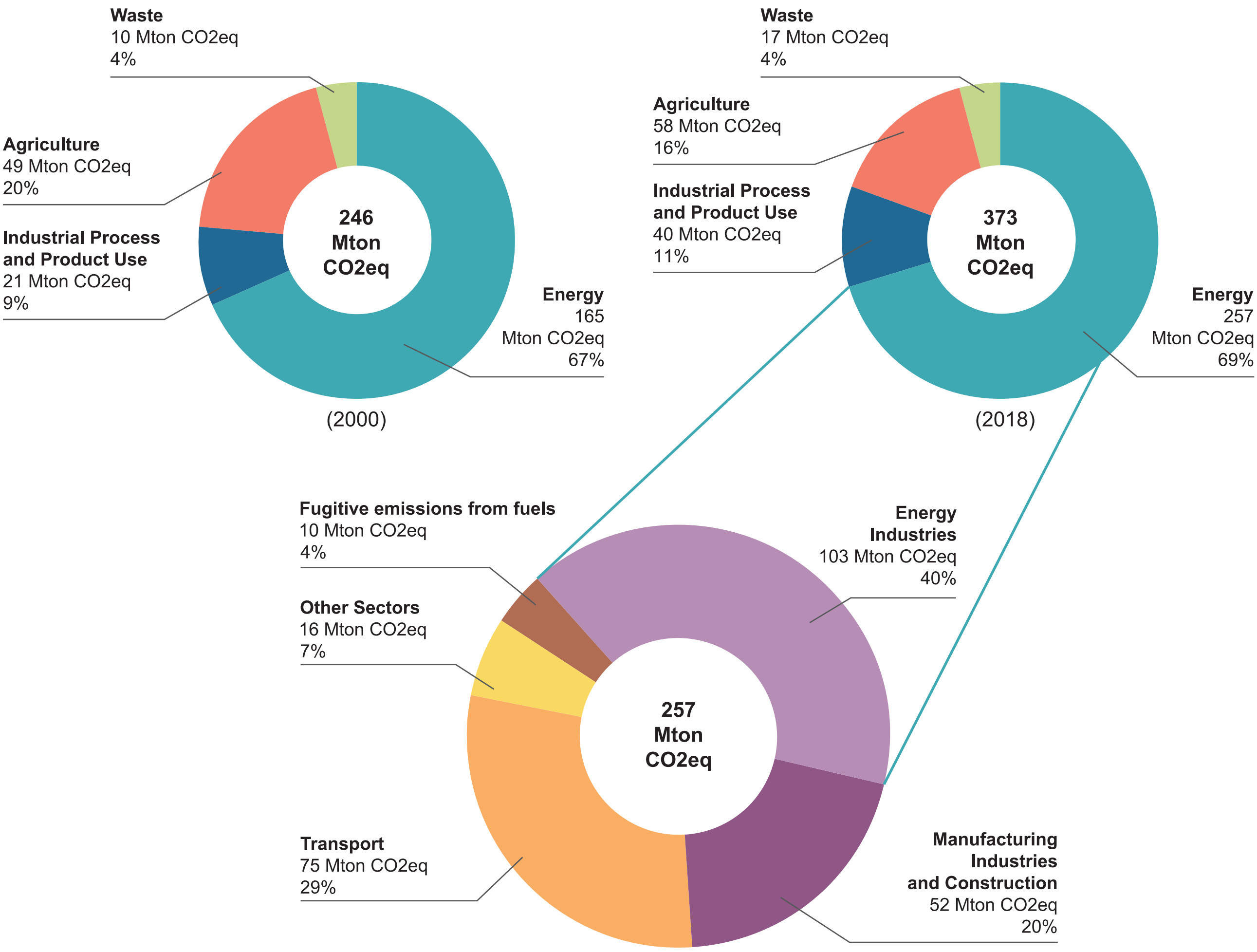


Figure 1.2: Total GHG emissions by sector (excluding LULUCF) in 2000 and 2018, and GHG emissions in the energy sector in 2018.
Source: (Ministry of Natural Resources and Environment, 2022)

The energy sector contributes to more than two-thirds of total greenhouse gas emissions.

The energy sector is the main contributor to GHG emissions, and its share of total national emissions increased in the last decade (from 67% in 2000, corresponding to 165 MtCO2eq, to 69% in 2018, corresponding to 257 MtCO2eq). The majority of GHG emissions in the energy sector were generated by fuel combustion from various activities, where the activities related to grid-connected electricity and heat production contributed the most emissions at around 40% of total emissions in the energy sector, followed by activities related to transport.

In 2016, in the context of its commitment under the Paris Agreement, the Thai government adopted its first NDC roadmap to reduce emissions in the energy, industry and waste sectors. The country has drafted several plans and programs which directly affect the reduction of GHG emissions in the energy sector: the Power Development Plan (PDP), the Alternative Energy Development Plan (AEDP) and the Energy Efficiency Plan (EEP). All plans and policies support the NDC objective of reducing GHG emissions by 20% against BAU levels by 2030. Each plan consequently establishes targets and measures in accordance with the NDC commitments (as discussed later in this chapter).

However, future efforts within the energy sector are still required to meet climate targets. According to the government, the three key GHG mitigation measures in the energy sector should be: increasing the proportion of renewable electricity generation, improving energy efficiency in every sector and introducing the use of current emerging technologies such as energy storage, hydrogen and carbon capture, utilization, and storage (CCUS) to further reduce emissions.

The current status of Thailand's energy system and supporting policies

After the COVID-19 pandemic, electricity demand has resumed its upward trend, especially in the industrial and residential sectors.

In 2021, electricity consumption reached 190.5 TWh (a 1.8% increase from 2020) with the industrial sector accounting for the largest share of consumption, followed by the residential and commercial sectors (Figure 1.3). Meanwhile, due to the COVID-19 pandemic, which resulted in work-from-home policies and travel restrictions, household electricity consumption increased by 2.7%. In contrast, electricity consumption in the commercial sector decreased by 5.5% as activity from businesses (including hotels, department stores and restaurants) decreased. In order to reduce high electricity costs, the utility EGAT has planned to reduce the power generation capacity reserve from 40% of total capacity (pre-pandemic) to 15% (Ministry of Energy, 2021). With high reserve margin, Thailand is expected to delay the signing of new renewable energy power purchase agreements, impeding the growth of renewable energy generation.

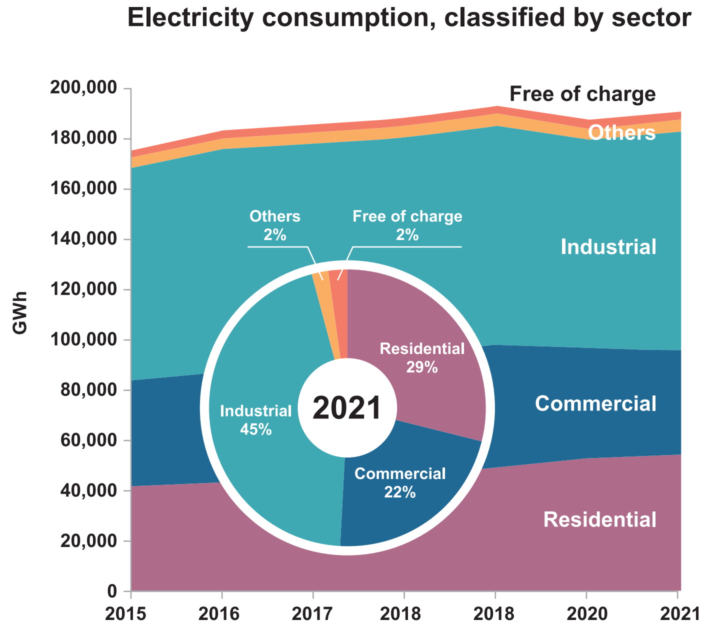


Figure 1.3: Electricity consumption classified by sector in 2021.
Source: (EPPO, 2022)

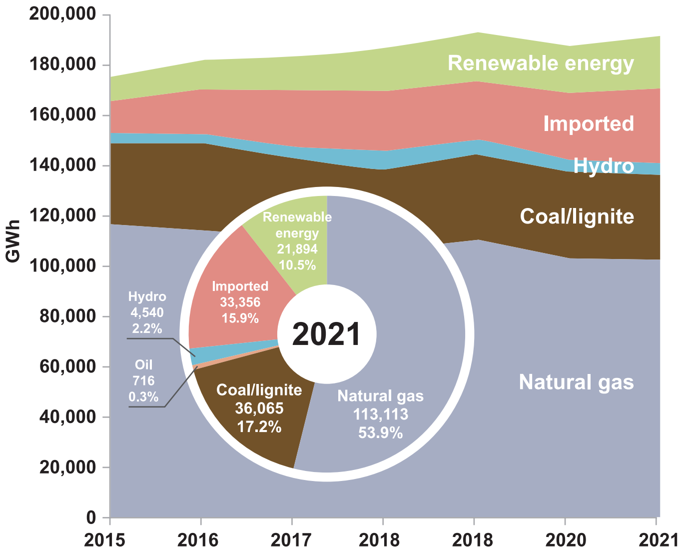
Under government plan, natural gas remains the primary source of electricity generation in Thailand through 2037.

Thai power generation is currently based on natural gas, coal and renewable energy, as shown in Figure 1.4. The primary sources of renewable energy are biomass at 30%, hydropower at both small and large scales at 25%, solar at 24% and wind at 12%.

Natural gas remains the dominant fuel in the Thai power sector because it is seen as a source with low generation costs and CO2 emissions when compared with coal. However, Thailand has faced the problem of declining domestic natural gas sources and has invested in natural gas infrastructure with the goal of further developing import and export potential by making Thailand an important LNG terminal hub.

Under the current power development plan (PDP2018 Rev.1), Thailand intends to increase its total power generation capacity to 77 GW by 2037, including 42.5% from natural gas-fired power plants, 32.5% from renewable energy power plants (primarily solar PV) and 6.3% from coal-fired power plants. This total installed capacity includes 46 GW of existing generation (until 2017), 56 GW of new generation and 25 GW of retiring generation from 2018 through 2037. In addition, 36% of new generation capacity have signed purchase agreement contracts and are expected to operate from 2018 through 2025.

Power generation classified by fuel type



Installed renewable energy capacity 2021

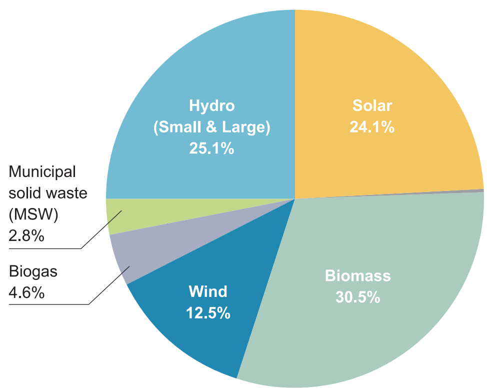


Figure 1.4: Power generation classified by fuel type
Source: (EPPO, 2022)
and installed renewable energy capacity for power generation in Thailand, 2021.
Source: (DEDE, 2022)

The majority of Thai power generation is sourced from thermal power plants of EGAT and independent power producers.

The structure of the power sector in Thailand is based on the so-called "Enhanced Single Buyer Model". The generation assets are owned by EGAT (around 30%) and private power producers (IPPs (23%), SPPs (25%), and VSPPs (6%))[2]. The remaining 16% of installed capacity are sourced from outside the country and are delivered to Thailand through electricity imports. Renewable energy generation capacity is mostly owned by EGAT and VSPPs through the Adder/Feed-in Tariff (FiT) programs. EGAT also owns 100% of the transmission assets. Two distribution utilities operate the transmission grids and retails: MEA is responsible for Bangkok and neighboring provinces while PEA is responsible for the remaining provinces. The current power market remains regulated by Thai Energy Regulatory Commission (ERC).

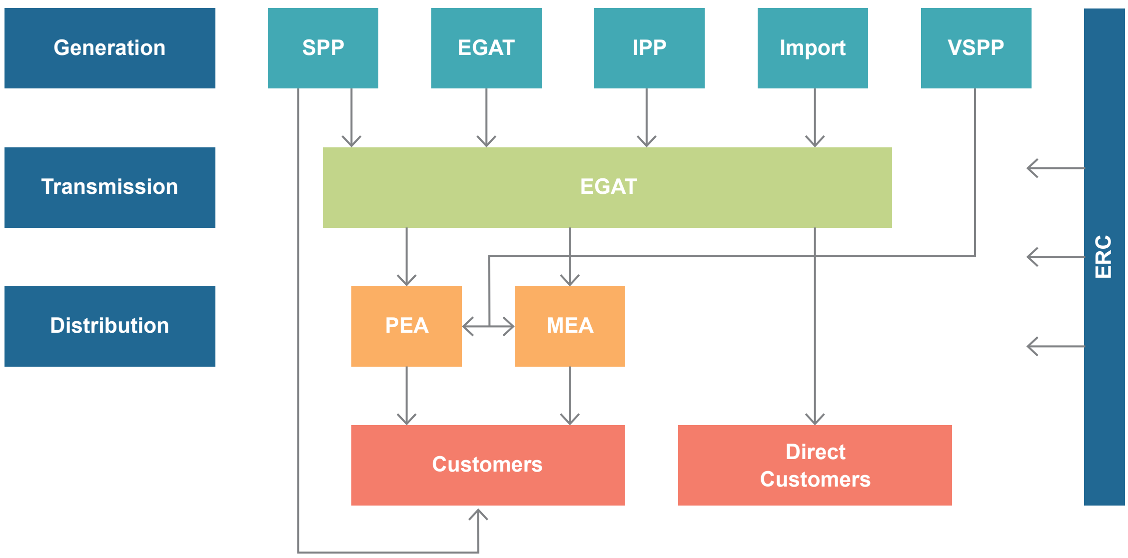


Figure 1.5: The power system structure in Thailand.
Source: (Chaianong et al., 2019)

[2] IPP: Independent Power Producer, SPP: Small Power Producer, VSPP: Very Small Power Producer

Thailand has pushed for reforms of the Thai electricity market to support renewable energy generation.

In recent years, efforts have been made to promote third-party access (TPA) to the transmission and distribution grids. TPA allows private electricity generators to directly buy and sell electricity to consumers. Although TPA could increase competition in the electricity market and require more renewable energy from the private sector, ERC is hesitant to move forward due to concerns about higher electricity prices. In this context, ERC established the ERC Sandbox Program in 2021 to test new technologies and business models, including local electricity markets, RE energy trading and carbon trading.

Thailand has begun to actively formulate policies and platforms to promote climate change targets.

The Energy Policy and Planning Office (EPPO) is in the process of preparing the National Energy Plan (NEP) as a new strategic plan supporting energy transition to achieve carbon neutrality. This plan will combine and synchronise five energy action plans, namely the Power Development Plan (PDP), the Alternative Energy Development Plan (AEDP), the Energy Efficiency Plan (EEP), the Oil Plan and the Gas Plan. The NEP is a combination of top-down and bottom-up approaches following the ambitious net-zero target and technology drivers based on the latest energy trends while, at the same time, integrating subsequent action plans from both the supply and demand sides. The plan is based on the main framework called “4D1E4” which was adopted to support and prepare Thailand in its energy transition. In addition, the NEP aims to increase the share of renewable energy used to generate electricity to 50% by 2050, as well as reduce energy intensity and promote the uptake of EVs. The country’s most recent EVs goal – known as the 30/30 policy – is to reach at least a 30% share of EVs from domestic vehicle production by 2030 (Tungsuwan et al., 2021).

Aside from the energy sector, Thailand has used the Bio-Circular-Green (BCG) model as part of its national economic agenda to strengthen the competitiveness of four industry value chains: agriculture and food; medical and wellness; bioenergy, biomaterials and biochemicals; and tourism and the creative economy. The BCG model, which aims to use natural resources more efficiently while minimizing environmental impacts, will support the development of alternative fuels from locally available bio resources, potentially reducing foreign fuel imports. Among BCG’s strategies are the implementation of carbon footprint labeling, green labeling, environmental labeling, carbon pricing and the polluter pays principle. For financial institutions, the Working Group on Sustainable Finance has been set to work on the guidelines for a Sustainable Finance Initiative for Thailand. A green taxonomy (i.e., defining and categorizing economic activities based on their greenhouse gas emissions) is being developed, and taxonomies for the energy and transport sectors are expected to be completed by 2023.

In addition, taking stock of the global trend in developing renewable energy – as well as the coming implementation of carbon border adjustment mechanisms in the EU and the U.S. – the Thai private sector has pushed for the development of more renewable energy sources and has promoted platforms for trading renewable energy and carbon credits under the ERC sandbox program. The RE100 Thailand Club was established in 2021 to encourage Thai industry to use 100% renewable energy. In addition, some companies have expressed goals of achieving carbon neutrality targets, such as Toyota Motor (Thailand) Co., Ltd. with a carbon neutrality target for 2035 (Toyota, 2021), DENSO (Thailand) Co., Ltd. with a goal of utilizing 100% renewable energy by 2035 and EGAT with apolicy of carbon neutrality by 2050 (The Nation Thailand, 2021; EGAT, 2021).

Developing an inclusive long-term energy scenario framework

Developing an inclusive long-term energy scenario framework

Energy and climate policy to reach net-zero requires new planning and implementation practices that are more complex and more uncertain than in the past, given the required multi-sectorial approach and the technological and economic uncertainties. Designing relevant energy transition pathways requires active participation from all stakeholders. It is imperative that the scenarios' design not only reflect available technological solutions, but also build consensus amongst stakeholders on what the future may look like (IRENA, 2020).

A key part of this study was to closely engage with Thai energy and non-energy stakeholders. Throughout the study, Thai stakeholders were invited in an iterative process to provide input on visions, as well as assumptions and data for detailing and refining the energy and power system model. The process is depicted below:

Building scenarios based on collective visions for Thailand.

During the scenario building process, key energy and non-energy stakeholders were invited to discuss common visions for the energy transition in Thailand. All stakeholders agreed that a vision on energy and climate commitment is most important. However, at the beginning of the process, there were differing perspective on the speed of transition and, in particular, when Thailand could reach net-zero emissions (spanning from 2050 to 2090)[3]. Most stakeholders agreed that socioeconomic factors should be put at the forefront. Industry stakeholders envisioned increasing the competitiveness of Thai industry at the global level while also ensuring co-benefits at the local level. Concerns regarding affordability were also regularly mentioned. Energy stakeholders elaborated on Thailand's opportunity to become a regional technology hub, increasing the share of renewables and electric vehicles while modernising its energy infrastructure. Energy utilities prioritised energy security concerns and the reduction of fossil fuel import dependency through scaling up the production of indigenous variable renewables.

Based on the discussions, common visions for the future of the Thai energy system were formulated as depicted in Figure 2.2. The key drivers included cost efficiency, technology maturity, global trends and country-specific policy preferences.

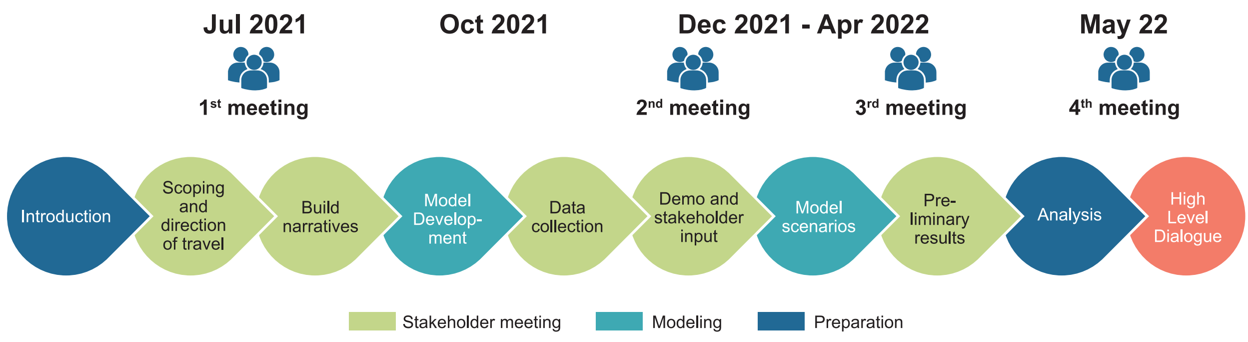


Figure 2.1: Stakeholder engagement process.

[3] A series of discussions was conducted in July 2021 before the carbon neutrality announcement by the Prime Minister in October 2021.

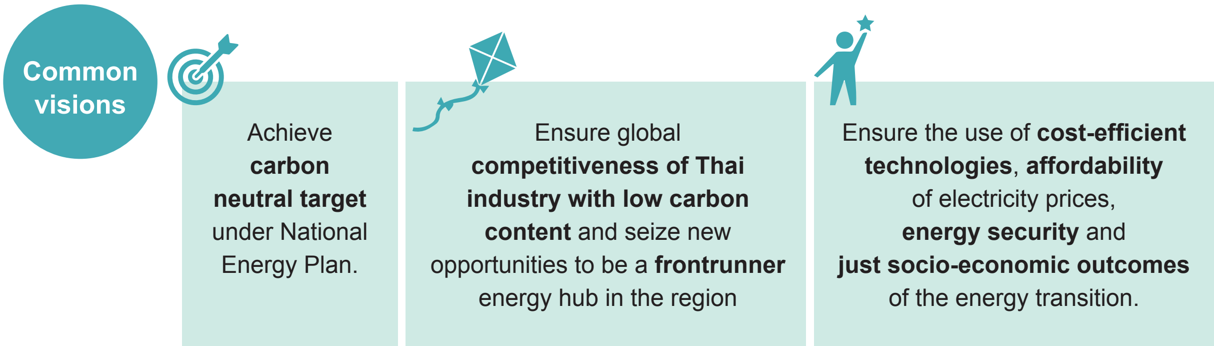


Figure 2.2: Common visions discussed with Thai stakeholders.

Global trends, technology maturity and cost as drivers.

With 75% of global GHG emissions coming from the energy sector (with electricity and heat generation as the largest emitting sector), building scenarios on the energy sector transition is a key component for showcasing how to achieve climate goals. There is no one size fits all pathway, and many possible scenarios could be built from various measures and speeds of the energy transition to achieve climate goals, considering availability of resources, the pace of innovative technology development, policy directions and regulatory and behavioral changes in the country context.

In global scenarios, renewable energy and energy efficiency represent immediate measures to be undertaken in the near-term to reduce CO2 emissions as technologies are commercially available, while electrification of end-use sectors and green hydrogen are critical for meeting long-term carbon emissions reduction goals.

Building on various global scenarios to achieve climate goals, five key technological transitions in the energy sector have been highlighted, by the IEA and IRENA, as main pathways to achieve global net-zero emissions and the 1.5 degrees C climate goal by 2050:

- renewables in the electricity sector and direct renewables in end uses
- energy efficiency
- electrification of end-use sectors
- clean hydrogen and synthetic fuels
- carbon capture, utilization, and storage (CCUS).

Readily available technology such as renewable-based electricity and energy efficiency represent immediate opportunities to significantly contribute to CO2 emissions reductions in the short-term. In the IEA's net-zero scenario, solar, wind and energy efficiency contribute to about 50% of emissions reductions in the next decade. In addition, the use of bioenergy in transport and industrial applications also plays an important role in reducing emissions in the near-term (IEA, 2021b). These mitigation options, such as solar PV, wind energy, energy efficiency and electrification of the transport and building sectors, were assessed as relative cost-effective options based on estimated net lifetime costs of avoided GHGs to reduce net emissions (IPCC, 2022).

A zero-emission power sector is a robust characteristic of carbon-neutral systems.

Many modelling studies looking at carbon neutrality demonstrated a significant role for a fully decarbonised power system due to technology readiness. The trends in the power sector towards digitalisation, decentralisation and electrification will be critical for accelerating the energy transition to meet long-term emissions reduction goals (WEF, 2017). In most 1.5 degrees C global scenarios, power sector emissions should reach zero by between 2040 and 2050.

As the electricity sector will have been thoroughly decarbonised, electrification of end-use sectors, either directly or indirectly through the use of green hydrogen, will be the next critical pathway (when certain technologies have emerged on a larger commercial scale) to achieve climate goals (IRENA, 2022b). Figure 2.3 illustrates readiness levels of technologies for electricity generation, infrastructure and electrification of end-use sectors (IEA, 2020). Accelerated deployment of green hydrogen and sustainable biomass are key solutions for reducing emissions in hard-to-abate sectors, while also contributing to energy security to achieve the 1.5 degrees C pathway by 2050 (IRENA, 2022b).

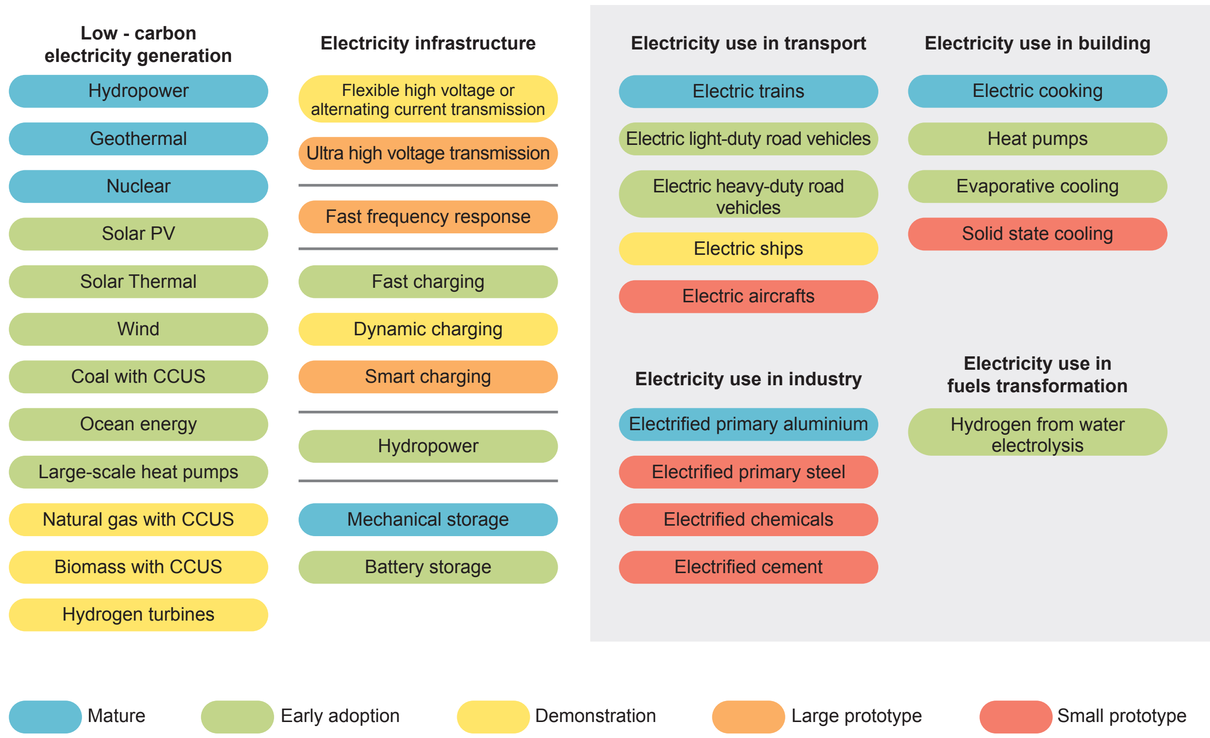


Figure 2.3: Readiness of technologies in the low-carbon electricity value chain.
Source: (IEA, 2020)

Technology readiness (e.g., costs, technology maturity, policy preferences, market and country conditions) is a cost-efficient principle used in scenario building to set short-term and long-term pathways for the uptake of available technology options to reduce emissions in the energy sector. In addition to technological readiness, an orderly transition across the energy sector is needed to ensure security of fuel and electricity supplies at all times, minimize stranded assets where possible and avoid energy market volatility (IEA, 2021b).

The IEA's in-depth global net-zero scenario (2021) is designed to determine pathways considering technical feasibility, cost-effectiveness, economic growth and security of energy supplies to achieve the target without relying on negative emissions technologies or carbon sinks. Following multiple scientific studies, the land sink should not be relied upon to reach net-zero emissions due to uncertainties in both natural and human-induced factors, such as climate variability in temperature, rainfall and deforestation. These findings are significant for policymakers' decisions on reducing fossil fuel use (Goswami, 2021). The role of carbon sinks should be considered a last resort for other hard-to-abate sectors such as agriculture, rather than offset alternatives for the energy sector, which is economically more readily decarbonised due to the availabilty and cost-effectiveness of available technologies.

Based on consultations with a broad range of stakeholders, Thailand's energy system transition was modelled in two distinctive scenarios.

Two scenarios were constructed, aiming to reflect stakeholders' input as well as inform different policy measures to transform Thailand's energy sector. The two scenarios differ in the speed and ambition of the transition: the first maintains existing energy infrastructures and does not conform with the net-zero commitment, while the second considers an accelerating diffusion of low-carbon technologies as observed globally, leading to net-zero emissions in 2050.

The reference scenario (REF) assumes a continuation of traditional planning, where Thailand explores the possibility of meeting development, energy and climate targets without a significant transformation of the energy system. The scenario is driven by existing policies (e.g., the latest Power Development Plan). Since development of renewable energy technology may be constrained by existing contractual operations, emissions reduction is not rapid enough to meet the global climate challenge. This also implies a reliance on future non-mature technologies.

The carbon-neutral 2050 scenario (CN) assumes a clear policydirection on renewable energy and sustainable industry, making Thailand a regional leader of the energy transformation. This scenario is driven by a cost-optimal transformation of Thailand's energysystem to reach carbon-neutrality goals. It is based onincreasingly available andeconomically viabletechnology but requires a fundamental redesign of the way the system is planned and operated.

Both scenarios consider similar general macro-economic assumptions (such as population and GDP growth). The model ensures uninterrupted service to citizens (i.e., electricity demand is met at all times), making conservative assumptions to ensure system stability (i.e., 20% of dispatchable generation is available at all times to provide balancing services, but in a more modern power system those services could actually be overtaken by other power-electronics technologies, such as batteries).

	Reference scenario	Carbon Neutral 2050
Power generation	**Increase RE** to at least 30% at 2030, based on existing policy Based on revised PDP2018 Rev.1 during 2021-2030 annouced in Nov 2021	Faster deployment of **RE and storage**, including at utility scale and prosumers **Phase out of coal** power plant **Flexible system operation**
Transmission	Increase interconnection **based on existing plan**	Increase interconnection **based on optimization**
Energy demand or End-use	Reduce intensity more than 30% using modern technologies and energy management innovations 100% **zero emission vehicle** sales in 2035 Fuel switch from coal to biomass, electrification of heat	**Increase efficiency** by higher efficiency rating and benchmarked technology in ASEAN or beyond 100% **zero emission vehicle** sales in 2030 Fuel switch from coal to biomass, electrification of heat **Hydrogen** for heat generation in industry

Policy driven, based on government data | Policy driven, based on expert assumptions | Cost driven, based on regional/global assumptions

*more detail assumptions in the Annex.

Infobox

Comprehensive tools to model the Thai energy transition

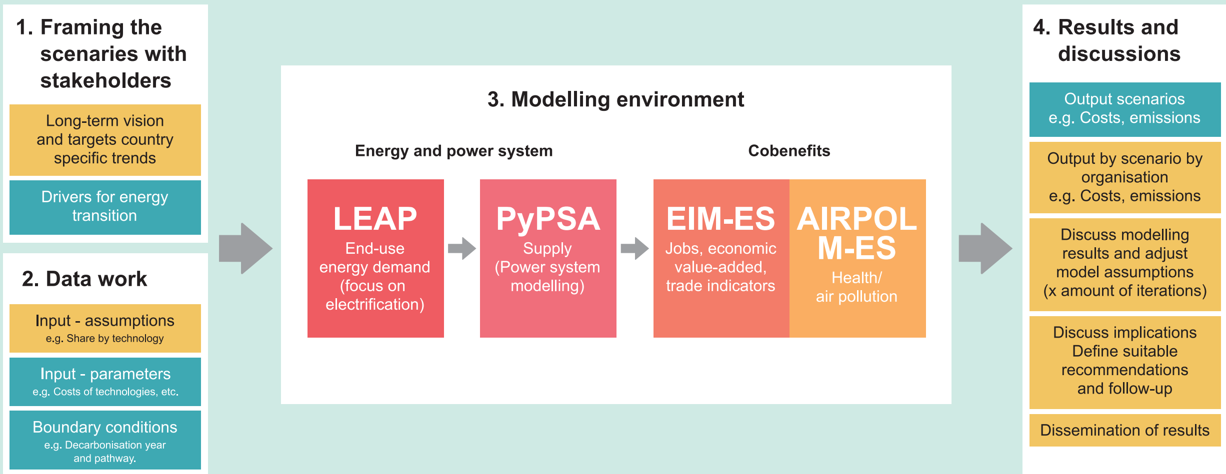
The study used four main tools to analyse the energy transition pathways (more details in the Annex):

The long-term evolution of **energy demand** was conducted using the LEAP modelling framework, which is widely used in the region. Energy demand was represented through a mix of bottom-up and top-down approaches. Industry sub-sectors were represented and clustered into high-temperature heat demand and low-temperature heat demand, following a top-down approach. The modelling of the residential and transport sectors followed a detailed bottom-up approach. The impact of the electrification of end-use energy demand was analysed through macro-economic assumptions and an assessment of techno-logical global trends (e.g., the growth of EVs and other electric appliances).

The **power sector** analysis was conducted using the open-source tool PyPSA. The model represents over 40 technologyoptions for power generation and industry heat supply, including emerging technologies, such as PtX, CCUS and battery storage. The Thai power system was represented by five different nodes, representing the most important regions and allowing analysis of cross-border trading. The model analyses multi-year capacity expansion under cost-optimization constraints.An hourly time resolution provides a robust analysis of power supply and demand and requirements for power system flexibility.

The **job creation and economic impact** analysis was conducted using EIM-ES, an Excel-based tool that covers all relevant electricity generation techno-logies – both low-carbon and fossil fuel-based plants – in order to provide an assessment of job creation under different future pathways. It also provides information on wider economic indicators such as investment requirements, economic value-added and trade.

The **impacts on health and air pollution** were analysed using AIRPOLIM-ES, an Excel-based tool that estimates the impacts on mortality (premature deaths and years of life lost) from four adulthood diseases: lung cancer, chronic obstructive pulmonary disease, ischemic heart disease and stroke, all of which are more prevalent with higher levels of pollution. The tool can be used to compare the magnitude of health impacts under different scenarios across both existing and planned plants.



Brief comparison between the reference and carbon-neutral scenarios.

Comparing the two distinct scenarios allows us to highlight some clear observed trends related to electricity and renewable energy growth and discern a clear picture of how Thailand can achieve its carbon-neutrality target.

Electricity and oil consumption remain predominant over the course of the transition and renewable electricity gradually replaces fossil fuel consumption, leading to electricity demand that is expected to double in subsequent decades.

In 2050, electricity is projected to cover at least 50% of total energy demand, highlighting the importance of power sector transformation. In the carbon-neutral scenario, total energy demand is lower, driven by more ambitious energy efficiency measures and a higher rate of end-use electrification (e.g., due to higher EV penetration and industry electrification).

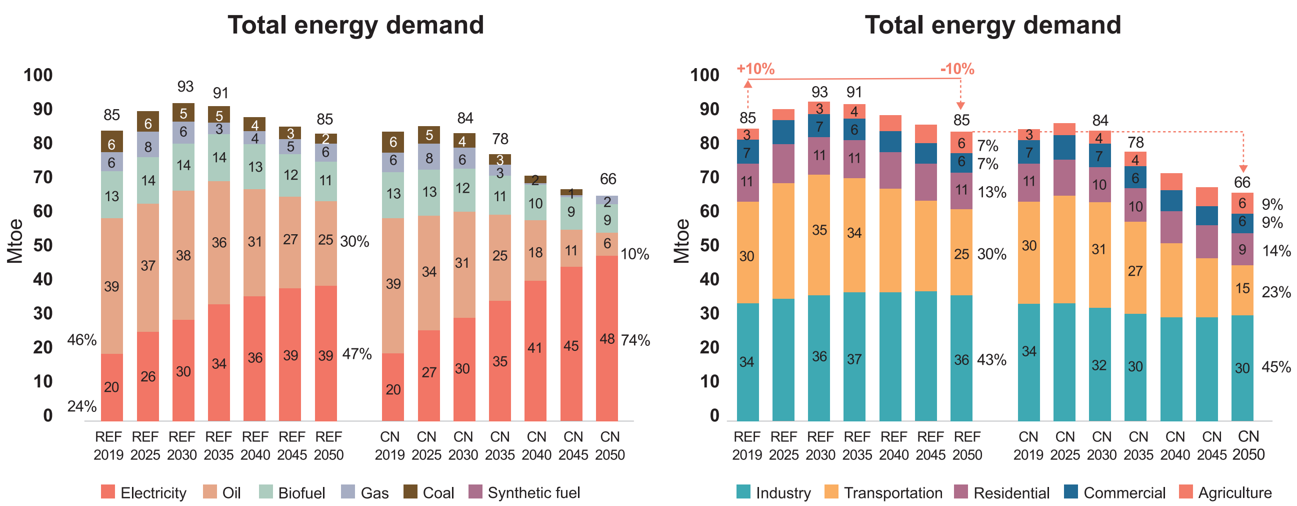


Figure 2.4: Total energy demand by energy carrier and by sector.

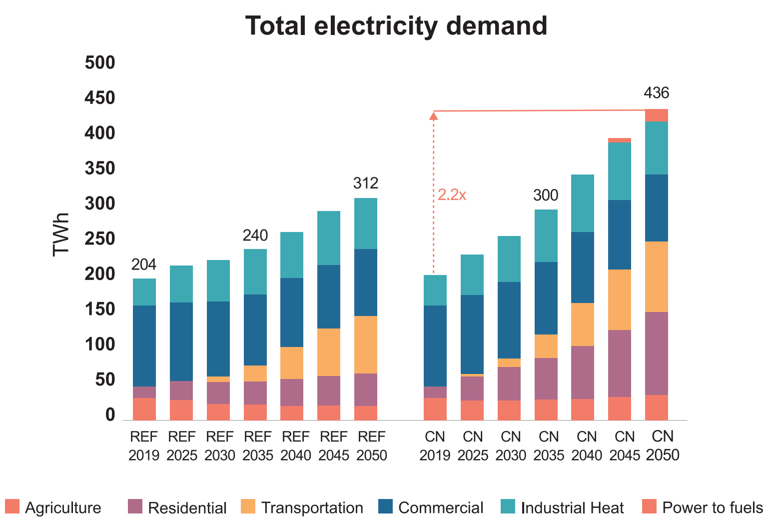


Figure 2.5: Total electricity demand.

Due to cost competitiveness, renewables grow in both scenarios. The scale of growth needed to reach carbon neutrality in 2050 requires a fundamental shift in the power sector investment structure.

In the reference scenario, 10 GW of solar PV are installed in 2030, accounting for 10% of total power generation. PV installation grows to account for 32% of total power generation in 2050. However, the share of fossil fuel generation remains high, with gas power still covering 50% of power generation in 2050, resulting in a modest decrease of CO2 emissions reduction (10 MtCO2eq over 30 years). In contrast, the carbon-neutral scenario shows a much higher penetration of solar PV (renewables covering 70% of supply in 2050), with annual emissions falling to 35 MtCO2eq in 2050

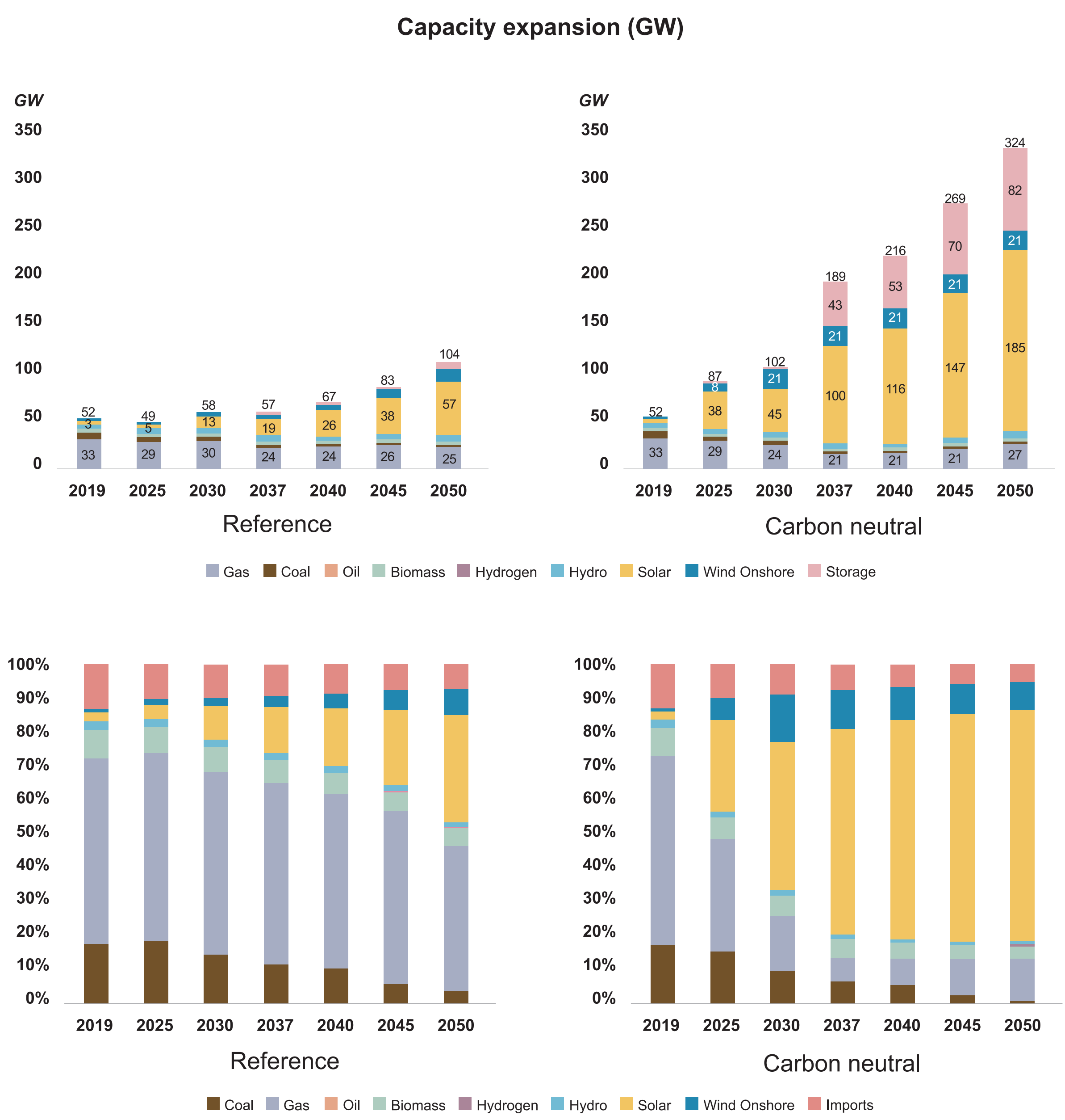


Figure 2.6: Capacity expansion (GW) and power generation mix (%).

Given the uncertainty surrounding carbon sink levels by 2050, reaching carbon neutrality may require even more radical action.

The carbon-neutral scenario investigated in this study, while ambitious, may actually not be totally aligned with the 2050 carbon-neutrality target. This scenario still emits about 60 MtCO2eq in 2050 (assuming a coal phase-out for power generation and steelmaking), not taking into account non-energy related emissions (such as those in the agriculture sector). Maintaining coal operation for steelmaking would increase those remaining emissions to 30 MtCO2eq per year. This scenario is labeled "carbon-neutral" because of the important role played by sinks in Thailand.

Based on its long-term strategies, Thailand is assumed to increase its carbon sinks to 120 MtCO2eq in 2050 (compared with between 60 to 90 MtCO2eq based on historical trends). However, the reliance on negative emissions is a highly uncertain strategy. Delaying mitigation in some sectors, such as the power sector, which could be completely decarbonised based on mature technologies will also affect the availability of large-scale carbon sinks for other sectors, such as the agriculture sector, which cannot be totally decarbonised. The share of carbon sinks should be reserved primarily for reducing greenhouse gas emissions in those sectors (industrial processes, waste and agriculture, which may range in total from 35 to 95 MtCO2eq in 2050). To reduce the risk of having insufficient CO2 sinks, the government should accelerate actions based on mature technologies in "easy-to-abate" sectors, such as power generation.

It is also important to note that the presented pathway is not aligned with the 1.5 degrees C emissions range analysed for Thailand. Alignment with this range would mean reducing emissions in the power sector to zero in 2045, or even reaching zero emissions for the whole energy sector. Given the uncertainties in the available level of carbon sinks, a more ambitious decarbonisation pathway may be required to reach net-zero emissions in 2050.

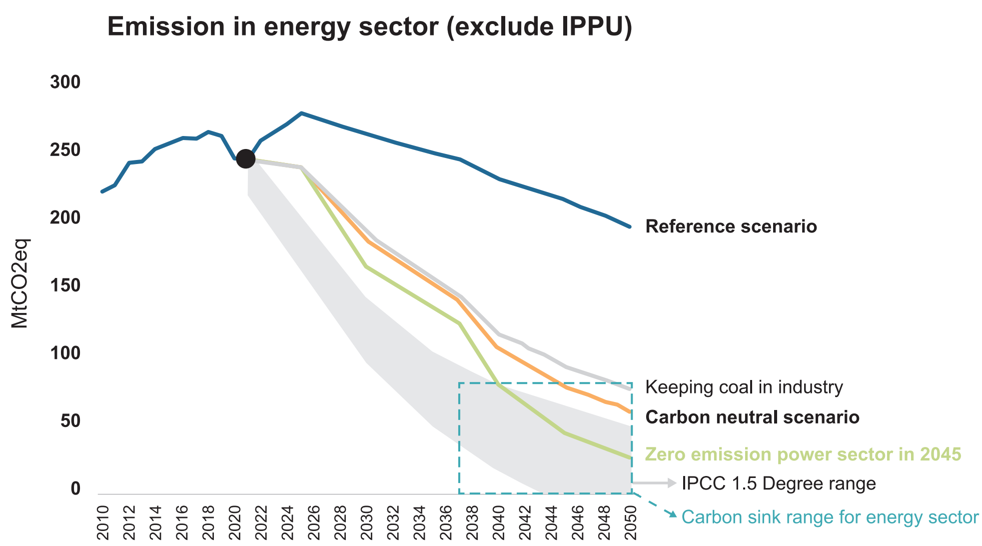


Figure 2.7: Emissions in the energy sector based on several scenarios.

The pathway towards carbon neutrality by 2050

The pathway towards carbon neutrality by 2050

The pathway depicted here represents the outcome of several "what-if?" thought experiments. It is not the only pathway for reaching Thailand's goal of carbon neutrality, but represents a plausible, while ambitious, pathway framed by the following guiding principles:

- the power sector is the key enabler for decarbonising several other end-use sectors (low-temperature heat in industry, electric vehicles in transport, etc.)
- the best technologies are available at decreasing costs over the course of the transition, following global trends (e.g., electric vehicles)
- Thailand's pursuit of its vision to become a front-runner in the energy transition
- carbon sinks are available to offset remaining emissions
- the power and heat supply side are decarbonised solely under cost-optimization constraints, without additional climate constraints

These principles resulted in both immediate emissions reductions based on mature technologies in the power and industry sectors, as well as an equal contribution of power, transport and industry to reduce emissions throughout 2050.

This section lays out a pathway to carbon neutrality in the energy system[4] in three steps:

By 2023	By 2030	By 2037	By 2050
overall CO2 emissions peak	reduce by 30% against 2019 levels	emissions are reduced by 50% against 2019 levels	Thailand achieves carbon neutrality through a phase-out of fossil fuel and phase-in of green molecules.

[4] The text focuses on the building, transport, industry and power sectors. Energy consumption in agriculture is covered and the transformation includes mostly switching from diesel to electric-based machinery, reaching 50% of energy consumption in agriculture by 2037.

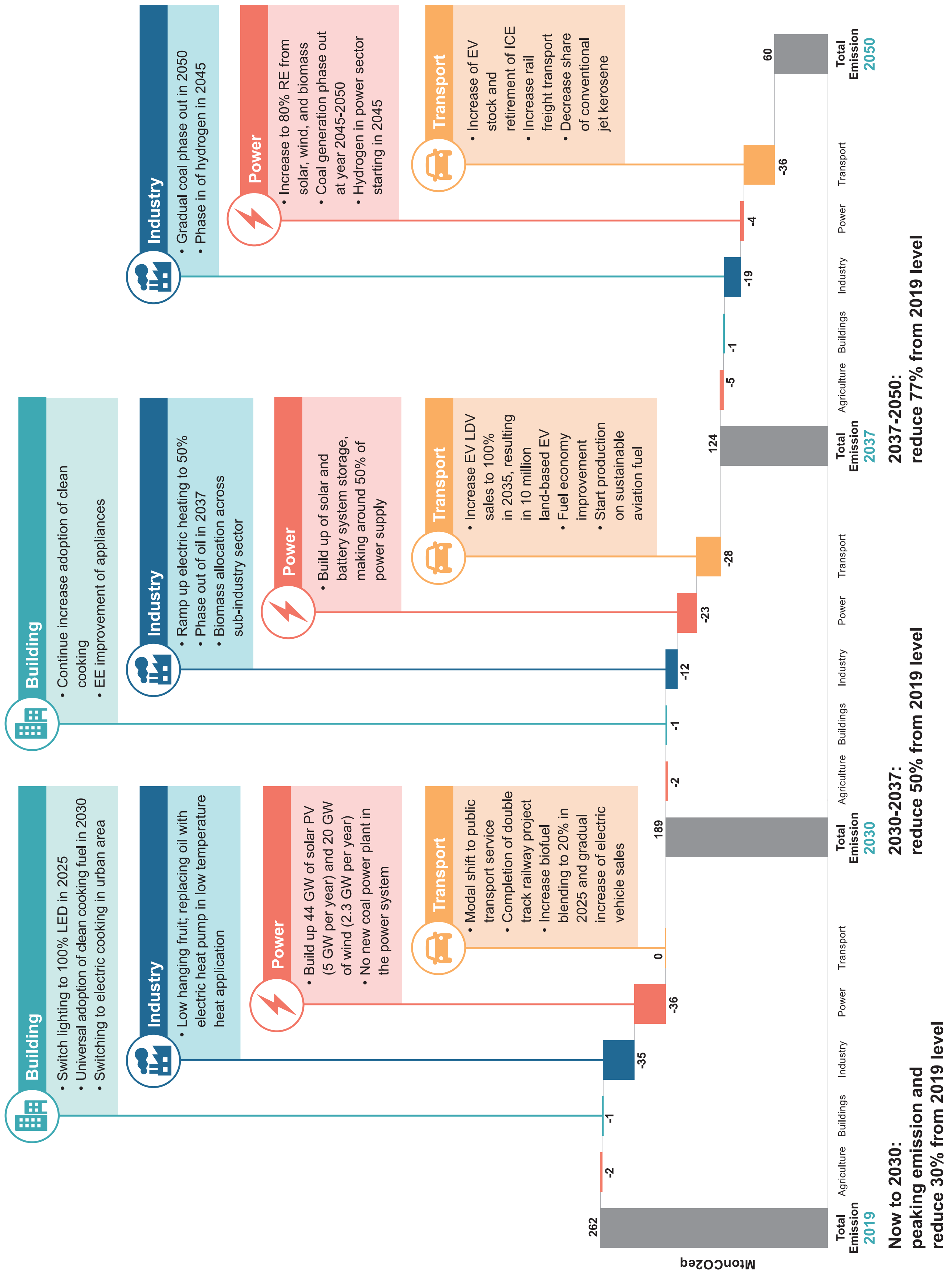


Figure 3.1: Three steps to carbon neutrality.

Step 1: Peaking emissions immediately and reducing energy-related emissions by 30% in 2030 against 2019 levels

Thailand's energy demand is expected to increase sharply in the coming years, mostly driven by population growth and the post-COVID-19 recovery. Despite this economic growth, the first important step is to curb CO2 emissions as quickly as possible by increasing investment in zero-carbon technologies, especially in the power sector. In addition, quick gains can be made in decarbonising Thai industry given its significant use of low-temperature heat which can be switched to direct electrification. **In total, the power and industry sectors are the main contributors during the first phase of the transition, with a reduction potential of 73 MtCO2eq in 2030 compared to 2019.**

In the power sector, the acceleration of renewables uptake is one of the main contributors to achieving greater emissions reduction. Due to its cost competitiveness, solar PV will be the main source of renewable power supply. The build-up of solar PV (around 5 GW per year) and onshore wind (around 2 GW per year) results in a total installed capacity of 64 GW of variable renewables in 2030 (44 GW of solar PV and 20 GW of onshore wind). Together with hydropower, renewables supply more than 120 TWh of renewable electricity (corresponding to 60% of total power generation). This capacity expansion is radical and about 12 times higher than the existing pipeline of projects – 3 GW – planned in the next 10 years. It is, however, not unimaginable, especially given the exponential trend seen in the global solar PV market[5]. At the same time, electricity generation from fossil fuel power plants will slightly decrease. Coal power generation will decrease from 18% today to 8% in 2030. This also implies that no new coal-fired power plants can be built in the power system, as they would be incompatible with the CO2 reduction pathway and represent a high risk of stranded assets (due to high costs and the increase of renewables uptake that reduce the capacity factor of coal power plants). A reinforcement of transmission grids across the various regions of the country, as well as flexible operation of gas power plants, will support the integration of variable renewables by enhancing power system flexibility.

The dominance of low-temperature heat in the Thai industry structure (e.g., the food and beverages and pulp and paper industries) provides room for emissions reduction through readily available electrification technologies. A rapid increase in the installation of electric heat pumps can support the complete phase-out of oil boilers in those industry sectors, contributing to an emissions reduction of 35 MtCO2eq in 2030 (compared to 2019).

In the building sector, the diffusion of LED lighting technology can contribute to emissions reductions as low-hanging fruit, even though its total effect is moderate. Indeed, switching to 100% LED lighting in 2025 can save about 0.2 MtCO2eq annually. Additionally, clean cooking fuel is adopted fully by 2030, especially through the reduction of charcoal and fuelwood in rural areas, contributing to an additional emissions reduction of 1 MtCO2eq.

The transport sector is one of the key sectors with the largest transitional and contingent investment needs. (Transitional investments lead to incremental emissions reductions over time through measures such as modal shift. Contingent investments induce changes in other sectors instead of providing immediate emissions reductions, for example through the development of EVs). The rising demand for transport services is met through an increase of modal shift to

[5] According to (Solar Power Europe, 2022) global solar capacity within a decade has reached 1 TW in 2022 and is expected to reach 2.3 TW within the next 3 years.

public transport service. Two-wheelers continue to play a central role in public mobility and contribute to a gradual increase in EV adoption in the country. Around 3.2 million motorcycles will be on the street in 2030.

With high penetration of solar PV and increased use of biofuels blending to 20% driven by policy and gradual electrification of the transport and heat sectors, renewables are expected to cover 33% of total primary energy supply in 2030.

Step 2: Reduce CO2 emissions by 50% in 2037 compared to 2019 levels

During the second phase of the transition, the transport sector contributes to a larger share of emission reduction, followed by the power and industry sectors.

In 2037, renewable energy is expected to cover 50% of the total primary energy supply. This is made possible by using existing and mature technology, as well as upcoming technologies like battery storage, for which costs are expected to drop significantly. During this second stage of the transition, electricity will overtake oil as the major energy supply source, highlighting the importance of the transformation of the power sector. Some groundwork performed in the 2020s in improving the regulatory and market framework should enable an acceleration of low-carbon investments.

In the power sector, solar PV deployment continues, reaching about 50% of total power generation in 2037, contributing to additional emissions reductions of about 23 MtCO2eq. Battery storage systems will become cost-effective and reach the Gigawatt scale, supporting the flexibility of the power system's operation by absorbing excess solar production during the day and supplying it during the nighttime. Investing in power system flexibility and changes in operational practices will become a key priority of the transformation of the power system.

In the industry sectors, energy demand will stabilize to 2015 levels due to energy efficiency measures. Driven by cost decreases, fuel independence and high efficiency, electric heat pumps will provide the majority of the low-temperature heat supply. At this stage, the reallocation[6] of biomass towards the sectors most difficult to electrify will be crucial. Given its limited availability, biomass resources must be provided to the sectors that need it most. Its use will therefore need to shift from the current provision of low-temperature heat to high-temperature heat in heavy industry.

In the building sector, a 30% energy efficiency gain for electric appliances (air conditioners, refrigerators and other appliances) compared to 2010 levels resulted in an 18% reduction in energy demand. The adoption of clean cooking will continue, especially through the switch to electric cookstoves that will become standard in new buildings in urban areas.

Electric vehicles dominate the transformation of the road as battery-powered two-wheeler, car and bus sales will increase to 100% in 2035, resulting in 10 million land-based EVs. This target increases electricity demand while reducing energy consumption of passenger transport by a total of 88 Mtoe, resulting in a reduction of 28 MtCO2eq.

[6] In this study, we assume a constant level of sustainable biomass.

Step 3: Reach carbon neutrality in 2050 through the total phase-out of fossil fuels and increase of green fuels

By 2050, urban and rural energy demand shares will flip, with urban areas constituting 60% of residential energy demand. While the population starts to decline, energy consumption per household will increase in urban areas. Electricity demand in the residential sector will double mainly due to space cooling. Liquefied petroleum gas (LPG) consumption will fall further to around 15% of cooking fuel and will be replaced by electrification alternatives.

The power sector will continue to drive the decarbonisation of the entire energy system. Renewable energy provides around 80% of total power generation, while coal generation will gradually decrease from 2% of generation in 2037 to be completely phased out in 2050. Zero-carbon gas will contribute to further decarbonise the Thai energy system, in particular the power sector, where it provides long-term storage. Beginning in 2045, green hydrogen blend in gas power plants will increase to 10 TWh, contributing to further decarbonise the electricity supply while ensuring power system adequacy during days characterised by low solar PV output (occurring mostly in July).

In addition to the power sector, green hydrogen produced locally through solar PV will provide a small fraction of high-temperature heat in industry starting in 2040. However, biomass will remain the main source of high-temperature heat (around 60%) and will completely displace coal use. This will result in a complete phase-out of coal use in the industry sector in 2050. Green hydrogen is expected to play a minimal role in road transport but will find some application in air transport. The share of conventional jet kerosene will be reduced by 2% p.a. from 2030 and will be substituted by bio jet and synthetic fuel. All new sales in freight transport are expected to be electric by 2040. Despite an ambitious target of EV sales, ICE vehicles are assumed to still be circulating in 2050 due to the high survival rates of vehicles, therefore highlighting the importance of stock turnover. All in all, modal shift, electrification and energy efficiency measures reduce energy demand in the transport sector by 50% compared to 2019 levels, contributing to a reduction of 36 MtCO2eq.

Properly planning the road to climate neutrality must take into account uncertainties and precise contributions of each sector, given their specific constraints and interactions between each other. In particular, the reliance on a large share of sinks to offset emissions that are not-that-hard-to-abate (such as in the power sector) is a risky strategy that may jeopardise the achievement of carbon neutrality. The next chapter will discuss key findings and strategies to reach carbon neutrality.

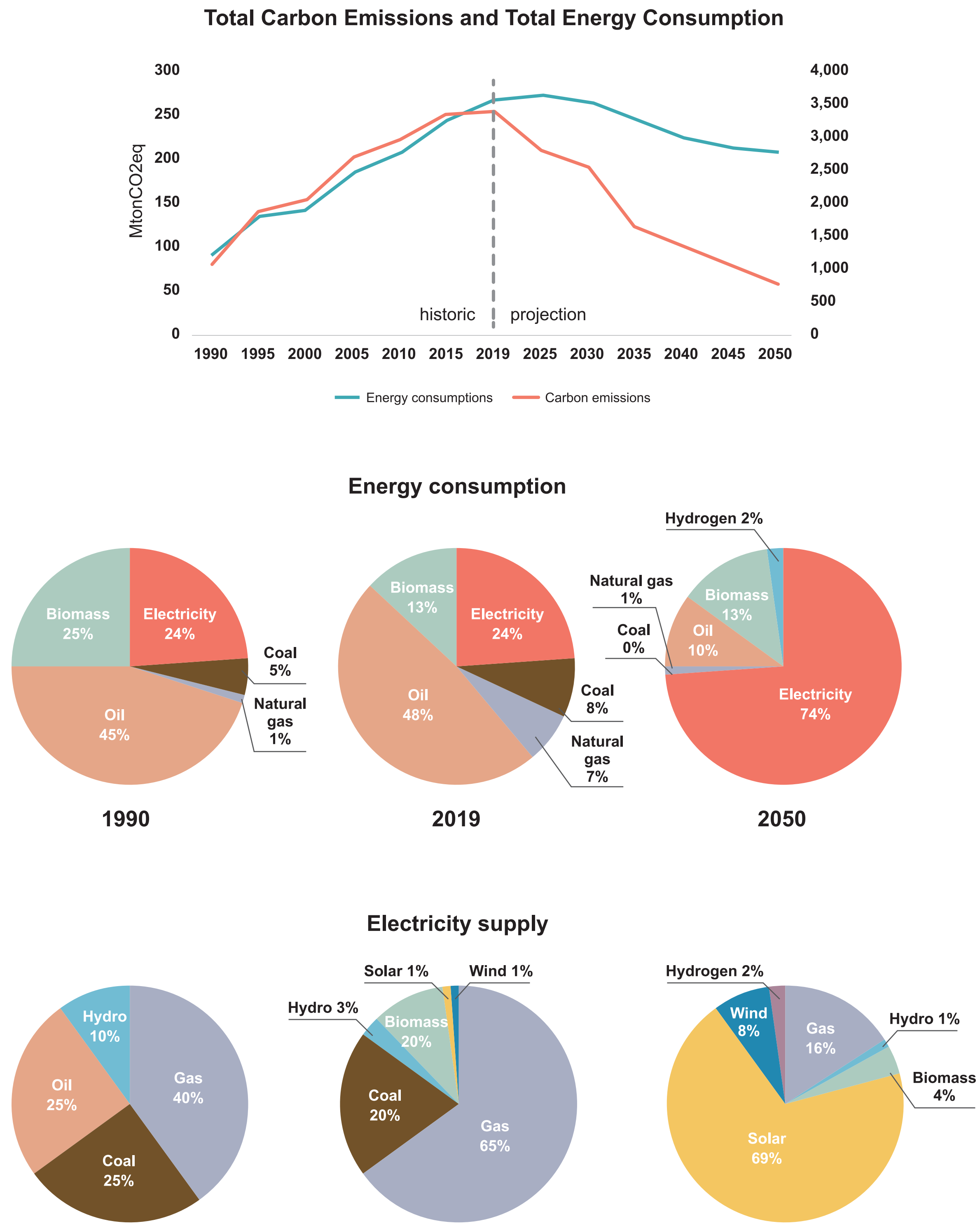
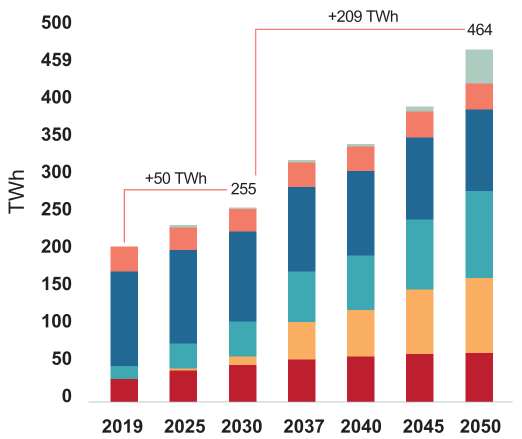


Figure 3.2: Reaching a low-carbon energy system requires a fundamental transformation of the ways energy is consumed and supplied.



	2030	2050
H_2	-	Production of 43 TWh
	Electrification of machinery	Electrification of machinery
	Efficient lighting, heatpump	Heat pump, Phase out LPG in 2050
	100% LED lighting, Universal clean cooking	Increase efficiency of appliances
	3 million electric motorcycles, 1 million private cars	All new vehicle sales are electric
	Electrification of low-temperature heat	Electrification of high-temperature heat

Figure 3.3: Gross electricity consumption per sector up to 2050.

Key findings and strategies to reach carbon neutrality in Thailand

The future Thai energy system will not be similar to that of today.

As Thailand pledged to reach carbon neutrality in 2050,

this transition to a low-carbon energy system will require a fundamental shift in the way energy is consumed and produced. It requires a radical transformation of the power system, driven by renewables deployment, as well as gradual electrification of end-use sectors and improvements to energy efficiency. In this chapter, we discuss in more detail four key findings and strategies to reach carbon neutrality:

Increase
low-carbon electricity supply through domestic renewables

Increase
power system flexibility

Transform
the transport sector

Transform
the industry sector

Increase low-carbon electricity supply through domestic renewables resources

Power systems become the backbone for the decarbonisation of the overall energy system through increased renewables-based electrification in all end-use sectors. Hence, decarbonising the power supply is a key prerequisite for energy-system decarbonisation. This can be achieved through a rapid increase in energy supply coming from renewables, especially solar PV, that both compensate for the increase in electricity demand and the reduction in the overall share of fossil fuel-based energy supply.

Putting Thailand on track to meet its long-term net-zero commitment requires an early and rapid expansion of renewables, driven by domestic solar resources.

The power system in 2050 will be based on 85% renewables generation, with the remaining covered by gas-fired and hydrogen-fired power plants.

During the first phase of the energy system transformation, the electricity supply from variable renewables must be increased to 110 TWh in 2030 (45% of power supply), including 74 TWh from solar PV and 35 TWh from onshore wind. Taking into account other renewables, such as hydro and biomass energy, the share of renewables must reach 60% of power supply in 2030. Due to limited availability of optimal wind resources in Thailand, generation from wind energy cannot significantly expand. With the further renewables-based electrification of end-use sectors, the share of solar power will continue to increase, reaching 167 TWh in 2037 and 306 TWh in 2050, corresponding to 52% and 65% of total electricity generation, respectively. In 2050, almost 85% of power supply is provided by renewables, including solar, wind, hydro and biomass. The integration of variable renewables is facilitated through flexibility options, including battery storage, and sector integrations, in particular EVs, electric heat and the production of e-fuels. Those technological developments are discussed in more detail in the following sections.

Meeting mid- and long-term decarbonisation targets requires rapid development of solar power.

Renewable electricity generation technologies specifically solar PV and wind energy have seen a rapid decrease in costs in the last decade. They are becoming the lowest-cost source of electricity generation and will play a key role in meeting long-term climate targets.

In the carbon neutral scenario, the capacity of solar PV (including rooftop) increases to around 44 GW by 2030, 100 GW by 2037 and 185 GW by 2050. Reaching these targets means adding approximately 5.5 GW/year of solar capacity until 2030, approximately 8 GW/year between 2030 and 2037 and 6.5 GW/year from 2037 to 2050. Even in the reference scenario, where gas continues to play a stronger role in the power system, solar power increases rapidly in the next 10 years – three times more than what is currently planned in the latest PDP (10 GW). Similarly, other long-term scenarios for the future of the Thai power system highlight that solar power can contribute up to 30% of electricity supply in 2030 ((Thai Government, 2021a); (IEA, 2021c)).

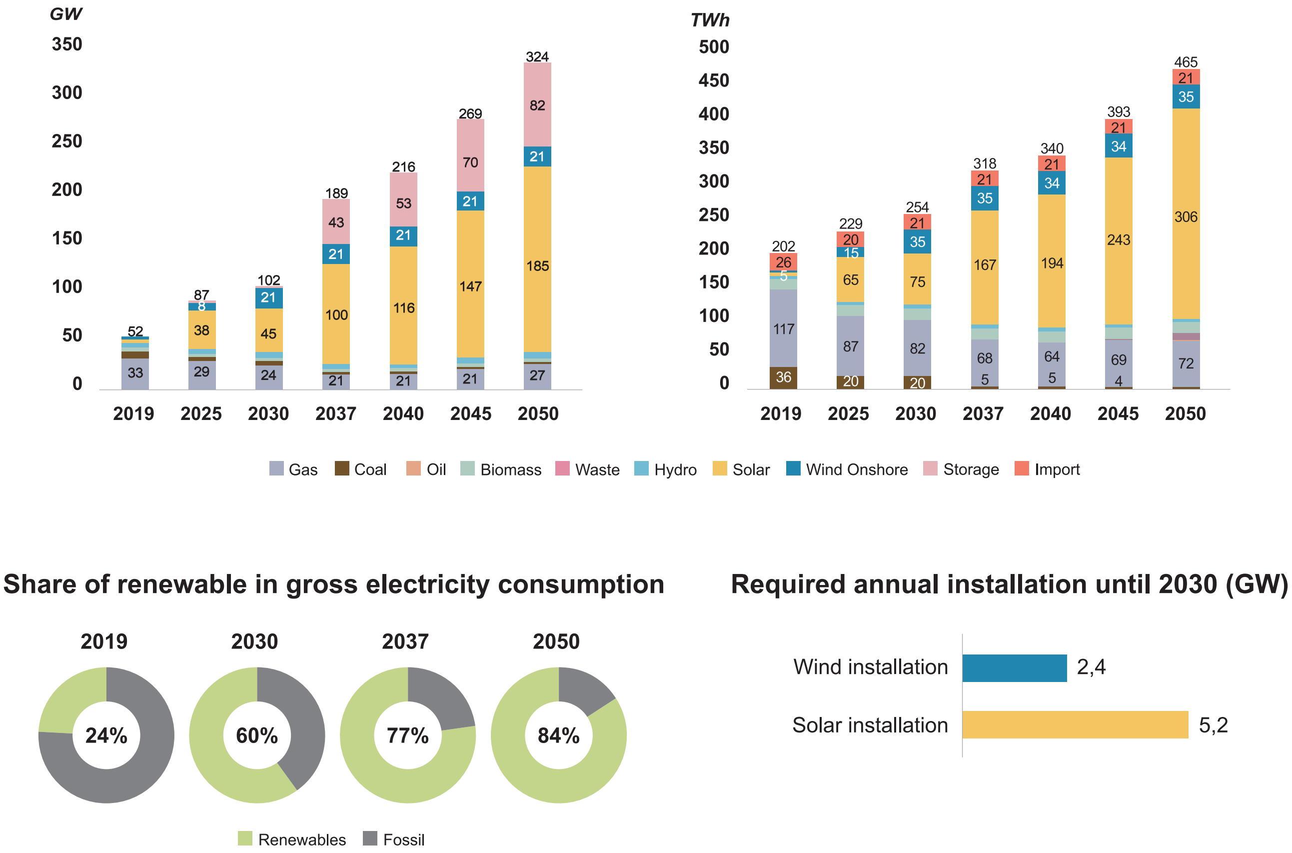


Figure 4.1: Capacity mix (GW) and generation (TWh) expansion in the carbon neutral scenario.

Large shares of solar PV can be integrated up to 2030 without waiting for battery storage. Reaching higher PV shares beyond 2030 will go hand-in-hand with a roll-out of cost-competitive storage solutions.

The falling cost of storage will act as an enabler for integrating the high share of solar capacity. Battery storage, especially Li-ion batteries, are undergoing rapid cost decreases primarily fueled by economies of scale from their application in EVs. In 2040, approximately 53 GW (160 GWh) of battery storage will be needed in the Thai power system. By 2050, the storage capacity will double to 82 GW (324 GWh).

However, until 2030, with installed solar capacity of approximately 45 GW, no additional battery storage is required for integrating solar PV into the power system. Solar PV can then be integrated into the power supply through other flexibility options, in particular the flexible operation of dispatchable power plants, flexibility provided by the grid and imports from neighboring countries. Only at the end of the 2030s will battery storage become system-relevant (even though battery storage may find applications in the power system before that, especially at the distribution level, to provide grid services and remove congestion). This development would then require supportive regulatory and market conditions to synchronize PV and battery uptake and accelerate cost reductions.

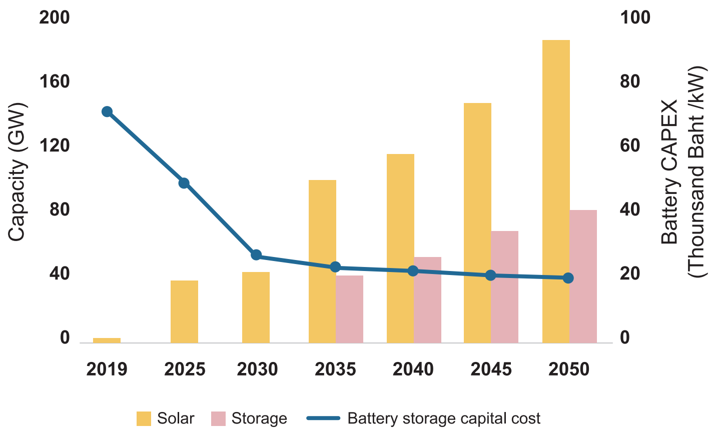
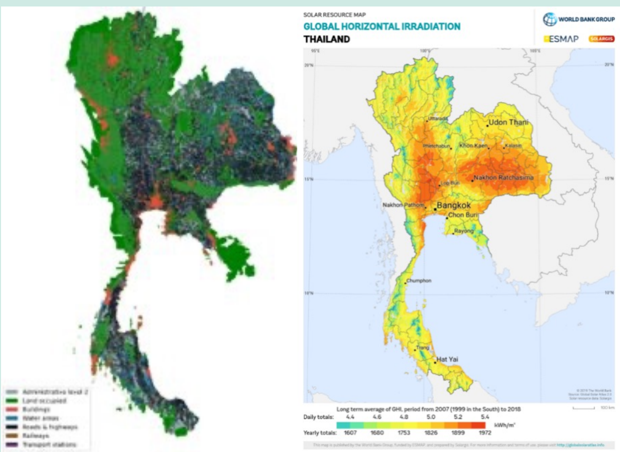


Figure 4.2: Battery storage expansion driven by falling costs.

Infobox

Potential of solar PV in Thailand and land use

In this study, the solar technical potential per region in Thailand has been calculated using GIS (Geo-Informatic System) analysis (with more details described in Annex C). The analysis is based on calculating land availability by considering vegetation areas, built areas, water bodies, transport infrastructure and mountainous areas. The analysis shows large solar technical potential, with more than 300 GW, while considering only high irradiance (>1850 KWh/m2), and only taking up less than 2% of total land area.



In the carbon neutral scenario, the solar capacity reaches 185 GW in 2050. A large share of solar capacity is concentrated in the central region. This is because of its proximity to the two highest load centers Central and Bangkok regions and the high level of interconnection already available between the Central and Bangkok regions. Since the highest capacity expansion is in the central region, it also sees the highest land area required for utility-scale solar installation, with around 630 km2 in 2050. This represents 0.68% of the total land area of the region and 73% of the land suitable for solar installation. Land-use for solar power plants is much lower in the North and Northeast regions, covering only around 0.05% of the total land used, and translating into 11% and 16% of unused land in each region, respectively.

Phase-out of fossil fuels to reduce economic risks.

No new coal power plants must be built, as they are incompatible with climate objectives and bear energy security and economic risks.

In 2019, fossil fuel-based power plants provided almost 80% of power generation in Thailand, with 58% (117 TWh) coming from gas and 18% (36TWh) from coal. Reaching the carbon neutrality target requires phasing out generation from both sources. In the carbon-neutral scenario, generation from coal-fired power plants is phased out after 2045. Given the long lifetime of coal power plants (i.e., 30 years), this means any new investments in coal power plants will not be in line with reaching climate goals. The current gas capacity, in combination with the expansion of renewables, is sufficient to meet the increased demand and maintain generation adequacy.

In 2021, Thailand's total coal consumption (including lignite) reached 39.6 Mt, which was almost equally divided between consumption for power generation (21.3 Mt) and industry (18.3 Mt). During the same year, Thailand imported around 24 Mt of coal, representing 60% of the country's total coal consumption. This raises significant energy security risks and economic vulnerability to international coal prices. The evolution of international coal prices is highly uncertain; however, recent years have seen a rapid increase in international coal prices, with an increase of more than five times since 2020 (Trading Economics, 2022) fueled by the current international energy crisis. High dependence on imported coal increases Thailand's vulnerability to such international shocks. Any addition of new coal power plants would be detrimental not just towards meeting climate goals but also towards Thailand's energy and economic security. With sufficient gas capacity in the current system to address both the adequacy and flexibility needs required by the uptake of variable renewables, the reduction of coal consumption in the power sector should be prioritized. This would almost completely eliminate Thailand's dependency on coal imports.

Generation from gas-fired power plants will also be cut by almost half between 2019 (117 TWh) and 2037 (68 TWh). Gas-fired power plants will continue to play an important role in providing flexibility to the system during the transition and in supporting supply adequacy in Thailand. In 2050, gas-fired power generation will provide around 16% (72 TWh) of electricity supply. With more ambitious climate goals, those gas-fired power plants should be able to run with low-carbon fuels, most notably green hydrogen (either pure or in the form of ammonia). Reducing the share of generation coming from natural gas-based power plants also decreases power system susceptibility to fluctuating gas prices.

Based on the Thai Gas Plan (Ministry of Energy, Thailand, 2018), pool gas (gas sources from the Gulf of Thailand, Myanmar and other long-term LNG contracts) is expected to decrease by 60% between 2018 (4676 mmscfd) and 2037 (1800 mmscfd). Continuing business as usual trends would require covering two-thirds of gas demand in 2037 with additional sources, potentially via imports. In the carbon-neutral scenario, energy efficiency measures, renewable uptake and end-use electrification result in a 60% decrease of gas demand in 2037 compared to 2019 levels, following the expected depletion of national resources. This essentially eliminates the need for Thailand to import gas, therefore decreasing risk susceptibility from global fluctuations of gas prices while increasing Thailand's energy security.

Despite the phase-out of coal power plants, generation adequacy is ensured at all times throughout the transition.

During the transition, sufficient resources are available in the Thai power system to meet peak load at all times, even during days with low solar resources and during hours with high inflexible demands. For example, in 2050, when the level of thermal capacity (coal- and gas-fired power plants) is reduced to 10 GW, adequacy is maintained through a combination of gas power plants (operating as peakers and potentially powered by clean fuels such as green hydrogen), battery storage, hydropower and imports. At this time horizon (60% solar PV in total power generation), the system sees strong fluctuations between days and months. During days with low solar generation, for example in July, the maximum solar peak generation is 50 GW lower (80 GW peak) than during days with high solar generation (130 GW peak). During daytime, peak solar generation is still higher than the inflexible power load. Furthermore, excess energy is stored in batteries and used to supply demand during part of the night. The production of synthetic fuels is reduced significantly during these days. The remaining energy is supplied through other available resources such as gas-fired power plants (natural gas or green gas), wind and hydro imports and potentially gas-fired capacities.

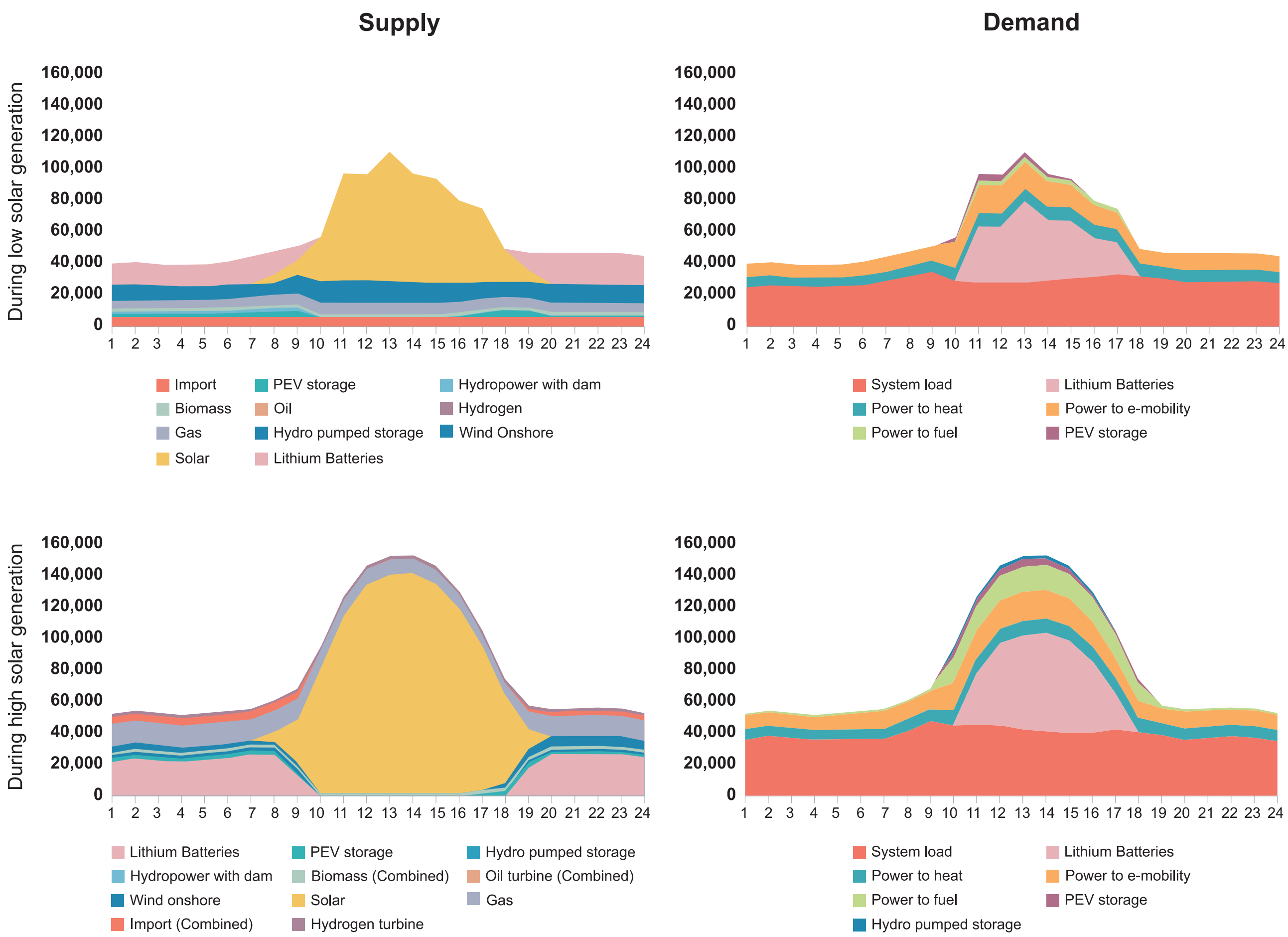


Figure 4.3: Supply during days with high and low solar generation and demand (GWh per hour) in 2050.

The long-term role of gas-based power plants in Thailand will be different than today.

The role of gas changes from providing base load to peakers and flexibility providers.

Currently, gas-fired power plants cover 60% of total power generation in Thailand. The level of installed capacity will decrease from 33 GW today to around 26 GW in 2050. Gas-fired power plants (running on natural gas or clean gas, such as green hydrogen) are still required to ensure system adequacy during times with low renewables output (June and July). They play a role as seasonal storage, but their capacity level is reduced (given the existence of other flexibility options).

In addition, the utilization of those gas-fired power plants changes significantly, as the total share of gas power in electricity production drops from 60% today to 16% in 2050. At the power plant level, the utilization rate drops significantly (from an average utilization of 40 to 45% today to an average utilization of about 30% for old power plants and 5 to 10% for new units in 2050). Gas-fired power plants move from a baseload or mid-merit technology to peakers and flexibility providers.

On the road to 2050, the economics and operating structure of gas power plants will change progressively as renewables enter the system.

This drop of utilization rate significantly affects the earnings and costs structure of power plants. This change will be particularly important for new investments that are not yet covered by long-term contracts (utilization of new power plants will be only about 5 to 10%). But this will also impact existing assets significantly during the transition, as utilization also drops to 30%.

This situation requires the design of new cost-recovery mechanisms for gas power plants that must take into account flexibility requirements along the trajectories of renewables intake. Additionally, renegotiations of existing contracts are necessary to ensure system cost savings and unlock the flexibility potential of power plants.

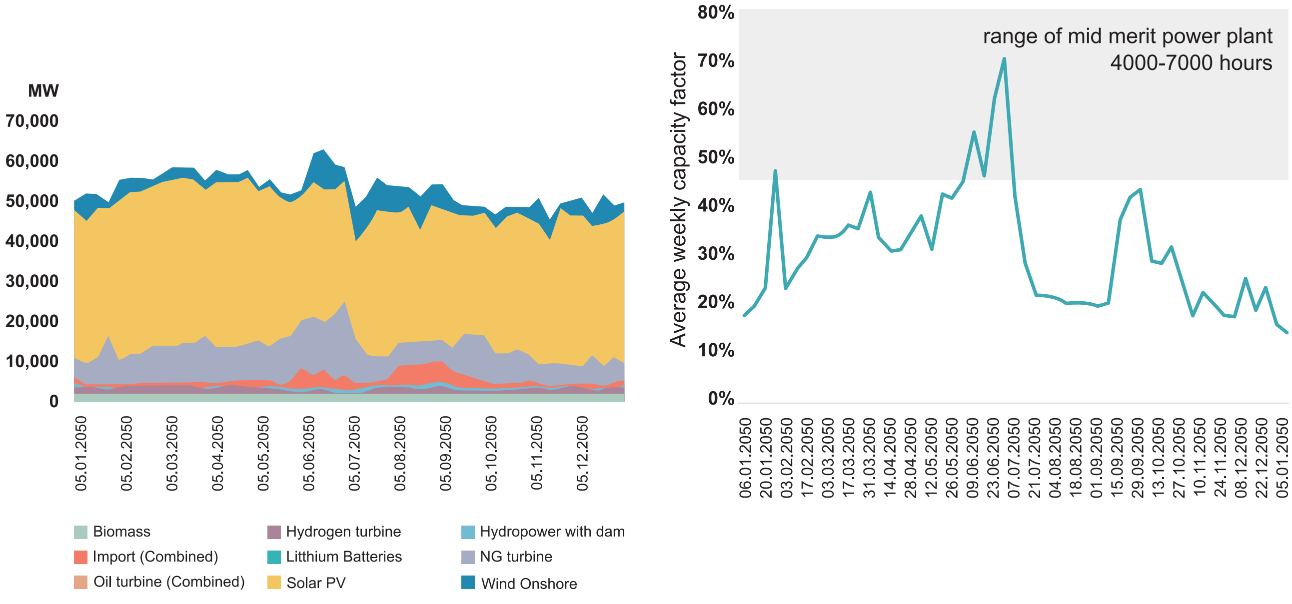


Figure 4.4: Average weekly generation and average gas capacity factor in 2050 (26 GW of gas installed).

To anticipate long-term needs, the government should develop a natural gas transition plan with all concerned stakeholders.

In addition to changing the role of gas-fired power plants, a gradual switch from natural gas to green hydrogen is also foreseen starting in 2045. At this stage, hydrogen will be cost competitive with the assumed gas price. The speed of the transition away from natural gas towards green hydrogen will depend on the level of climate ambition (and, in particular, the level of sinks dedicated to offset energy-related emissions), carbon pricing instruments and the long-term price evolution of fossil fuels.

This carbon-neutral scenario is considered conservative[7] as it still results in the power sector emitting around 38 MtCO2eq in 2050, all coming from gas-fired power plants. Other global carbon neutral or net-zero scenarios reduce power sector emissions to zero by 2040 or 2045. Thailand can reduce power sector emissions more quickly and deeply by switching sooner from natural gas to low-carbon hydrogen. In that case, the green hydrogen phase-in will be much faster, growing from 1% of power generation in 2037 to 18% in 2050.

One key strategy to meet this transition towards green hydrogen is to **ensure that any new investments in gas power plants be H_2-ready.** More globally, the natural gas policy of the Thai government should be assessed in greater detail, particularly in light of energy security and external price shocks, climate constraints and the optimal cost structure of the power plant mix.

[7] In addition to supply adequacy, gas power plants remain in the system due to model assumptions. Based on discussions with stake-holders, 20% of inflexible demand is assumed to be met by gas and biomass. These rotating generators provide inertia which maintain the stability of the grid. However, this is a conservative assumption, as frequency stability could also be provided by other technologies, such as hydro power and storage technologies.

Increase power system flexibility

Electricity is becoming a major energy carrier. With increasing uptake of variable renewable energy in the electricity mix, as well as new electricity end-uses such as electric mobility, power system flexibility is becoming the new paradigm of power system planning and operation. This means that the power system must cope with more variability and uncertainty on the supply and demand sides. (Historically, variability was mostly a demand-side constraint, while uncertainty mostly came from unexpected failures of generators or grid infrastructures).

In the short term, existing flexibility options can support variable renewables integration.

During the first phase of the Thailand transition (<5% share of VRE), the impact of variable renewables might be insignificant at the bulk power system level, but could be a challenge in some parts of the distribution grid.

The priority during this initial phase of the transition is to bring down costs of renewables (through supportive regulatory frameworks) and facilitate their integration into the grid (e.g., through a revision of grid codes). Several regulatory, financing and technical frameworks must be reviewed, in particular:

- designing appropriate technical regulations for grid connection
- assessing the capacity of existing grid networks and the potential need for grid expansion, avoiding generation hotspot through RES zoning instruments
- improving renewable forecast systems, including establishing a renewable energy control center
- promoting system operations practices closer to real time, incentivizing flexible operations of power plants

Beyond a certain level of VRE share[8], the impact starts to be perceived by the operator, requiring changes in operational procedures.

In the carbon-neutral scenario, generation from solar PV and wind energy can cover between 20% and 100% of total electricity loads, depending on the hour. This greater variability in net load profile requires some changes in operational practices of thermal power plants, including more frequent start-ups, shutdowns and cycling. Critical hours that require high flexibility from thermal generators typically occur between 8:00 and 9:00 am (when PV is starting to feed-in) and between 6:00 and 7:00 pm (when PV is starting to fade-out). But Thailand's power system has existing latent flexibility coming from gas and hydropower[9] which allow for integrating this share of renewables. However, these are often constrained by existing operational standards. One of the technical options to unlock this potential is reducing the minimum load level or minimum stable level (MSL) of gas power plants, for example from the current level at 60% to 30% (IEA, 2021c).

[8] Depending on the system challenges, can be 5-20% of VRE.

[9] Thailand obtains hydropower from local dams as well as imports from Laos. Flexibility can be provided by local hydropower plants. However, local dams are used not only for electricity generation but also for irrigation. The operation of local hydropower plants as peaking power plants must take irrigation constraints into account.

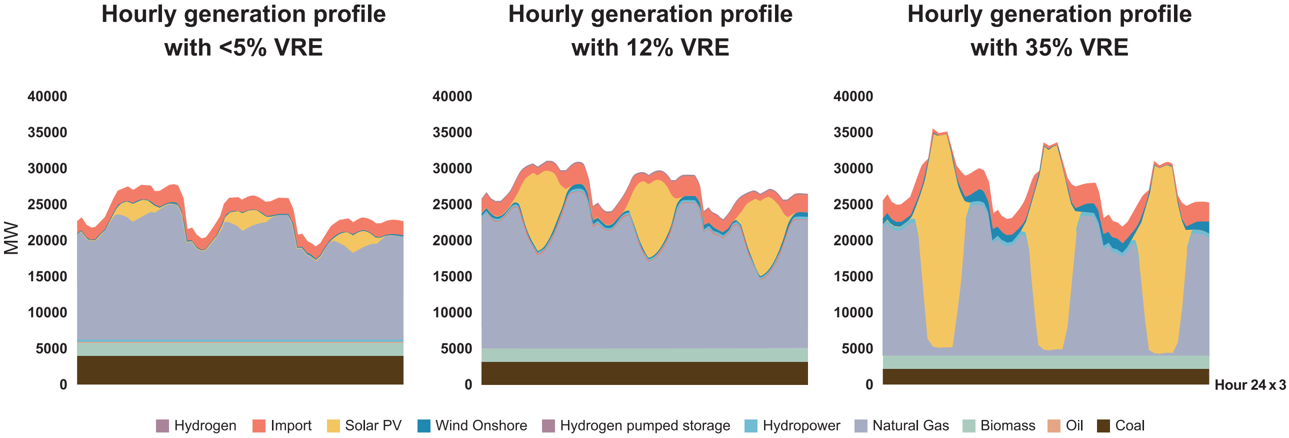


Figure 4.6: The hourly generation profile of the Thai power system at 5%, 12% and 35% shares of variable renewables.

In the long term, increasing flexible demand through sector integration is key.

As the share of VRE increases, the power system is expected to be more flexible to respond to greater gaps between supply and demand.

After 2030, the Thai power system will need to look at broader flexibility options and invest in power plants, storage, grids and demand-side flexibility. With anticipated falling costs, battery storage is expected to be a cost-optimal option for integrating solar PV. Utility-scale battery storage can support absorbing excess solar generation during the daytime and utilize the stored electricity during nighttime.

At this stage (i.e., beyond 50% of VRE generation), there are structural surpluses which will be curtailed if not utilized. Strategies like demand-side response from EV and hydrogen production help integrate renewables generation, limit curtailment and provide support during seasonal deficits.

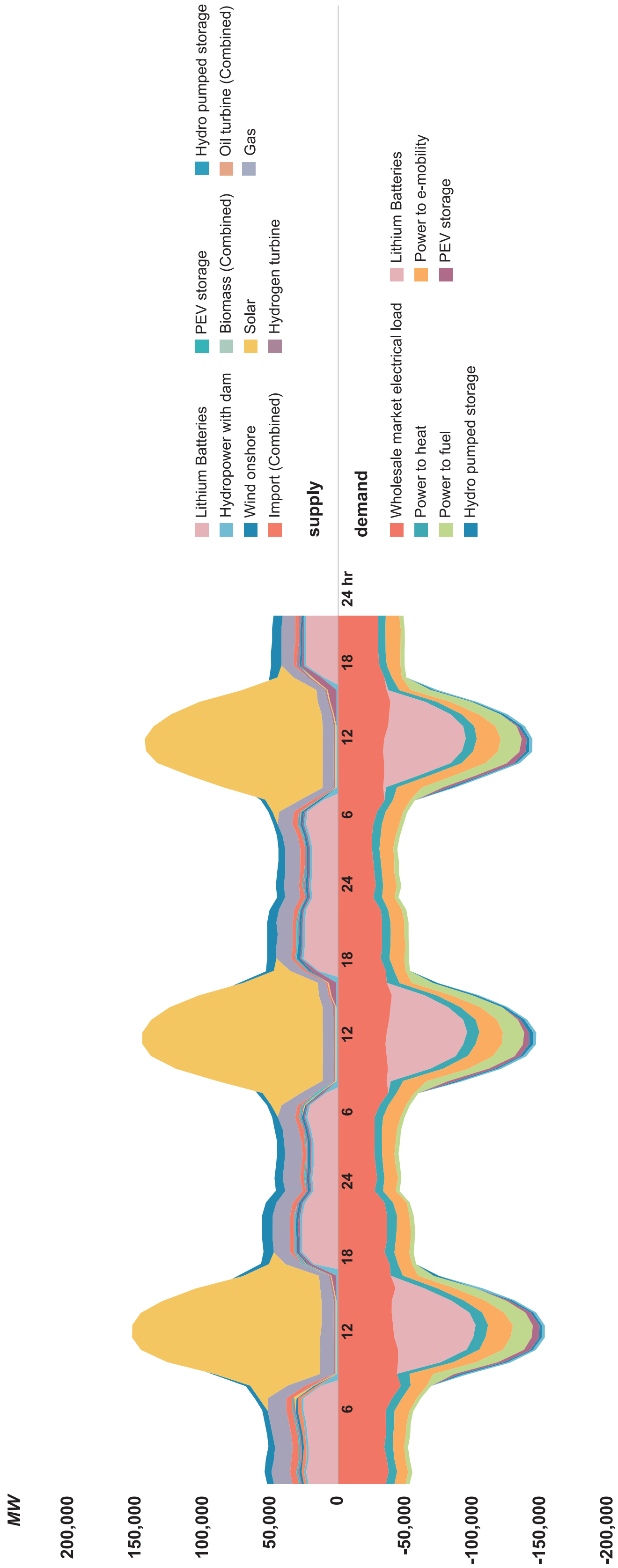


Figure 4.7: Hourly generation and demand profile in 2050,
during a three-day period with 73% variable renewables.

Figure 4.7 shows exemplary operation of the power system during three consecutive days of high solar generation in March. The peak solar generation reaches approximately 130 GW. The inflexible power load (which excludes electrification of mobility and transport, PtX application and storage) has a peak load of around 40 GW. Thereby, the operation of the power system requires the absorption of about an additional 100 GW of solar generation. This is achieved through sector coupling (in particular, through EVs) which provides flexible load. This flexible load helps integrate renewable generation and the curtailment is limited. In 2050, the annual curtailment of wind and solar generation is limited to 7% (22 TWh).

The key flexibility options provided by sector integration are described below with some quantifications:

- **Battery storage** operates as flexible load with a peak of around 60 GW. In one day, around 330 GWh of electrical power is stored in batteries during the day and used during the first evening/night, providing around half of the overnight demand.
- **Optimal EV charging** plays a crucial role in ensuring optimal power system operation. Smart charging leads to increasing charging during peak solar generation hours around noon. Hence, public charging infrastructure, such as those at office parking locations, should be prioritized to help absorb solar generation during the day. On the other hand, charging during the evening (around 6:00 pm) should be deprioritized as this also coincides with low solar generation and high inflexible **peak power load.**
- **Production of synthetic fuels (e.g., green hydrogen)** is another important flexible demand. The production of hydrogen is carried out primarily during solar generation hours. This provides a flexible peak demand of around 16 GW. 138 GWh of solar generation is converted to hydrogen. The hydrogen produced is used for supplying high-temperature heat and power generation acting as long-term storage.

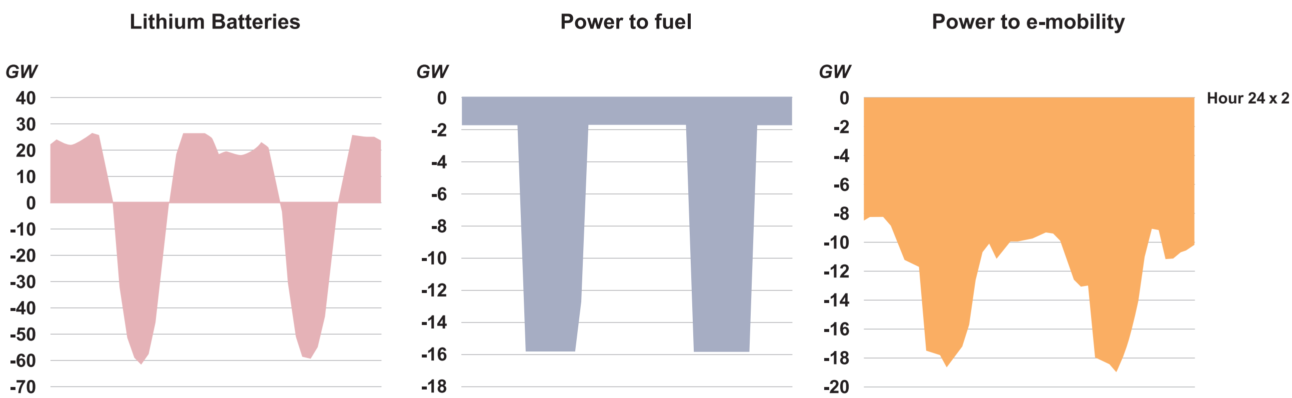


Figure 4.8: Flexible load (battery storage, power to fuel and e-mobility) hourly profile in 2050.

System flexibility can be enhanced through contractual flexibility and price signals.

PPA and fuel contract restructuring is critical for increasing Thailand's power system flexibility.

In the vertically integrated Thai power system, power generation relies heavily on independent power producers' (IPPs) long-term PPA contracts with minimum-take capacity obligations, which create structural inflexibility in the Thai power system. In addition, the existing fuel supply contract structure in Thailand imposes restrictions on the use of otherwise available and optimal resources, leading to unnecessary increases in system operational costs (IEA, 2021c). As increasing power system flexibility is strongly needed to integrate a larger share of variable renewables like solar PV and wind energy, policy efforts to restructure existing contracts (i.e., renegotiated at expiry or restructured before expiry) are essential to provide incentives for more flexible operations. This would save operational and fuel costs of gas power plants, minimize CO2 emissions and benefit end-consumers. Without changes in existing contracts, Thailand would lose the opportunity to utilize existing assets (coal-fired, gas-fired and hydro power plants) more optimally in providing flexibility and saving fuel costs.

According to the IEA's Thailand Power System Flexibility Study (2021), the shift towards more flexible PPAs and fuel contracts could result in significant cost savings that are greater than the savings from investments in technical flexibility resources. Following the IEA's study, Thailand could enhance commercial flexibility, provided by contractual structure, to facilitate the optimal use of the technical flexibility resources through the following options:

- Adapt the **PPAs of fossil fuel generation assets** to better reflect the technical flexibility of power plants by introducing technical requirements such as ramp rates, minimum stable operating levels and start-up times in providing system services.
- Introduce a minimum capacity of storage condition into **hydropower contracts.**
- Create **more flexible fuel supply contracts** through a portfolio procurement approach for fuel supply, with a mix of short-term and long-term products, as a way of relaxing the current take-or-pay obligations, in particular for LNG contracts.
- Restructure contracts with generators by **implementing auctions with a new/restructured** contract that have more flexible terms (e.g., selecting the plants that are willing to run a lower minimum guaranteed production level at the lowest cost).
- Implement **clear rules for VRE curtailment in PPAs** and a suitable compensation mechanism to VRE owners to curtail VREs only a last resort.

In addition, regional integration and multilateral power trading can play a key role in increasing power system flexibility in Southeast Asia in the long-term, particularly by increasing the flexibility of hydropower imports for Thailand.

To send price signals to flexibility services, market structure should be designed to recognize both spatial and temporal values of electricity.

With the increasing dominance of VREs that also require increased diversity of flexibility sources, **a holistic integration of both renewable electricity procurement and power system flexibility will be needed as a way forward** to address energy transition challenges through power system organizational structure (IRENA, 2022d).

Such **dual-procurement mechanisms include long-term renewable energy contracts and short- and long-term flexibility procurement.** While long-term renewable energy will be procured based on mechanisms such as auctions, short- and long-term flexibility procurement are **designed to match supply and demand through short-term dispatch mechanisms such as balancing markets, or**

regulated dispatch. Short-term flexibility procurement could also be designed to **recognise the spatial and temporal values** of electricity and flexibility, considering characteristics of flexibility sources such as dispatchable renewable power, storage and demand-side resources including demand response, distributed energy resources and sector coupling resources such as vehicle-to-grid and power-to-x.

With reform of the power structure, a competitive wholesale market for power generation could provide a mechanism to reward flexibility through price signals from short-term markets that incentivize system-friendly deployment of renewables. Also, a separate wholesale price for each regional zone could be considered to provide a signal for the value to the transmission grid.

While establishing a competitive wholesale market for power generation in Thailand is still uncertain with a lack of clear policy commitment and a roadmap for practical implementation, Thailand has made progress towards unlocking private electricity trading that will increase competition in Thailand's power market with a draft criteria and guidelines on the third-party (e.g., private power business operators or licensees) access code (TPA codes) for the electricity network systems. Next steps for electricity market enhancement should consider a separate procurement of energy and flexibility services, as well as consider how this is reflected in the tariff for the end-consumer. Furthermore, the price signals through demand response measures and EV charge rates could potentially increase power system flexibility from the demand side by encouraging consumers to change their electricity consumption pattern to reduce peak loads or to charge electricity at grid-optimal times.

Transformation of the transport sector

The transport sector in Thailand is largely dominated by road transport, which represents about 95% of total energy consumption of the sector. Road transport energy consumption is split roughly equally between passenger and freight (55% and 45%, respectively). The remaining 5% of total energy demand in the sector is distributed between rail, domestic aviation and waterways transport.

Due to the characteristics of the Thai transport sector, this study conducts a detailed analysis of road transport, particularly on the development of vehicle fleets. A detailed assessment allows for the exploration and quantification of the impact of different decarbonisation strategies and trends in the sector, such as fuel switching with the rollout of EVs, improvements in fuel economy, blending mandates and modal shift. Other sub-sectors are also included in the analysis for completeness.

The decarbonisation of the transport sector requires a broader approach beyond the deployment of EVs.

Decarbonisation of the sector must consider far-reaching strategies beyond electrification, such as stricter fuel economy standards, the role of biofuels and modal shift.

A deep decarbonisation of the transport sector that puts Thailand on a trajectory towards carbon neutrality by mid-century requires structural changes in the sector and broader strategies that are not solely focused on the deployment of electric vehicles. These strategies should include carbon and energy efficiency measures that include more stringent fuel economy standards for newer vehicles, consider the role of biofuels in the mid-term and encourage behavioral changes to spur modal shift in the mid- and long-term.

Importantly, broader strategies to restructure transportation in the country can deliver additional benefits that go beyond the decarbonisation of the sector. For example, reducing consumption of fossil fuels in combustion vehicles can improve the air quality of cities and modal shift through behavioral changes can significantly reduce the number of vehicles circulating on roads, thus improving traffic.

The fuel switch from internal combustion engine (ICE) vehicles to EVs is the single most significant measure for decarbonising the transport sector. As shown in Figure 4.9, the switch to EVs represents up to 50% of the emissions reduction in the sector achieved in the carbon-neutral scenario in 2050. Fuel switch is achieved through an annual increase in the share of EV sales until achieving 100% EV sales in 2035 for light-duty vehicles (LDV) and in 2040 for trucks.

However, a decarbonisation strategy focused on achieving ambitious targets of 100% EV sales by 2035-2040 is not enough by itself to lead the sector towards a carbon-neutral pathway. While it will have visible impacts on energy consumption and declining emissions in 2050, EV sales targets do not substantially alter the trend of the sector in the next decade due to the marginal impact on the total vehicle fleet during this period. This has implications for cumulative emissions until 2050 and the contribution of the transport sector to achieve the pledged emissions reductions in the 2030 Thai Nationally Determined Contribution (NDC).

Additional measures, such as modal shift and improvements to fuel economy, can further reduce emissions, representing 34% of total emissions reductions achieved in the carbon-neutral scenario in 2050. Notably, the impact of these measures is more visible in the next decade. The implementation of measures that encourage modal shift in passenger and freight transport represents 81% of emissions reductions achieved in the carbon-neutral scenario in 2030. These measures are complementary and reinforce the impact of fuel switch strategies. For example, modal shift strategies are more impactful if transportation shifts to modes that are already largely electrified (e.g., buses, trains and taxis). Since public transportation can be electrified faster than private transportation, modal shift that encourages the use of public transport and its electrification are the most impactful measures for decarbonising the transport sector until 2030. The faster the adoption of measures in coming years, the faster and deeper the effects of fuel switch in the mid- and long-term.

The electrification of the transport sector makes the decarbonisation of power supply crucial for achieving deeper emissions reductions.

A cleaner power mix as achieved in the carbon-neutral scenario represents 16% of emissions reductions in 2050, corresponding to indirect emissions in the sector from electricity consumption. The importance of a cleaner power mix for the transport sector increases as its electrification increases, becoming more prominent by mid-century and beyond.

Full electrification of transportation is incomplete unless it is accompanied by strategies to decarbonise the power supply. Despite EVs being more energy- and carbon-efficient than ICE vehicles (in terms of energy consumption per distance travelled), such efficiency gains can be substantially reduced in a fossil-dominated power supply. The increase in electricity demand from the electrification of transport can also amplify the effects of efficiency losses in fossil fuel-based power generation, transmission and distribution losses.

The decarbonisation of the transport sector therefore requires a broader strategy that focuses not only on the rollout of EVs but also on other equally important and complementary measures, such as modal shift, improved energy and fuel efficiency and the decarbonisation of the electricity supply. Importantly, a broader strategy will also deliver progress on other development goals, such as improving traffic and reducing air pollution. An integrated planning strategy that considers technology developments, urban planning and cross-sectoral cooperation is key to achieving these goals.

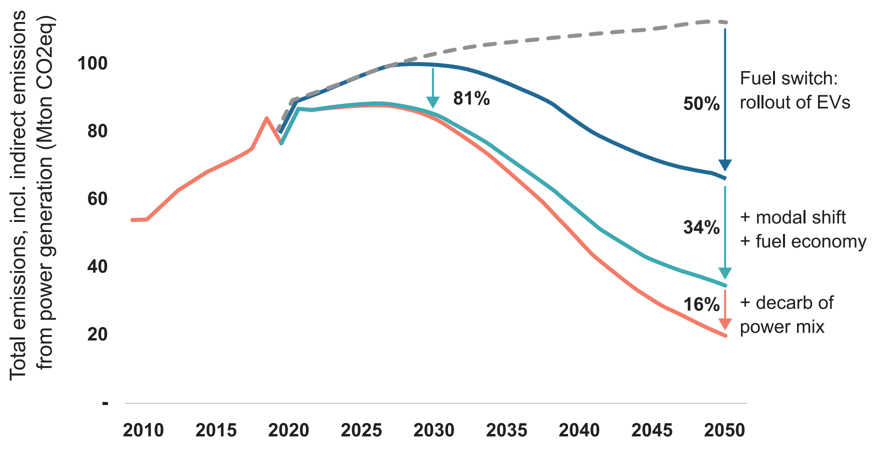


Figure 4.9: Effects of emissions reduction strategies in the transport sector.

Electrification of transport drives down total energy demand and reduces dependency on oil products.

Beyond a reduction in emissions, electrification leads to increased electricity demand, improved average energy efficiency and diversified fuel resources for the transport sector.

Electricity consumption in the transport sector is negligible today, but gradual electrification of different transport modes can lead to moderate growth in the next decade. By 2030, the annual electricity demand in the transport sector will be around 12 TWh, or about 3% of total electricity demand. While this increase in electricity demand could require adjustments in local networks at the distribution level, its impact on the power system at the utility-scale are negligible.

However, the picture changes after 2030 and up to 2050. The upward trend in EV sales – up to 100% of sales in 2035 for LDV and in 2040 for trucks – leads to a gradual increase in electricity consumption in the sector, becoming more visible from 2035 onwards. Electricity demand in the transport sector increases significantly (by a factor of eight) between 2030-2050. In 2050, electricity demand in the transport sector can reach up to 18% of total electricity demand in Thailand.

On the other hand, fully electric vehicles are more efficient than conventional ICE vehicles. On average, EVs consume about three times less energy as ICE vehicles to travel the same distance. The remarkable difference between EVs and ICEs in terms of energy efficiency adds to the importance of electrification as a strategy for Thailand, not only to decarbonise the transport sector but also to improve energy efficiency[10], save energy and bring down transport costs.

Deep electrification strategies can also help Thailand diversify fuel resources for the transport sector, strengthening energy security and minimizing the sector's vulnerability to volatile and high oil prices.

Electrification leads to net energy savings where the savings in oil product consumption more than offsets the increase in electricity demand.

The savings from the reduced consumption of oil products in the transport sector more than offsets the increase in electricity demand as a result of electrification. The implementation of EV national targets as announced in 2021 reaches 69% of EV sales by 2035, as defined in the reference scenario, could potentially reduce the consumption of oil products by 54% in 2050 compared to a scenario in which no EVs are deployed. The strengthening of the targets to 100% EV sales between 2035 and 2040[11] supported with modal shift strategies, as defined in the carbon-neutral scenario, can further reduce consumption of oil products by 66% in 2050 compared to the reference scenario.

By 2037, the carbon-neutral scenario can save up to 78 Mtoe in consumption of oil products compared to the reference scenario, which is equivalent to three times the annual consumption of oil products in the transport sector in 2019. By 2050, this cumulative figure increases to 211 Mtoe savings compared to the reference scenario, which is equivalent to more than seven times the annual consumption in 2019. Taking into account the consumption of electricity and biofuels in the sector, the net energy savings of the carbon-neutral scenario are 10 Mtoe in 2050 and 190 Mtoe between 2020 and 2050 compared to the reference scenario.

[10] It refers to the ratio of energy consumed to useful energy.

[11] The electrification strategy is different for each type of vehicle, responding to the technological maturity of EVs. The carbon-neutral scenario assumes that the competitiveness of electric trucks will be delayed by 5 to 10 years with respect to LDV, achieving 100% EV sales in 2040.

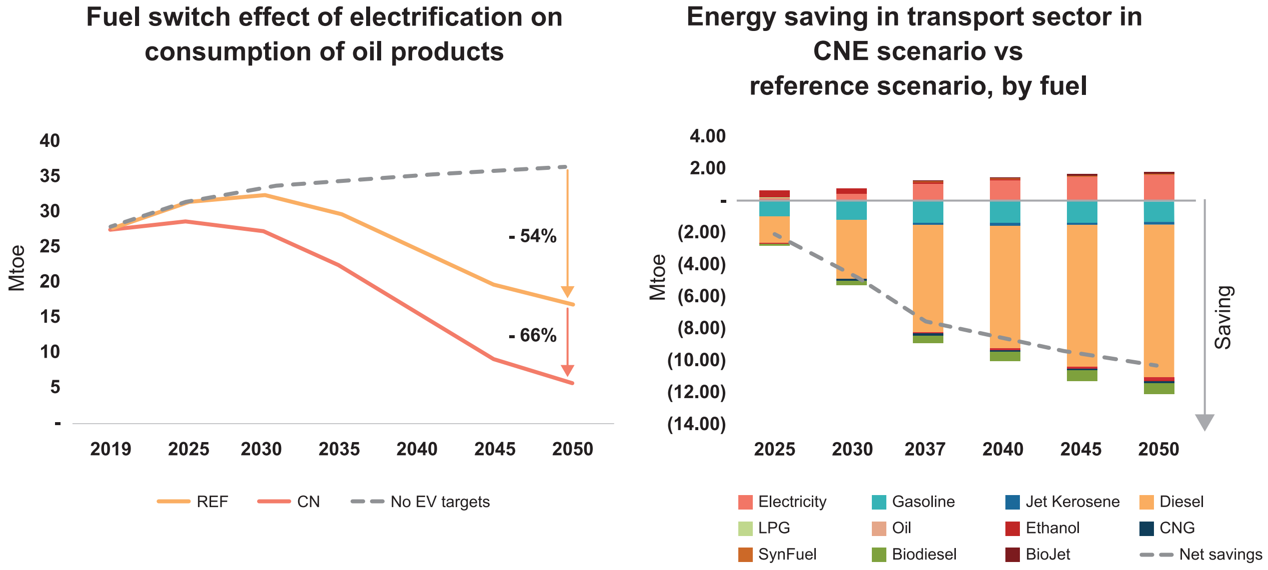


Figure 4.10: Fuel switch effect of electrification and energy savings by fuel.

Most of the energy savings in the carbon-neutral scenario are on diesel consumption. This is an obvious outcome, as diesel consumption accounts for two-thirds of the total energy consumption in the transport sector in 2019. Currently, 94% of pickups and 97% of trucks are diesel-powered vehicles. These two categories alone capture around 84% of total diesel consumption in the sector. The electrification of these two types of vehicles would lead to major energy savings in the sector.

The savings until 2030 are mostly influenced by modal shift to rail transport (gradually increasing to 20% of freight transportation in 2050) and electrification. After 2040, the uptake of electric trucks and the rapid turnover of older ICE trucks accelerates the electrification of freight transport from 2040 to 2050, considerably reducing diesel consumption during that decade compared to less ambitious EV sales of trucks in the reference scenario. The remaining diesel consumption until 2050 is mainly influenced by pickups. Almost two-thirds of all pickups on the road in 2050 will still be diesel-powered in the carbon-neutral scenario.

In addition to the electrification of passenger and freight transport, the strengthening of blending mandates (especially biodiesel in diesel) can further reduce the consumption of oil products in the transport sector. However, blending mandates and the associated increased production of biofuels must consider their impact on sustainability, including biodiversity, deforestation and land use, as well as interactions with food supplies.

The acceleration of EV sales will lead to the transformation of the vehicle fleet.

Beyond increased electricity demand and savings on consumption of oil products, the electrification of the transport sector through the deployment of electric vehicles leads to a reconfiguration of the vehicle fleet in the country.

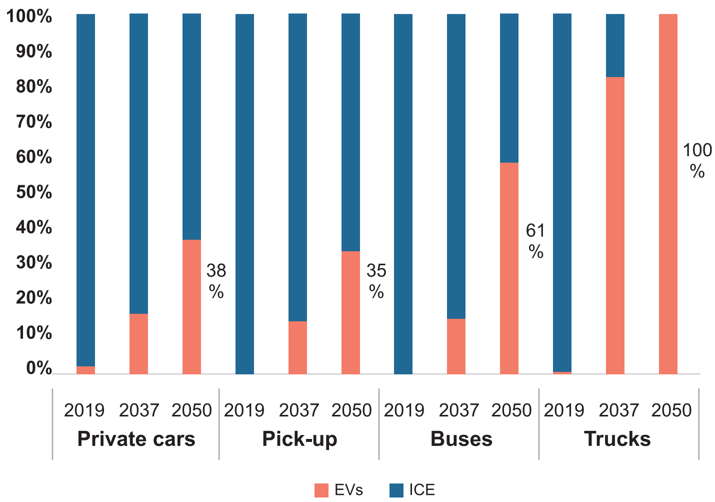
Despite ambitious sales targets for EVs, a significant number of ICE vehicles will still be on the road by mid-century.

For LDVs, the target of 100% EV sales by 2035 reduces the share of ICE vehicles on the road in 2050 to 60% for private cars and 65% for pickups. Despite having a 100% EV sales target for trucks by 2040 (five years later than the target for light duty vehicles) its impact is visible in the following decade, reducing the share of ICE trucks on the road to less than 40% in 2050.

The remaining share of ICE vehicles in 2050, especially for LDVs, underpins the need to complement the electrification strategy with policies and measures that target the remaining ICE fleet, such as emissions and fuel economy standards.

The reconfiguration of the vehicle fleet through the modelling period also leads to a change of energy consumption in the sector. In 2019, energy consumption in the sector is dominated by diesel, which covers two-thirds of total energy demand. As electrification becomes the main trend in the sector, electricity consumption takes on a larger share of total energy demand: 15% in 2037 and 58% in 2050. Electricity demand in 2050 is concentrated in freight transport, accounting for about 60% of total electricity consumption in the sector due to modal shift (increased use of electrified rail) and the deployment of electric trucks. Although decreasing in share over time, diesel consumption still accounts for 27% of total energy demand in the transport sector in 2050, largely due to the legacy of existing diesel-powered pickups and those sold between 2020 and 2030, in addition to the slow turnover of the fleet's shift to EVs.

Difference in stock size per vehicle mode as a result of modal shift measures (carbon neutral vs. reference scenario)



Penetration of EVs in total stock

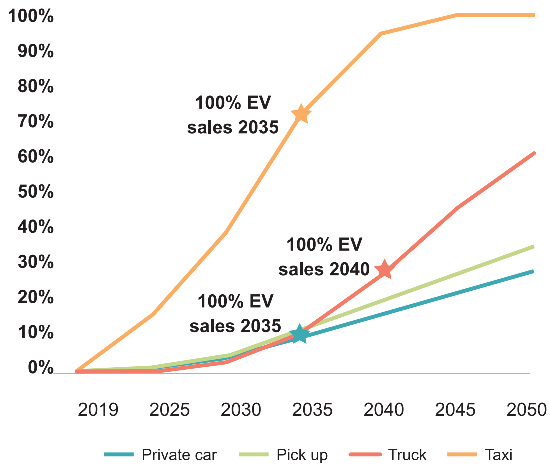


Figure 4.11: Target of EVs and stocks vehicles.

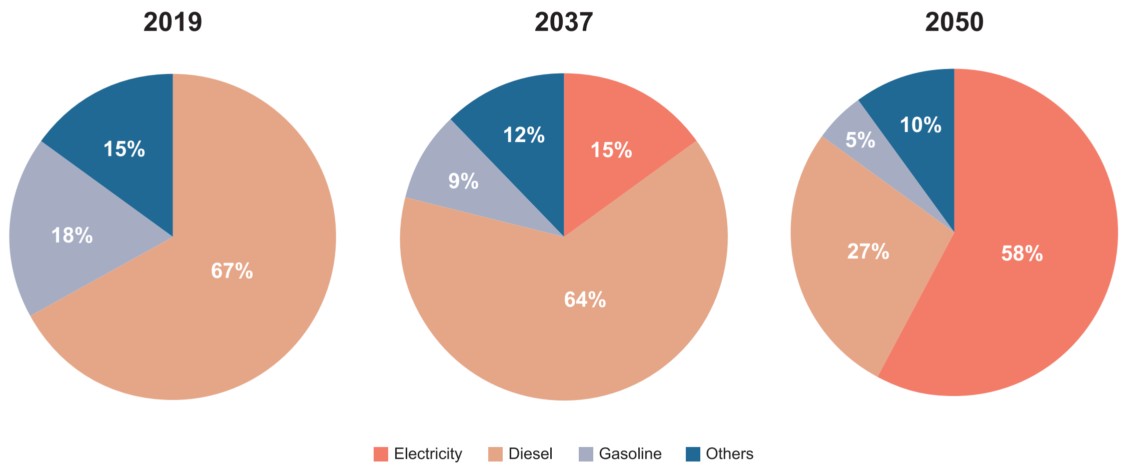


Figure 4.12: Energy mix in the transport sector.

The effectiveness of measures or policies that target new vehicles do not only depend on their ambition or their implementation schedule, but also on their ability to change the vehicle fleet in the mid- and long-term.

This is the case for electric vehicle sales targets and stricter fuel economy standards for new vehicles. The effectiveness of these measures is subject to the dominance of the existing fleet and to the speed at which it is renewed (i.e., fleet turnover). Despite assuming the same EV target and schedule for private cars, pickups and taxis (a gradual increase of shares of EVs in total sales before reaching 100% in 2035), the uptake of EVs for taxis is significantly higher than for private cars and pickups. Similarly, a faster turnover of the truck fleet accelerates the uptake of electric vehicles to reach a higher penetration of the total fleet compared to private cars and pickups, despite its 100% sales target coming five years later.

The fleet turnover rate is influenced by the survival rates of vehicles and the average distance travelled by older vehicles. Taxis and trucks have a shorter survival rate than private cars and pickups. While all taxis are replaced after 10 to 12 years and only 25% of trucks are still on the road after 30 years, more than 70% of private cars and pickups are still on the road after 30 years. In addition, the distance travelled by older vehicles also determines the need to replace them with newer ones. For example, while 30-year-old private cars still cover an average of 25% of the distance they covered when they were new, similarly old pickups cover an average of 45% of the distance they covered when they were new. This difference explains the faster uptake of EVs for private cars compared to pickups.

The turnover rate therefore determines the inertia of the existing fleet and the need to replace vehicles with new sales that are increasingly EVs. These results show that, with slow turnover, the vehicle fleet in 30 years will be strongly influenced by sales in the next decade. This suggests the importance of strengthening EV sales targets by 2030, since having a more ambitious target only in 2040 will have a limited impact on the decarbonisation targets in 2050 and 2060.

The policies and measures to decarbonise transport should target vehicles with slower turnover.

The present analysis shows that, despite being an important measure, decarbonisation strategies in Thailand should not solely revolve around EV sales, but should also be accompanied by other measures that support modal shift and energy efficiency. This is particularly true in the case of private cars and pickups. The electrification of transport modes with faster vehicle turnover that quickly adopt EVs, such as in public transportation, and the shift to these modes of transportation would lead to faster and deeper decarbonisation of the transport sector.

Additionally, other measures that can be considered are those aimed at accelerating vehicle turnover and reducing the influence of older vehicles on future energy consumption and emissions. These measures aim to use less or more quickly replace older vehicles to increase the predominance of newer vehicles on the road. Some measures and policies to encourage faster turnover include:

- Early retirement (signs to retire older vehicles or ban ICE vehicles in a given year in the future)
- Limiting the circulation of older vehicles in certain areas or providing preferential access to EVs (e.g., preferential city access, lanes and parking)
- Enacting stringent emissions and fuel economy standards for vehicles on the road
- Strengthening automotive industry to reduce costs and make new vehicles more affordable in order to make fleet renewal more attractive
- Encouraging circular economy practices to receive older vehicles before the end of their lifetime

These measures would not only make the impact of measures targeting new vehicles, such as EV sales and fuel economy standards, more effective by reducing the inertia of older vehicles, but would also increase the total number of vehicle sales, fostering increased economic activity of the automotive industry in Thailand.

Modal shift strategies could lead to additional benefits beyond the decarbonisation of the sector.

Besides contributing to the decarbonisation and reduction of energy consumption in the transport sector, modal shift strategies also reduce the need for larger fleets in the future. This could potentially have positive impacts on reducing traffic and air pollution in the largest cities.

The implementation of strategies in passenger transport that encourage the shift from private vehicles (e.g., cars and pickups) to public transportation such as trains and buses leads to a substantial reduction of the size of the vehicle fleet. By increasing public transportation to 25% of total passenger transportation by 2050, as assumed in the carbon-neutral scenario, the total fleet of private cars and pickups decreases by 18% and 10% in 2050, respectively, compared to a scenario with the current modal split.

Naturally, the number of public transport vehicles increases with this modal shift. The number of buses increases by 16% compared to an unchanged modal shift scenario. However, this increase in the number of vehicles is more than offset by the reduction in the fleet of private cars and pickups which, together with motorcycles, make up the majority of vehicles currently on the road. This significant reduction in the size of the vehicle fleet could have positive impacts on traffic, commuting times, road accidents and air pollution.

While having suitable infrastructure for public transportation is a key enabler for facilitating a modal shift, it needs to be complemented by policy measures that encourage passengers to shift towards public transportation. For example, urban planning and behavioral changes towards cycling, walk and emerging transport modes for short distances can reduce overall travel demand. Technological advances in connectivity, automation, sharing and electrification will significantly change mobility. For example, car-sharing policies could increase occupancy rates and complement modal shift measures to further reduce the number of vehicles on the road.

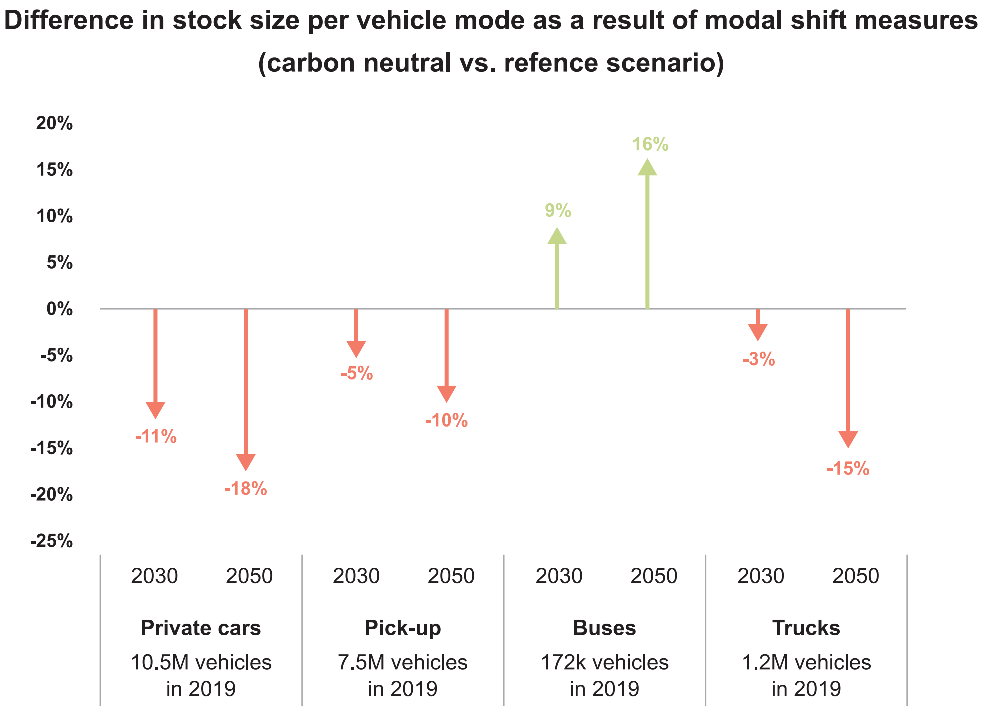


Figure 4.13: The difference in fleet size per vehicle mode as result of modal shift measures (carbon-neutral vs reference).

Transformation of the industry sector

The structure of the Thai industry today provides opportunities to decarbonise using readily available technology powered by clean electricity.

The Thai industry is the largest consumer of energy and currently contributes to up to 30% of overall CO_2 emissions. The share of total energy demand in the industry sectors is projected to grow from 34% of total energy demand in 2019 to 45% in 2050, highlighting the importance of emissions reduction efforts in this sector. To be in line with the carbon-neutrality target, industrial carbon emissions should be reduced by 90 percent in 2050.

In this study, we split the energy demand of the Thai industry into two temperature levels (high-temperature heat, i.e., more than 1000 degrees C, and low-medium temperature heat, i.e., up to 400 degrees C)[12] . Process emissions (for example, in the cement or chemicals industry) have generally not been taken into account[13] in this study. Analysing in detail the Thai industry structure informing viable decarbonisation strategies, such as energy efficiency, fuel switching to electricity and low carbon fuels like biomass and hydrogen and carbon capture, utilization, and storage (CCUS).

Industries with the largest energy consumption use low- and medium-temperature heat, covering sectors such as food and tobacco (44% of total industrial energy demand), machinery (8%), paper and textile (3% each). Non-metallic minerals industries, such as the cement industry, as well as iron- and steel-making, represent 26% and 5% of total energy demand, respectively, mostly through the use of high-temperature heat.

[12] Based on stakeholder discussions, the structure and contribution of various Thai industries are kept at similar levels. Assumptions of new S-curve industries are excluded and could be addressed in future studies.
[13] With the exception of process emissions related to redox processes in producing iron. Indeed, even though iron reduction is not strictly speaking a combustion reaction and is often accounted as "process emissions", we counted it here as energy-related emissions, as the process uses cokes/coal.sales in 2040.

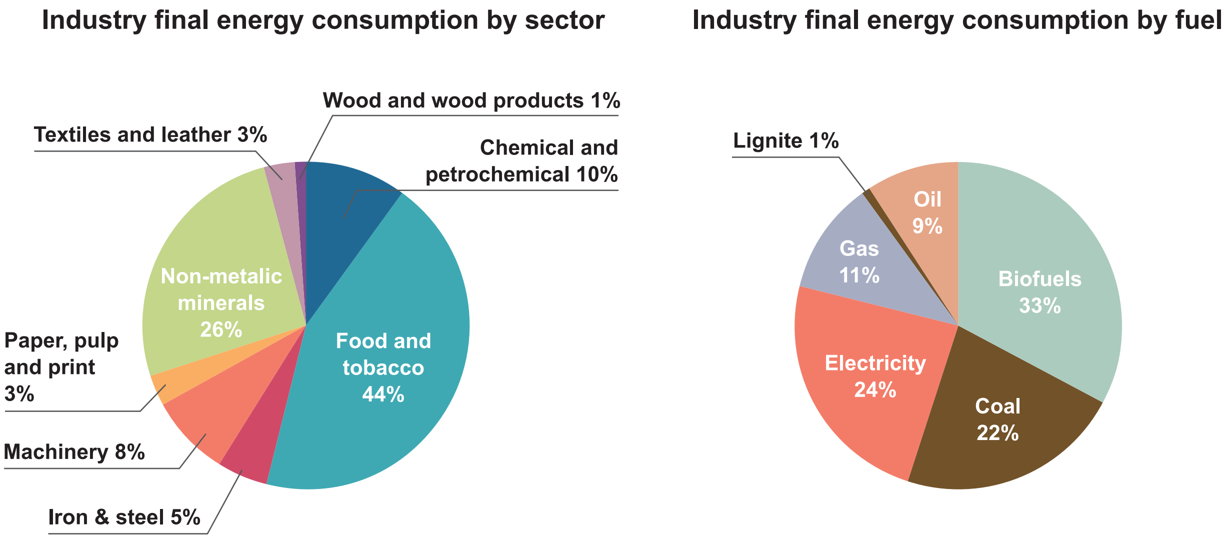


Figure 4.14: Final energy consumption in Thai industry by sector and by fuel (2019).

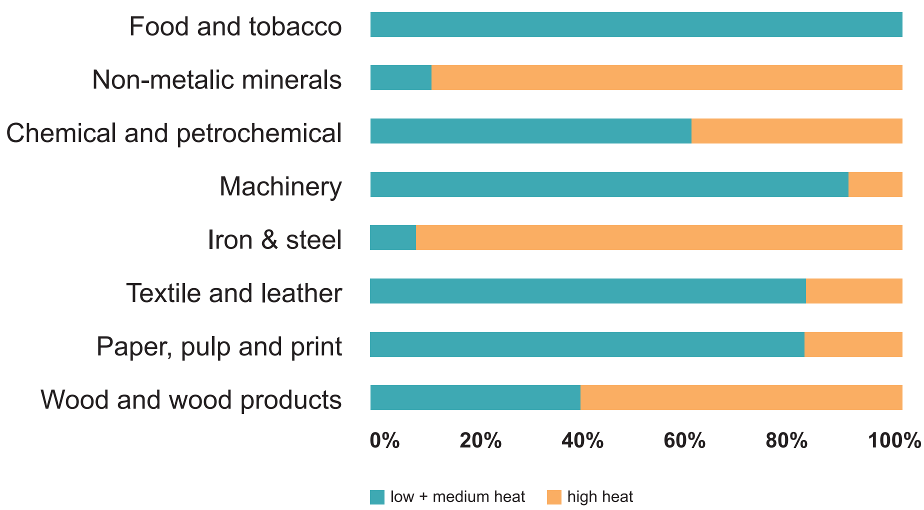


Figure 4.15: Split of low- and high-heat shares by sector.

Renewables-based electrification of heat and energy efficiency measures are key for reducing fossil fuel energy demand in the Thai industry.

The total energy demand in the industrial sectors will slightly increase in the next 10 years, induced by increased industrial activities. This demand then decreases by 10% from 33 Mtoe in 2030 to 30 Mtoe in 2050, driven by further energy efficiency measures, as well as electrification of low-temperature heat. Until 2037, the efficiency measures include improvements in industrial facilities such as stricter energy efficiency standards, the introduction of energy management systems, the introduction of higher labelling and energy codes as promoted in the Thai Energy Efficiency Plan of 2018. Beyond 2037, gains come from investments in new highly efficient appliances that follow global standards.

Due to the high share of low-temperature heat in Thai industry, the decarbonisation of those sectors can be achieved with readily available technology powered by electricity (which, in essence, is more efficient, as it avoids conversion losses coming from burning fossil fuels). In total, the structural change induced by the electrification of low-temperature heat reduces energy consumption of the industry by around 10% in 2050 (compared to a system with lower electrification). Due to the high share of low-temperature heat in Thai industry, decarbonisation can be achieved by readily available technology powered by electricity. One example is the diffusion of heat pumps (i.e., electric heating technologies which provide low temperature heat (up to 160 °C) with high performance coefficients[14]) which makes them an economical option compared to boilers. Heat pumps can be used for drying, washing and processing water in the food, wood, paper and pulp and textile industries. Other electric technology exists for higher temperature heat, for example the use of electric arc furnaces for melting scrap and recycled steel (2 Mt production per year in Thailand).

By 2050, industrial heat will be provided mostly by renewable electricity for low-temperature heat and by biomass for high-temperature heat.

Today, around 10% of gas demand in Thailand is used for low-temperature heat (e.g., in the chemical, machinery and pulp and paper industries. This low-heat temperature will be fully electrified in 2050, mostly using heat pumps, while around 15% of high-temperature heat will also be electrified. In total, the share of electricity for providing heat will grow from 17% in 2019 to 67% in 2050. The remainder will be supplied by biomass, which replaces the use of coal in heavy industries, and a small share of gas and green hydrogen.

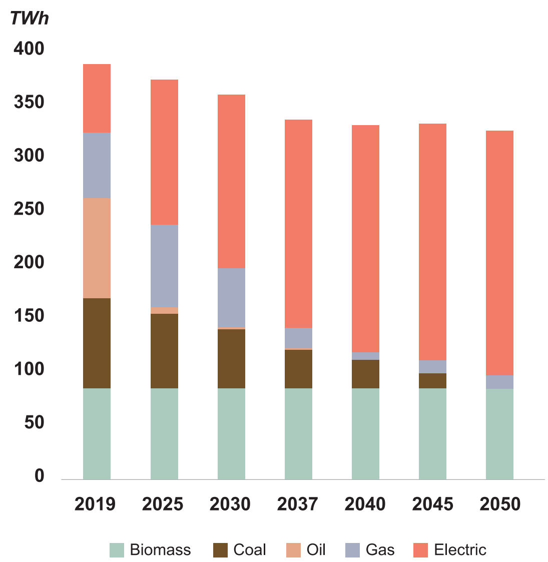


Figure 4.16: Industrial heat supply mix.

[14] Kwh heat output per kwh electricity input.

The electrification of industry process requires policies to drive electricity costs down.

In addition to policies and regulations which incentivise the adoption of new clean technologies in the industry sectors, ensuring low electricity costs will be the key driver for the electrification of industry processes. Indeed, electrification of heat will make economic sense only if electricity prices are lower per unit compared to fossil fuel options. Indirect electrification through the use of green hydrogen will also be driven by renewable electricity costs.

The falling costs of renewable generation and increasing deployment of renewables are key measures to lower electricity costs. Our model result shows that heat pumps would outcompete gas boilers as early as 2030 (with electricity costs of 21 USD/MWh and gas prices of 51 USD/MWh at this time horizon). This condition is possible with accelerated deployment of renewables. Industry sites could invest directly in renewable energy facilities for their own consumption, allowing them to reduce their energy bills and their reliance on volatile fossil fuel prices. Not only could this measure save on electricity costs, particularly due to the falling prices of renewables and increasing prices of fossil fuel, but it is also aligned with the existing discussion on carbon border adjustment mechanisms (CBAM). In addition, policymakers could consider pursuing specific policies aimed at reducing the relative price of electricity consumed by the industry sector.

Low-carbon fuels, such as biomass and green hydrogen, will become increasingly significant for decarbonising high-temperature heat.

A large share of low-temperature heat can be supplied directly by electricity in Thailand. This means more expensive decarbonised fuels (such as biomass and green hydrogen) should only be used for high-temperature heat applications that cannot be electrified. In addition, carbon and storage technologies, that are costly and induce other sustainability issues, should only be used to abate non-energy related emissions, in particular in the cement sector, or in combination with biomass to produce net-negative emissions (BECCS).

Sustainable biomass should be targeted for high-value use.

Currently, biomass is the largest renewable energy source used in the Thai industry sector. Constrained by the structure of the supply chain and optimal use of agriculture byproducts, biomass is mainly used to provide low-temperature heat in the food, tobacco, wood and pulp and paper industries.

In our analysis, the availability of biomass for industrial heat generation is kept at a constant level during the entire transition. This assumption is based on discussions with stakeholders and on the consideration of factors such as the competition of biomass with other land uses and the modification of the structure and share of the agriculture sector in the economy (in particular in the context of further industrialization and growing GDP), as well as on sustainability constraints. Similarly, in another study (IRENA, 2022a) the quantity of biomass use in Thailand is expected to increase only slightly, with an annual growth rate of 1% from 2025 to 2030 and of 0.3% from 2030 to 2050.

Since biomass is a limited and costly resource, its use should be in line with the cascading principle. This means that biomass should be utilized only where its economic and environmental value is the highest, in particular as a source of renewable carbon and in processes generating negative emissions (BECCS) and where no other low-carbon options exist. Examples are the use of biomass as a renewable fuel for high-temperature heat in industry, as well as in the production of biocarbon for the metallurgical industry, possibly in combination with CCU and CCS. Other important options are the production of advanced biofuels as feedstock for the chemical industry or as aviation fuel/biojet.

Shifting the use of biomass away from the sectors where it is currently used (and where it competes with cheaper and more sustainable options through electrification) will require the design of new policies.

Hydrogen, produced from solar power, will play a relevant role in decarbonising some industrial sectors in the long-run, but its role will likely remain marginal in Thailand.

Green hydrogen application will become more relevant in the long-term, particularly in decarbonising the iron and steel industries. Production costs for green hydrogen are decreasing rapidly due to cheaper renewable electricity and economies of scale in the electrolyser markets. Rising gas prices – as with those experienced in 2022 – would also increase the price competitiveness of green hydrogen (Collins, 2022). In this study, domestic production of green hydrogen is expected to reach levels of about 1.2 THB/kWh in 2045, when it would be comparable to Thai gas prices (1-1.8 THB/kWh), opening the door to its use in some industrial sectors. As shown in the following figure, green H2 will be produced at a time with very low electricity prices in the middle of the day, with very high solar PV feed-in. Ensuring this competitiveness in the long-run requires a mix of policies, including enabling and rewarding flexible operation and other system services provided by low-carbon power and industrial plants and fuel productions.

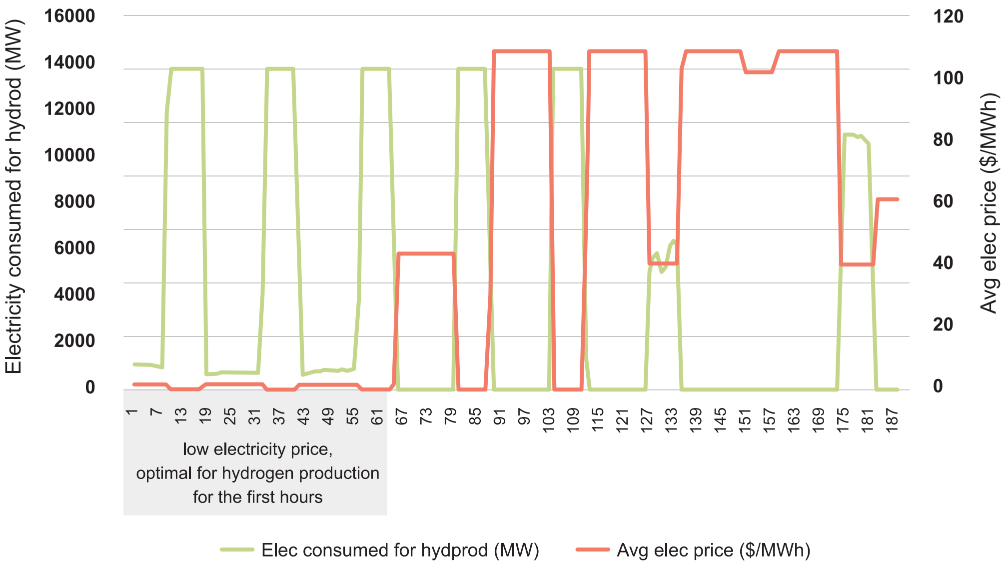


Figure 4.17: Production of hydrogen at low electricity prices, which coincides with a “surplus” of solar PV production (middle of the day).

Relying on CCUS to decarbonize the industrial heat supply is too costly.

Continuing to keep coal in the system (which currently supplies 30% of the total heat in Thailand) would increase emissions of the industry sector by 10 MtCO2eq in 2030 and 25 MtCO2eq in 2050, jeopardising the Thai carbon-neutrality target. Industrial CCUS was one of the technology options considered by our model, but it was not implemented due to its high cost. Similarly, as analysed by (IPCC, 2022), fuel switching was considered as a cheaper option compared to CCUS. To reduce 1 GtCO2eq in 2030, coal fuel switching would cost 20 to 50 USD/ton CO2 while CCUS would cost 100 USD/ton.

It is important to note that this study focuses only on energy-related emissions and heat decarbonisation, where relying on CCUS is not a cost-optimal solution. Nevertheless, CCUS could play a role in achieving deeper decarbonisation after 2045, essentially by capturing industrial process emissions, especially from cement and chemical production. In combination with the use of biomass, CCS could also lead to potential negative emissions (BECCS). Finally, the application of CCUS in the industry requires consideration of the full value chain, including transport and domestic storage of CO2 (onshore and/or offshore).

Infobox

CCUS in Southeast Asia

Existing CCUS applications focus on gas processing rather than on the power sector.

The discussions in Southeast Asia on CCUS focus on three different uses: gas processing, industrial products such as hydrogen and ammonia and the potential use in the power sector. However, planned CCS projects in Southeast Asia until 2030 are mostly focused on gas processing and industry/ ammonia rather than on the power sector.

Today, CCUS capacity capture only about 40 MtCO2eq per year globally, with more than 70% to increase oil and gas production. Only one commercial CCS power plant is in operation worldwide (coal-fired).

CCUS could play an important role for deep decarbonisation of some industry processes, but it should not be used to delay important decisions in the power sector where cheaper renewables-based options exist. The cost of CCUS applications varies by CO2 source, concentration of CO2 and technological readiness. Applications with a more 'diluted' gas stream, such as direct air captured cost ranges from 150-350 USD/ton CO2 (Source: (IEA, 2021a)). Some CO2 capture technologies are commercially available now, while others are still in development, which further contributes to the wide range of costs.

Ensuring affordability during the transition means CCUS should not be a distraction from mature and viable technology.

One of the key challenges in Southeast Asia is ensuring a just and affordable energy transition. Renewable energy deployment and energy efficiency measures remain the most cost-optimal strategies for reaching carbon neutrality. In contrast, given its comparatively high costs, CCUS adoption in Southeast Asia remains unlikely in the near future.

While it should not be a distraction from mature and viable technology, several factors should be considered for the viability of CCUS:

- **High carbon valuation.** CCUS viability relies on a climate-constrained environment that value carbon at a high price. At the moment, only Singapore has a carbon pricing mechanism in place in ASEAN, with a relatively low price (5 USD/ton until 2023).
- **Public funding support.** Deployment of CCUS so far depends on public funding. The U.S. has spent at least USD 1.1 billion of public funds to support CCUS development, with limited progress. Similarly, in European countries (e.g., Norway), the development of the USD 2.7 billion CCUS cluster plan is backed by the national CCUS fund. Southeast Asia should consider to which extend public funding are available for technology development.
- **Full cost analysis.** Assess the full cost of CCUS as its operation consumes significant amounts of energy, of which associated emissions need to be considered.
- **Identification of storage resources.** The capacity is expected in deep saline formations and depleted oil and gas reservoirs. However, the exploration and estimation capacity are often uncertain, therefore requiring more certainty for financiers.

Source: (Adhiguna, 2022) (IEA, 2021a)

Socioeconomic opportunities of the power system transition in Thailand

Socioeconomic opportunities of the power system transition in Thailand

It is essential to mainstream climate considerations into broader development goals, clarifying interlinkages between climate policy and socioeconomic priorities. While measures to tackle climate change in the power sector can lead to a wide range of benefits, any form of structural transformation is likely to produce divergent gains and losses for different parts of the economy and between different communities and social groups.

The analysis of sustainable development impacts not only helps to understand the benefits of the energy transition in Thailand, but also potential trade-offs (e.g., jobs lost in certain sectors). Identifying these trade-offs can support the design of strategies to mitigate associated risks and to leave no one behind. For example, negative labour market impacts associated with certain – typically fossil fuel-based – technologies are often cited to argue for a slower transition. A full analysis of impacts on jobs and on the wider economy of electricity supply activities can help counter that narrative, enabling support for those who stand to lose out during the transition and cultivating the skills and capacities required for systematic change. Another problem is that topics with relevance for climate action and sustainable development are often not directly linked to climate policy but are rather treated as standalone issues in public discourse. In Thailand, the topic of air pollution, particularly in large cities, is high on the public agenda and prominent in public discussions. Highlighting the link to climate policy and its mutual benefits for both driving down emissions and providing positive health outcomes is therefore critical.

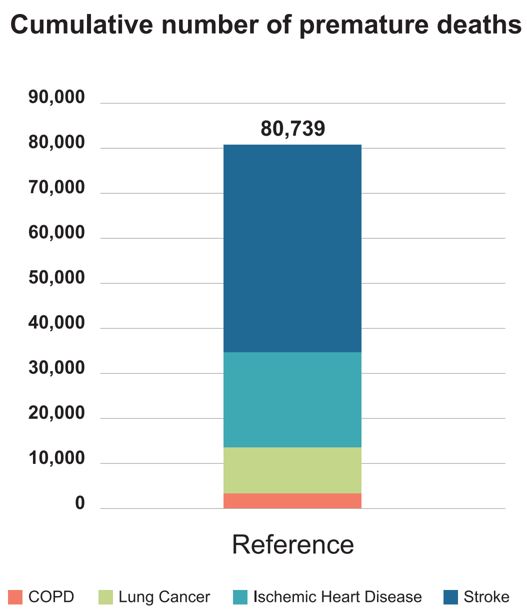
This chapter gives an overview of the impacts of Thailand's energy transition on health benefits from reduced air pollution, as well as job gains and losses, investments and power system costs.

The transition towards clean electricity improves public health by reducing the health impacts of air pollution, avoiding 15,000 premature deaths in Thailand alone

Air pollution released through energy-related fuel burning has negative impacts on human health and the environment. In general, air pollution represents the biggest environmental risk to human health globally (WHO, 2016). The energy sector, including both production and use, is the largest source of man-made air pollutant emissions, responsible for the production of 85% of primary particulate matter and almost all of the SO2 and NOx emitted worldwide (IEA, 2016; Watts et al., 2017). GHG emissions and air pollutant emissions often come from the same sources, such as fossil fuel-fired power plants, factories or vehicles. Consequently, mitigation measures that reduce the use of fossil fuels typically have a high potential to also cut emissions of other air pollutants.

Figure 5.1 gives an overview of the estimated cumulative number of premature deaths in Thailand for each scenario, broken down by cause of death. The leading cause of death in both scenarios is stroke, followed by ischemic heart disease, lung cancer and chronic obstructive pulmonary disease. Between 2020 and 2050, roughly 81,000 people would die prematurely in Thailand from air pollution caused by coal- and gas-fired power plants in the reference scenario. In comparison, roughly 66,000 people would die prematurely under the carbon-neutral scenario, which means that, in Thailand alone, 15,000 premature deaths could be avoided by adopting cleaner energy technologies, leading to less air pollution from coal- and gas-fired electricity generation between 2020 and 2050. An accelerated phasing out of reliance on fossil fuels would help save even more lives.

As air pollutants can travel several thousand kilometers, the impacts of coal- and gas-fired power plants located in Thailand can be felt far beyond its country borders (e.g., in Vietnam, Laos and Myanmar). Under the reference scenario, air pollution from Thai power plants causes an additional 450,000 premature deaths between 2020 and 2050, compared to 380,000 under the carbon-neutral scenario. This means an additional 70,000 premature deaths could be avoided mainly in countries neighbouring Thailand.



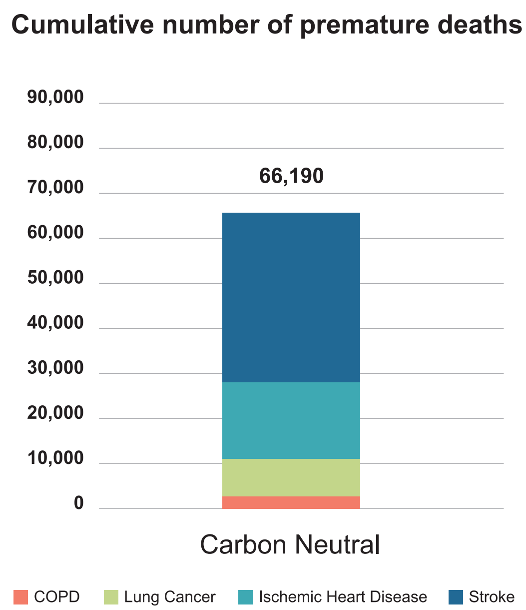


Figure 5.1: The cumulative number of premature deaths in Thailand from 2020 to 2050 by cause of death.

The estimated number of premature deaths from electricity generation equates to more than 2.5 million years of life lost[15] in Thailand under the reference scenario. Implementing the carbon-neutral scenario pathway would save 470,000 years of life amongst the Thai population, reducing the total years of life lost over the three decades to approximately 2 million. An additional 2.3 million years of life lost could be avoided beyond Thailand's borders.

While the majority of health impacts are caused by air pollution from gas-fired power plants, it is important to note that the negative impacts of coal-fired power plants are much larger in relation to total capacity installed. Roughly 80% of premature deaths are caused by air pollution from gas plants under both scenarios. On average, however, 1 MW of installed coal capacity causes 0.2 premature deaths per year while gas plants cause fewer than 0.1 deaths per MW installed.

The estimates of health impacts from transitioning the power sector included here are conservative figures, as the analysis focuses on key pollutants and fatal diseases and does not cover impacts amongst children. The actual health benefits of decarbonizing the power sector are therefore likely even larger if considering a wider range of indicators – including all morbidity-related factors, health impacts from other pollutants and in other countries, effects on children and workdays lost – and negative impacts on Thailand's economy.

Early expansion of renewable energy capacity creates new employment opportunities in manufacturing, construction and professional services

The development of the power sector and, in particular, the technology mix, influences where job opportunities are created and potentially lost over time, and has broader implications for industrial development.

Our analysis indicates that the carbon-neutral scenario would support on the order of 9 million direct job years[16] in electricity supply over the three decades from 2020 to 2050, and approximately twice as many than the reference scenario (see Figure 5.2). These are jobs that support the development of new electricity generation projects, the manufacturing of component parts (e.g., wind blades or PV modules) and their construction and operation, including fuel production and transportation (where relevant). Considering wider indirect and induced employment impacts, for example for those that provide intermediary products or services, as well as the wider ripple effect in the economy, the carbon-neutral scenario could support around 16 million job years over the three decades – 8.4 million more job years than under the reference scenario.

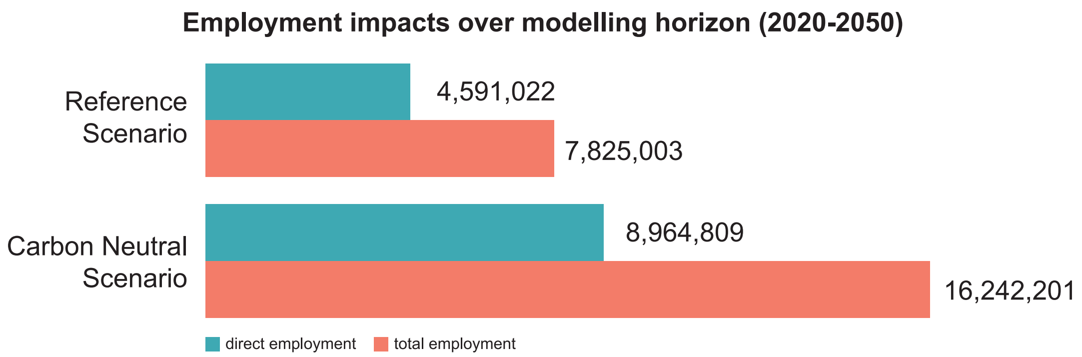


Figure 5.2 – Total (direct + indirect + induced) and direct employment in the power sector by scenario

[15] Years of life lost (YLL) quantifies the average years a person would have lived if they had not died prematurely.
[16] YA "job year" reflects one person in full-time employment for the duration of one year. For example, supporting 10 job years could imply employing 20 people for half a year, or two people for five years.

Three key factors drive the higher employment impacts in the carbon-neutral scenario:

- **Electricity demand is higher in the carbon-neutral scenario due to increased electrification of energy demand sectors.** Satisfying this higher demand requires greater investment in additional sources of supply, mostly new solar and wind capacity, with some further development of gas-fired power plants.

- **The expansion of renewable capacity is both earlier and higher in the carbon-neutral scenario than in the reference scenario,** stimulating capital investment and creating employment opportunities, particularly in manufacturing, planning and construction-related activities in Thailand. These technologies and associated jobs are more likely to form the core of future electricity supply both in Thailand and globally.

- **The domestic share of gas used in the power sector is considerably higher in the carbon-neutral scenario.** The carbon-neutral scenario has a lower level of demand for gas in the energy sector compared to the reference scenario. At the same time, domestic gas supply is limited and impliesincreasing imports in the reference scenario. Therefore, the study prioritises domestic gas to be utilised by non-power sectors, meaning that for each unit of gas used in the power sector the domestic employment estimated in our analysis is higher. However, in the reference scenario, these jobs – in extracting, processing and transporting gas – are likely still supported, albeit outside of the power sector value chain.

Employment in the gas industry is strongly driven by jobs in mining and extraction and highly dependent on uncertain availability of local gas supply in the future.

While half of direct jobs are driven by renewable energy, the other half comes from the gas industry. This is driven by continued development of new gas-fired capacity over the time period, although to a more limited extent in the carbon-neutral scenario.

Employment impacts created in the gas industry are strongly driven by jobs in mining and extraction (Figure 5.3). These jobs are highly dependent on the domestic gas supply in Thailand in the future – a key uncertainty in this modelling exercise[17]. Increasing Thailand's overall demand for gas (including from outside the power sector) could deplete the remaining national resources faster. An increasing gas supply through imports would affect the jobs created in the Thai upstream/gas extraction industry.

The majority of jobs created in the solar industry, however, are driven by employment in manufacturing and professional services (Figure 5.4) – even when making rather conservative assumptions for the local share of manufacturing – providing more stable, secure and higher-quality jobs for the Thai workforce.

Boosting opportunities in renewable energy roll-out, coupled with a national industrial strategy to increase the share of spending in these technologies that remains within Thailand (rather than directed to imports), could support more jobs than our analysis indicates and potentially facilitate an even faster ramp-up of renewable capacity.

[17] For more information, see Methodology in the Annex

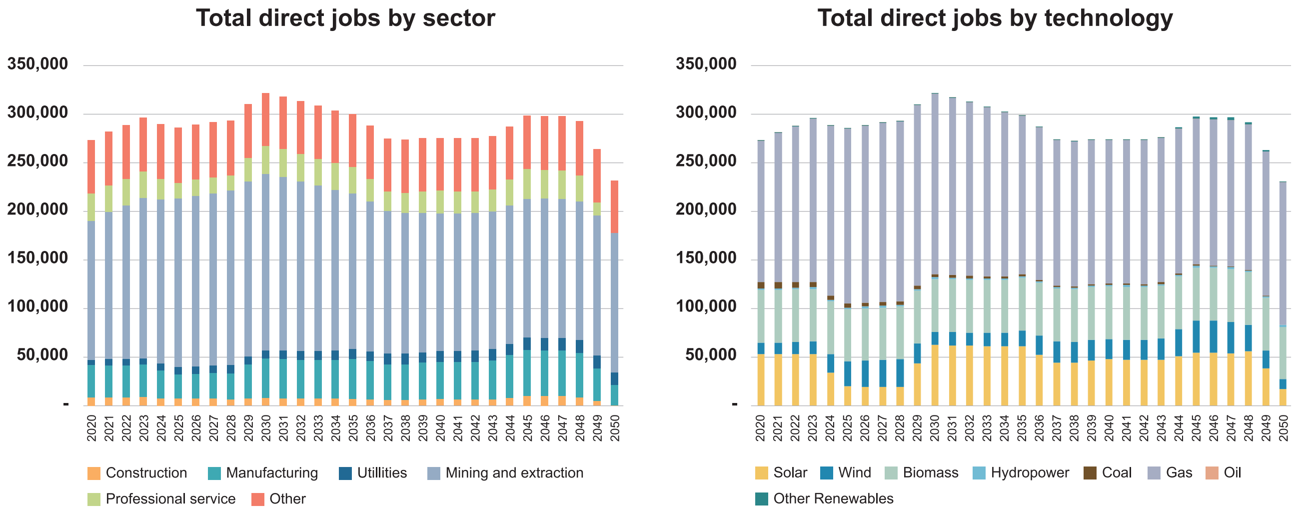


Figure 5.3: Employment impacts in the electricity supply by sector and by technology (2020-2050).

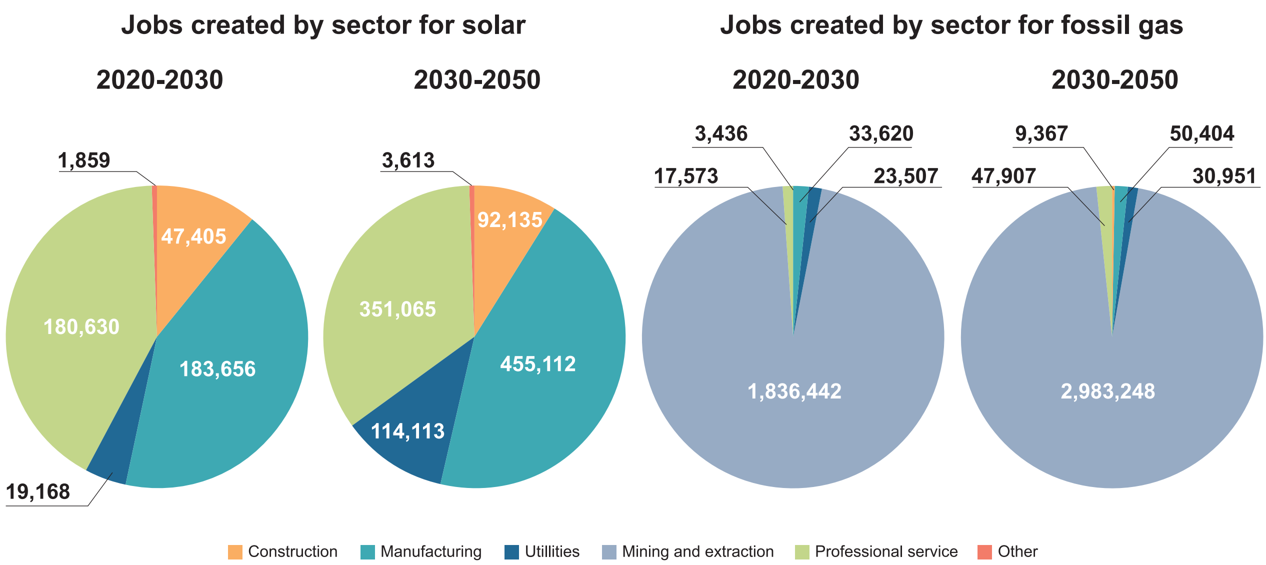


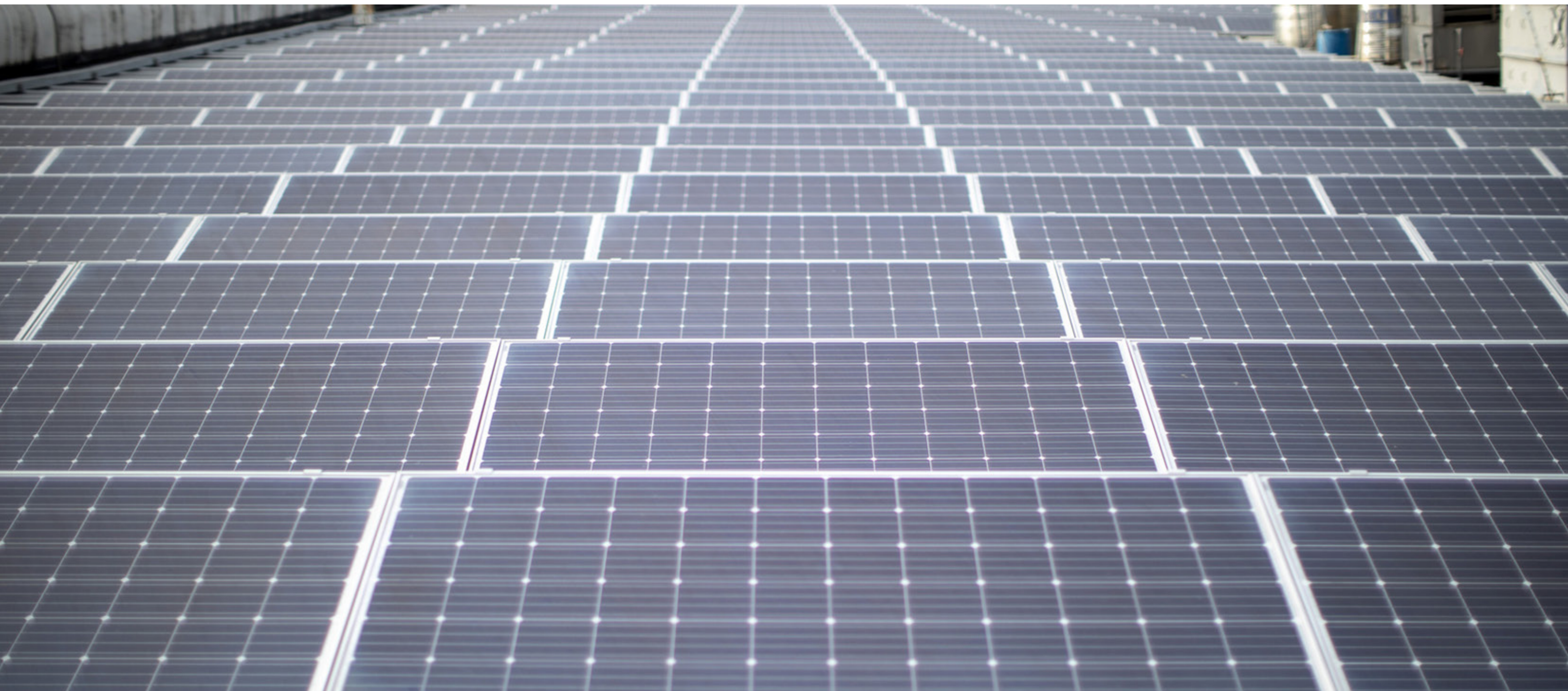
Figure 5.4: Jobs created by sector for solar and gas.

The road to carbon neutrality also comes with jobs lost in the coal industry, requiring a just transition for all to leave no one behind.

Whilst coal-fired generation accounts for a relatively small share of capacity and output in Thailand, the sector still supports several thousand workers today. In both scenarios, we analyse a downward trend of jobs in the Thai coal industry. In the carbon-neutral scenario, coal-fired generation is reduced much more rapidly than in the reference scenario, implying job losses particularly amongst workers involved in extracting and transporting coal, as well as in operating power plants. From 2020 to 2050, more than 70,000 job years will be lost in the coal sector under the carbon-neutral scenario. Part of this transition could be managed through the regular turnover of the workforce (as workers retire and/or choose to move to other sectors), but an accelerated phase-out would also require initiatives to re-train and support workers to relocate away from coal-related activities to other parts of the economy.

Impacts on investments and power system costs

Transitioning the energy supply in Thailand towards achieving the carbon neutrality target requires significant investments over the coming decades in renewables and flexible technologies, such as solar PV, wind, battery storage, etc. We estimate an annual investment of less than 0.6 trillion THB until 2037 and less than 0.9 trillion THB in 2050 (see Figure 5.5 for estimated investments under the CN scenario). These investments will enable the energy system to integrate higher shares of renewables and low-carbon technologies to replace the need for fossil fuels in the electricity system and end-use sectors through electrification, driving a significant reduction of carbon emissions. A future power system with high shares of renewables and flexible technologies, while requiring substantial investment (CAPEX), will result in a lower levelised cost of electricity (LCOE) over time. The cost structure of the power system will change with a decreased share of operational cost (OPEX) from a 70% share to around a 40% in 2050. The energy transition will not only encourage new investment opportunities in renewables and power system flexibility but also drive down power system costs and reduce exposure to volatilities from upward pressures on future fossil fuel prices.



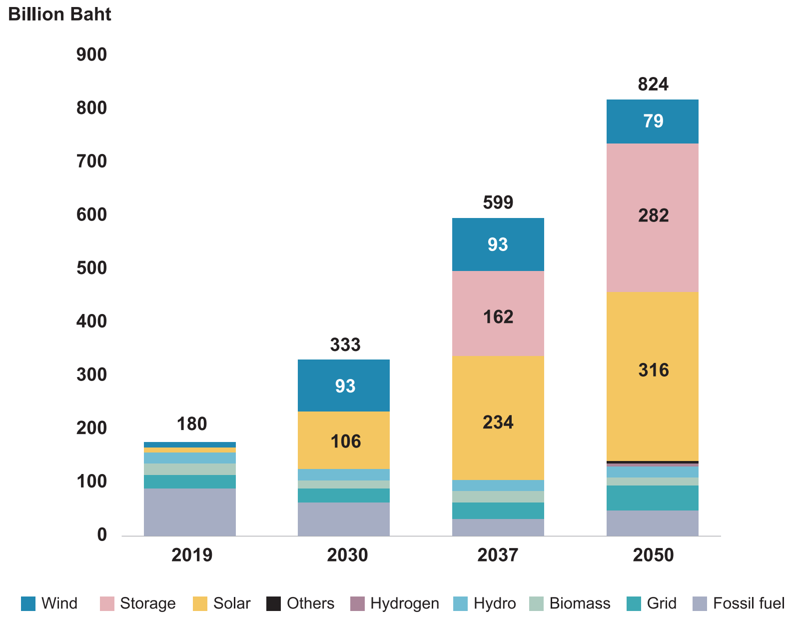


Figure 5.5: Selected annual investments under the carbon-neutral scenario.

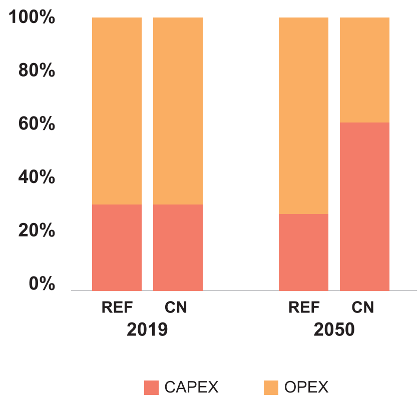


Figure 5.6: Share of CAPEX and OPEX in system costs in 2019 and 2050

Cross-sector collaborations

The road to climate neutrality requires the transformation of all sectors, which in turn calls for cross-ministerial dialogue and integrated planning.

To engage key actors, cross-ministerial dialogue and integrated planning are necessary to ensure that all implementation plans are working towards the same goals. In terms of government coordination, it is important to broaden the dialogue across institutions to include both government agencies (e.g., Ministry of energy, environment, finance) and the private sector in order to make them aware of common goals, exchange information, negotiate deadlocks and align plans.

Integrated planning regarding energy systems and climate commitments can shape new regulatory and market frameworks designed to spur technology cost reductions and unlock investments in renewables and other emerging technologies that will enhance power system flexibility and sustainable transport infrastructure. As the demand side tends to change from passive to active participants in the energy market, digitalisation will play a crucial role in collecting and monitoring energy data on the demand side, as well as GHG emissions as a key input for use in planning.

Thailand has made an important step with the drafting of its first Climate Change Act, in the process of approval by the cabinet. This act is critical for coordinating climate change action across the Thai government and for joining the rest of the world in addressing its root causes. In the energy sector, the Thailand National Energy Plan (NEP) has determined the direction towards emissions reduction, including an increase of RE share in new generation, energy efficiency improvements of more than 30%, an increase of EV share, enhancement of infrastructure and restructuring of the energy market to support the energy transition. However, the NEP should include short-, mid- and long-term actions in the main energy sectors (e.g., the power, industry and transport sectors). The actions presented in each sector will be useful to communicate with stakeholders and government agencies outside the ministry of energy.

Participation of the private sector is one of the key enablers on the road to climate neutrality.

A supportive regulatory framework is needed to attract investments and develop renewables at minimal costs. Investments do not need to come solely from the state and utilities, particularly because, during the energy transition, it is challenging for utilities to manage and balance the costs from stranded assets and new investments. Therefore, utilities and the private sector must collaborate with policymakers to reframe a regulatory structure that incentivises utilities and the private sector to invest in decarbonisation and electrification. Such regulations must provide a conducive environment for businesses, since infrastructure investments are capital-intensive. Committed goals and timelines in decarbonisation are essential components in building effective state-business relations.

Long-term planning towards carbon neutrality should consider possible uncertainties and explore strategies that can minimize those uncertainties.

To mitigate uncertainties, actions in areas that have larger potential and certainty of decarbonisation, such as the energy sector, should be accelerated, while carbon sinks should be left to compensate the hard-to-abate sectors such as industry processes and agriculture.

Some key uncertainties in Thailand that should be considered:

- Forest resources (e.g., uncontrolled deforestation), which has a direct impact on the level of carbon sink
- Volatile fossil fuel prices
- High investment costs and technological immaturity of low-carbon technologies, especially carbon, capture, utilisation and storage (CCUS) technology

In addition, several industries (e.g., fossil fuels and conventional vehicle manufacturing) are facing risks that are inherent in the energy transition, so this requires further assessments and strategies for a just transition. The committed targets or plans of the energy transition will support designing strategies to mitigate associated risks, setting a just transition plan and signaingl industries to adjust or transform their businesses, particularly workforce retraining and upskilling.

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List of Annexes

Annex A – Key input, assumptions, and output
Annex B – Methodology on energy demand
Annex C – Methodology on power and heat supply optimization
Annex D – Methodology on health impact
Annex E – Methodology on economic impact

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