Energy Transition Pathways for the 2030 Agenda

SDG 7 Roadmap for Thailand

ESCAP
Economic and Social Commission for Asia and the Pacific

NEXSTEP
National Expert SDG Tool for Energy Planning

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SDG 7 Road Map for Thailand

Developed using the National Expert SDG7 Tool for Energy Planning (NEXSTEP)

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Economic and Social Commission for Asia and the Pacific

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*The shaded areas of the map indicate ESCAP members and associate members.**

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กระทรวงพลังงาน
MINISTRY OF ENERGY

NEXSTEP
National Expert SDG Tool for Energy Planning

Foreword: ESCAP

The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) extends its gratitude to the Ministry of Energy of Thailand for its cooperation in developing the national SDG 7 Road Map for Sustainable Development Goal 7. This collaborative endeavour is a testament to the Government's commitment to achieve the ambitious targets of SDG 7 and the Paris Agreement. The SDG 7 Roadmap has assessed existing policies and plans, identified gaps and provided recommendations for an enabling policy framework and technological interventions to ensure the attainment of these targets. The Road Map has also delved into a comprehensive analysis of pathways towards carbon neutrality by 2050 and net zero emissions by 2065, offering suggestions to guide the bold commitments announced by the Government during COP26.

This analysis, with the tool developed by ESCAP -- the National Expert SDG Tool for Energy Planning (NEXSTEP) -- indicates that Thailand is largely on track to achieve the SDG 7 and NDC targets by 2030, with a few remaining gaps that need to be addressed. The analysis underscores the need for stronger government support to bridge the clean cooking gap. It suggests transitioning to electric cookstoves for households that have yet to make the switch, offering cost savings and improved efficiency. The current plan for improving energy efficiency is found to be robust, but further strengthening is necessary to reach the SDG 7 target. This may involve accelerating the implementation of certain measures outlined in the energy efficiency plan. Additionally, increasing renewable energy capacities beyond what is stipulated in the Alternative Energy Development Plan will be essential. Looking beyond 2030, achieving carbon neutrality by 2050 and net zero emissions by 2065 will require complete decarbonization of the power sector, fuel switching in the industry sector and the electrification of the transport sector.

The collaboration between ESCAP and the Ministry of Energy underscores a shared commitment to realizing the energy vision within the Sustainable Development Goals. The Road Map serves as a blueprint for continued prosperity in Thailand, aiding its recovery from COVID-19 and setting an example for other nations seeking to develop sustainable energy solutions. Anticipating the implementation of the Road Map by Thailand, I look forward to seeing its success in fostering a long-term, secure and sustainable energy future.

Ms. Armida Salsiah Alisjahbana
Under-Secretary-General of the United Nations and
Executive Secretary of ESCAP

Foreword: Thailand

I would like to express my sincere appreciation to ESCAP and all the key stakeholders for their invaluable support to the Government of Thailand in developing the Sustainable Development Goal 7 (SDG 7) Road Map. Thailand is setting an exemplary standard in Southeast Asia by actively promoting sustainable energy. The country has not only devised distinctive strategies to bolster sustainable energy but has also made audacious commitments, including the aim to achieve carbon neutrality by 2050 and net zero emissions by 2065, as declared during COP26. These ambitious targets position Thailand prominently on the global stage among nations dedicated to a sustainable future. Thailand is rich in indigenous and renewable energy resources, and the government has consistently emphasized their utilization to augment the share of renewable energy in the national energy mix.

The SDG 7 Road Map developed in collaboration between the Ministry of Energy and ESCAP has been a significant opportunity to assess Thailand's progress toward SDG 7 targets and the Nationally Determined Contribution (NDC). I am pleased to see that a comprehensive analysis has been conducted for the entire energy sector of Thailand, and the Road Map has put forth valuable recommendations to initiate necessary policy adjustments. The analysis indicates that Thailand is largely on track to achieve the SDG 7 and NDC targets by 2030, with a few remaining gaps that need attention to further strengthen the transition. The Road Map has also provided insights into the pathways for Thailand to achieve Carbon Neutrality by 2050 and Net Zero Emissions by 2065. The findings and recommendations of this study will offer crucial insights for updating national policies and strategies, facilitating Thailand's successful achievement of the SDG 7 targets and the NDC.

I am pleased to note that this document has been developed through an open, transparent, inclusive, and participatory consultation process involving all stakeholders. The success of this collaboration between ESCAP and the Ministry of Energy underscores our shared commitment to realizing the vision for energy outlined in the Sustainable Development Goals. I eagerly anticipate continued collaboration with ESCAP to implement the recommendations as we progress toward the 2030 Agenda for Sustainable Development and beyond.

Mr. Prasert Sinsukprasert
Permanent Secretary
Ministry of Energy

Abbreviations and acronyms

ADB	Asian Development Bank
AEDP	Thailand's Alternative Energy Development Plan
BAU	business-as-usual
BESS	battery and energy storage system
CBA	cost benefit analysis
CO2	carbon dioxide
CPS	current policy scenario
DEDE	Department of Alternative Energy Development and Efficiency
EE	energy efficiency
EEP	Thailand's Energy Efficiency Plan
EERF	Energy Efficiency Revolving Fund
EGAT	Electricity Generation Authority of Thailand
EPPO	Energy Policy and Planning Office
ERC	Energy Regulatory Commission
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
ESCO	energy services companies
EV	electric vehicle
GDP	gross domestic product
GHG	greenhouse gas
GW	gigawatt
ICS	improved cooking stove
IMO	International Marine Organization
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producers
IPPU	industrial process and product use
IRENA	International Renewable Energy Agency
ktoe	thousand tonnes of oil equivalent
kWh	kilowatt-hour
LCOE	Levelized Cost of Electricity
LEAP	Low Emissions Analysis Platform
LED	light-emitting diodes
LPG	liquified petroleum gas
MCDA	Multi-Criteria Decision Analysis
MEA	Metropolitan Electricity Authority
MEPS	minimum energy performance standard
MJ	megajoule
MoE	Ministry of Energy
MTF	Multi-Tier Framework
Mtoe	million tonnes of oil equivalent
MW	megawatt
NDC	nationally determined contributions
NEXSTEP	National Expert SDG Tool for Energy Planning
OECD	Organisation for Economic Co-operation and Development
PDP	Thailand's Power Development Plan
PEA	Provincial Electricity Authority
PP	power plant
RE	renewable energy
SDG	Sustainable Development Goal
SPP	small power producers
TFEC	total final energy consumption
TPES	total primary energy supply
TWh	terawatt-hour
UNEP	United Nations Environment Programme
US$	United States dollar
USDA	United States Department of Agriculture
WHO	World Health Organization

Executive Summary

Transitioning the energy sector to achieve the 2030 Agenda for Sustainable Development and the objectives of the Paris Agreement presents a complex and difficult task for policymakers. It needs to ensure sustained economic growth as well as respond to increasing energy demand, reduce emissions, and consider and capitalize on the interlinkages between SDG 7 and other SDGs. To address this challenge, ESCAP has developed the National Expert SDG Tool for Energy Planning (NEXSTEP).[1] This tool enables policymakers to make informed policy decisions to support the achievement of the SDG 7 targets as well as nationally determined contributions (NDCs). The initiative has been undertaken in response to the Ministerial Declaration of the Second Asian and Pacific Energy Forum (April 2018, Bangkok) and Commission Resolution 74/9, which endorsed its outcome. NEXSTEP also garnered the support of the Committee on Energy in its Second Session, with recommendations to expand the number of countries being supported by this tool.

The key objective of this SDG 7 Road Map[2] is to assist the Government of Thailand in assessing whether the existing policies and strategies are well-aligned to achieving the SDG 7 and NDCs targets by 2030. This Road Map presents three core scenarios (BAU, CPS and SDG scenarios) that have been developed using national data, which consider existing energy policies and strategies and reflect on other development plans. The Government also wanted to develop long-term scenarios in line with its commitment to Carbon Neutrality by 2050 and Net Zero GHG Emissions by 2065. These scenarios offer policymakers a strategic viewpoint on how Thailand could plan for a low-carbon energy pathway in alignment with the global race to net zero carbon.

A. Highlights of the Road Map

With the presence of multiple enabling frameworks, Thailand's progress towards achieving the SDG 7 and NDC targets is promising. In terms of access to modern energy, Thailand has achieved universal access to electricity in recent years. However, the current pace will not be enough to close the clean cooking access gap by 2030. Without a concerted effort, Thailand is unlikely to achieve universal access to clean cooking technology by 2030. One option for Thailand is to explore the use of highly energy efficient induction-type electric cooking stoves, particularly in areas where there is sufficient electricity supply.

Thailand is also on track to achieve its 30 per cent renewable energy target in final energy consumption (excluding non-energy use) and its 36 per cent energy intensity reduction target (compared with 2010 levels) by 2037. Thailand has also demonstrated that the existing policy framework may also help the country in achieving the unconditional emission reduction target pledged under the Paris Agreement. These results have been possible due to the presence of strong and integrated policy measures, which are the Power Development Plan (PDP), the Alternative Energy Development Plan (AEDP), and the Energy Efficiency Plan (EEP). Following the SDG 7.3 energy efficiency definition, Thailand's energy intensity is expected to be 3.5 MJ/US$$_{2017}$ in 2030 under the current policy scenario. NEXSTEP analysis identifies the fact that Thailand can even lower further its energy intensity to 3.1 MJ/US$$_{2017}$ in order to align with the global energy efficiency improvement rate of 3.4 per cent per annum, and achieve the conditional NDC target by accelerating the implementation of compulsory measure under EEP.

In addition to a highly efficient energy system, a faster transition towards cleaner energy sources, especially renewables, will help Thailand to reach Carbon Neutrality by 2050 and Net Zero GHG Emissions by 2065. This, however, requires an ambitious effort to switch fossil fuel-based energy systems to renewables. Electrification of existing technologies, such as vehicles and cooking stoves, will be a necessity in the long term. A deeper analysis indicates that phasing out coal-fired power plants by 2050 is feasible, since the lifecycle cost of renewable-based power generation is already cheaper than coal-fired energy.

1 The NEXSTEP tool has been specially designed to perform analyses of the energy sector in the context of SDG 7 and NDCs, with the aim that the output will provide a set of policy recommendations to achieve the SDG 7 and NDC targets.

2 This Road Map examines the current status of the national energy sector and existing policies, compares them with the SDG 7 targets, and presents different scenarios highlighting technological options and enabling policy measures for the Government to consider.

B. Achieving Thailand's SDG 7 and NDC targets by 2030

1. Universal access to electricity

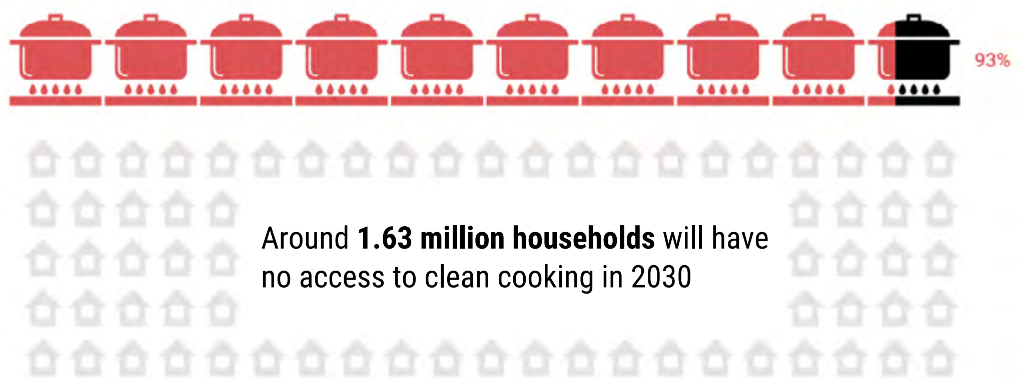
Around 0.2 per cent of Thailand's population lacked access to electricity in 2021. Some organizations reported that Thailand recently closed the electricity access gap (World Bank, 2020; ASEAN-German Energy Programme, 2021). There is a possibility that a small proportion of unelectrified households that exist may be unregistered. In such cases, it is suggested that mini/off-grid systems technologies (i.e., solar mini-grid and solar home systems) would be the more appropriate technologies, based on the technologies' cost-effectiveness and climate resiliency, while allowing faster implementation compared to the grid extension.

2. Universal access to clean cooking technology

Under the current policy settings, the clean cooking access is projected to reach only 93 per cent in 2030 from 85 per cent in 2021 (figure ES 1). This leaves around 1.6 million households still relying on the use of polluting solid fuel stoves (assuming biomass and charcoal as the primary fuels) in 2030. This will expose the population to negative health impacts, including non-communicable diseases such as stroke, ischaemic heart disease, chronic obstructive pulmonary disease and lung cancer, particularly among women and children (World Health Organization, 2022a).

This Road Map suggests closing the gap by using electric cooking, stoves since this option may provide a better long-term alternative compared to LPG stoves. With this measure in place, the share of electric cooking stoves will be 9.7 per cent, while the share of LPG will be 90.3 per cent in 2030 (under the SDG scenario).

Figure ES 1. Thailand's access to clean cooking under the current policy scenario



3. Renewable energy

The share of modern renewable energy (excluding traditional biomass usage in residential cooking) in the total final energy consumption (TFEC – including non-energy use) was 11.7 per cent in 2021. Based on current policies, the share of renewable energy is projected to increase to 18.7 per cent by 2030. The increase is due to the projected increase in renewable electricity as per the PDP as well as the growing renewable share for other purposes as per AEDP, such as industrial heating and biofuel for transportation. In the SDG scenario, the share of renewable energy is projected to increase to 25.7 per cent of TFEC in 2030. The additional 7 percentage point increase can be attributed to phasing out traditional biomass usage as well as further energy efficiency improvements to reach a lower energy intensity.

When non-energy use, such as Industrial Process and Product Use (IPPU), is excluded in the calculation, Thailand is on track to achieve its target of 30 per cent renewable energy share by 2037. By 2030, the renewable share calculated using Thailand definition will be 21.9 per cent for CPS and 29.4 per cent for the SDG scenario in 2030.

4. Energy efficiency

Thailand is on track to achieve the target of 36 per cent energy intensity reduction to 5.47 ktoe/billion Baht of GDP by 2037. Energy intensity is projected to be 6.25 ktoe/billion Baht in 2030 and 5.38 ktoe/billion Baht in 2037 under CPS. This would be possible due to the presence of compulsory and promotional measures under EEP which targets a 35.5 Mtoe energy demand reduction by 2037.

The energy efficiency indicator above is slightly different[3] from the one defined and measured under SDG 7. Therefore, these two values cannot be directly compared. Under CPS, the energy intensity is projected to drop to 3.5 MJ/USD_{2017}. Thailand can further reach an energy intensity of 3.1 $MJ/US\$_{2017}$, aligning with the global energy efficiency improvement rate of 3.4 per cent per annum, by accelerating the implementation of compulsory measure under EEP, such as energy management standard and building energy code.

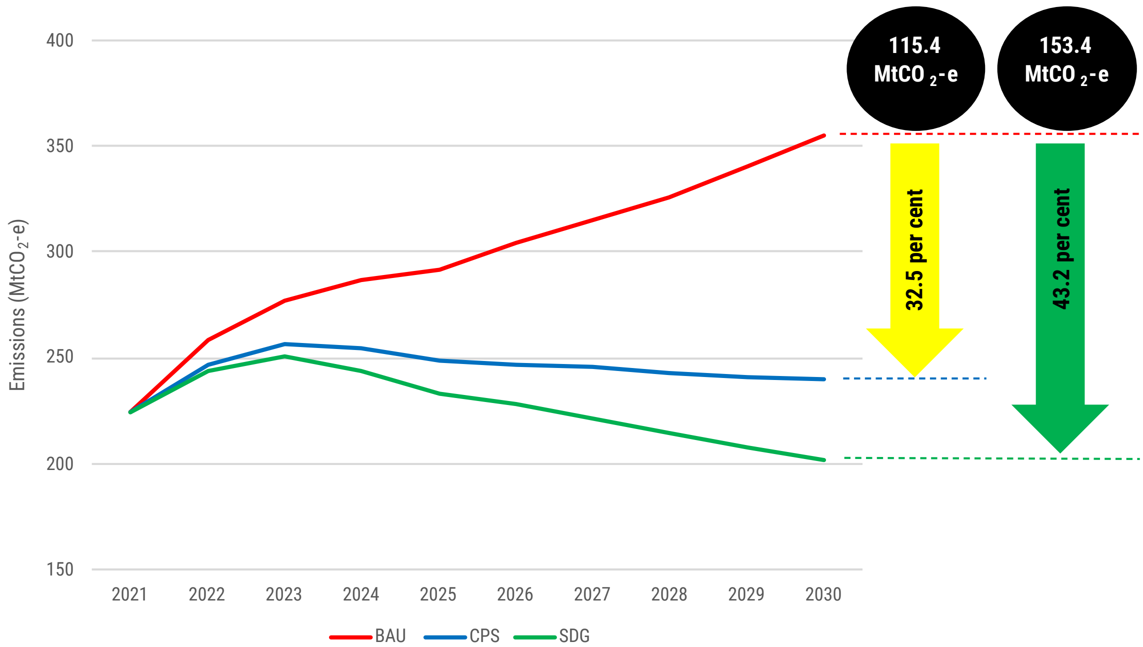
5. Nationally determined contribution

Thailand's updated Nationally Determined Contribution (NDC) sets ambitious targets to reduce greenhouse gas (GHG) emissions by 30 per cent unconditionally by 2030 (The Government of Thailand, 2022). Subject to international assistance, Thailand aims to reduce its emissions by 40 per cent in 2030.

Thailand will be able to achieve an unconditional NDC target by 2030. Emissions will reach 239.7 $MtCO_2$-e in 2030, a 115.4 $MtCO_2$-e (32.5 per cent) reduction compared with the BAU scenario. The decrease in GHG emissions, relative to BAU, is due to the higher renewable share in electricity supply according to PDP, the higher renewable share in heat and biofuel mix based on AEDP as well as significant energy efficiency saving under EEP.

Accelerating the implementation of compulsory energy saving measures in order to align with the global improvement target of 3.4 per cent will further help Thailand to achieve a conditional NDC target. In the SDG scenario, total emissions will reach 201.7 $MtCO_2$-e by 2030, corresponding to a 153.4 $MtCO_2$-e (or a 43.2 per cent) reduction compared to the BAU scenario (figure ES 2).

Figure ES 2. Comparison of emissions, by scenario, 2020-2030



3 Thailand measures its energy intensity target in terms of final energy consumption, whereas in SDG 7 it is measured in terms of primary energy supply.

C. Achieving Thailand's carbon neutrality by 2050 and net zero GHG emissions by 2065 targets

A well-planned and concerted effort must be undertaken by the Government of Thailand to reach carbon neutrality by 2050 and net zero emissions by 2065. Achievement of these two targets, particularly the Net Zero Emissions target, will require decarbonization of the energy sector. This is best done in the following two steps – (a) decarbonizing the power sector and (b) switching all energy consumption to renewables and electricity. Fortunately, the energy system of Thailand is well-positioned for an accelerated decarbonization effort – many of the required net zero technologies, such as renewable power generation, electric cooking stoves and electric vehicles, are mature and readily available technologies. Thailand also has ambitious targets that will open sustainable energy development opportunities in the long term. For example, biofuel blending and 30 per cent electric vehicles by 2030 will open a pathway for a higher share of electric vehicles by 2050. Due to certain limitations to implementing measurements in the transport and industry sectors, however, a small number of emissions would still be produced. Therefore, carbon sinks, such as reforestation or forest management, or other carbon capture technologies should be considered for absorbing the remaining carbon emissions.

D. Important policy directions

The Road Map sets out the following four key policy recommendations to help Thailand achieve the SDG 7 and NDC targets as well as reduce reliance on imported energy sources:

(1) **Strong policy measures are required to address the gap in clean cooking by 2030.** Achieving access to clean cooking fuels and technologies seems to be one of the remaining challenges. Adoption of electric cooking stoves in both urban and rural areas will significantly help improve clean cooking access. In the long term, the deployment of electric cooking stoves will also help Thailand achieve the carbon neutrality and net zero emissions targets. The cumulative cost of electric cooking stove deployment by 2030 would be US$ 265 million.

(2) **Accelerating the efficiency of energy use in all economic sectors should be pursued.** The EEP will help Thailand achieve the energy efficiency target by 2037. Thailand can even contribute more to achieving the conditional NDC target by enhancing its energy efficiency targets to align it with the 3.4 per cent global improvement pathway. These can be done by accelerating the achievement of mandated targets, such as energy management standard and building energy codes, in the years to 2030.

(3) **Fuel switching strategies, including electrification, accelerate SDG 7 progress and provide multi-fold benefits in the long term.** The electrification of end uses would be critical to decarbonize the entire economy by 2050. Since electrical equipment is more efficient compared to fossil-fuel based equipment, this will significantly reduce fossil fuel demand. Rapid adoption of electric vehicles, for example, reduces the demand for oil products, hence reducing Thailand's reliance on imported petroleum fuels. In terms of renewable energy, the current AEDP will help the country to achieve the 30 per cent renewable target in final energy consumption by 2037. This target, however, must be further increased to reach almost 100 per cent by 2065. This level of ambition might be a challenge currently, but in the long term the improvement of technology would make it possible. Furthermore, electrification of energy demand as well as higher adoption of efficient systems will reduce the investment in renewable energy systems.

(4) **Decarbonisation of the power supply provides the highest potential in GHG emission reduction as well as enables improvement of energy security.** In both ambitious scenarios, a projected decrease in grid emissions can realize a substantial GHG emission reduction. Investments in coal-fired power generation are no longer cost-effective compared with renewables and should be discontinued in order to avoid emissions lock-in. NEXSTEP analysis suggests that lifecycle costs of renewables, such as hydropower, solar, wind and biomass, are cheaper than coal-fired technologies. In the long term, investment in system stability should be considered to support high penetration of renewable energy generation for the grid. However, the underlying financial risks of investment in coal-based power plants should not be ignored. Fulfilling the required capacities in carbon neutral and net zero scenarios could be challenging technically and economically, yet these investments will help to improve energy security through the utilization of indigenous resources.

1. Introduction

1.1. Background

Transitioning the energy sector to achieve the 2030 Agenda for Sustainable Development and the objectives of the Paris Agreement presents a complex and difficult task for policymakers. It needs to ensure a sustained economic growth, respond to increasing energy demand, reduce emissions as well as consider and capitalise on the interlinkages between SDG 7 and other SDGs. In this connection, the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) has developed the National Expert SDG Tool for Energy Planning (NEXSTEP). This tool enables policymakers to make informed policy decisions to support the achievement of the SDG 7 targets as well as nationally determined contributions (NDCs) emission reduction targets. The initiative has been undertaken in response to the Ministerial Declaration of the Second Asian and Pacific Energy Forum (April 2018, Bangkok) and Commission Resolution 74/9 which endorsed the meeting's outcome. NEXSTEP also garnered the support of the Committee on Energy in its Second Session, with recommendations to expand the number of countries being supported by this tool. The ministerial declaration advises ESCAP to support its member States, upon request, in developing national SDG 7 Road Maps.

The Government of Thailand has expressed its interest in developing the SDG 7 Road Map to better understand if the existing policies and strategies are well-aligned to achieving the SDG 7 targets by 2030. The Government also wanted to develop long-term scenarios in line with its commitment to carbon neutrality (CN) by 2050 and net zero greenhouse gas (GHG) emissions by 2065. The objective of this SDG 7 Road Map is to assist the Government of Thailand to develop enabling policy measures to achieve the SDG 7 targets as well as set the course of the energy sector towards carbon neutrality and net zero emissions targets.

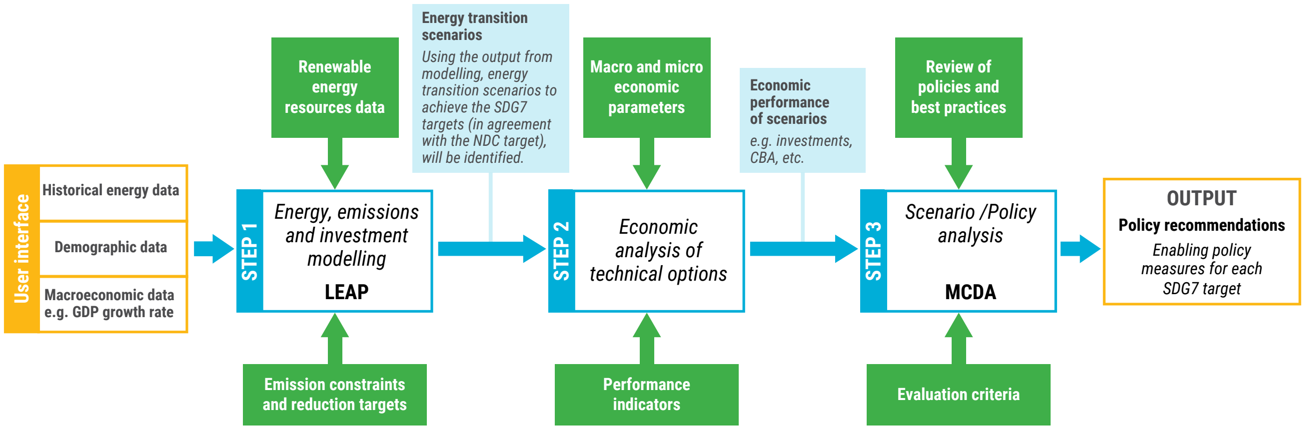
1.2. SDG 7 targets and indicators

7 AFFORDABLE AND CLEAN ENERGY

SDG 7 aims to ensure access to affordable, reliable, sustainable and modern energy for all. It has three key targets, which are outlined below.

- Target 7.1. "By 2030, ensure universal access to affordable, reliable and modern energy services." Two indicators are used to measure this target: (a) the proportion of the population with access to electricity; and (b) the proportion of the population with primary reliance on clean cooking fuels and technology.
- Target 7.2. "By 2030, increase substantially the share of renewable energy in the global energy mix". This is measured by the renewable energy share in TFEC. It is calculated by dividing the consumption of energy from all renewable sources by total energy consumption. Renewable energy consumption includes consumption of energy derived from hydropower, solid biofuels (including traditional use), wind, solar, liquid biofuels, biogas, geothermal, marine and waste. Due to the inherent complexity of accurately estimating the traditional use of biomass, NEXSTEP focuses entirely on modern renewables for this target.
- Target 7.3. "By 2030, double the global rate of improvement in energy efficiency", as measured by the energy intensity of the economy. This is the ratio of the total primary energy supply (TPES) and GDP. Energy intensity is an indication of how much energy is used to produce one unit of economic output. As defined by the International Energy Agency (IEA), TPES is made up of production plus net imports, minus international marine and aviation bunkers, plus stock changes. For comparison purposes, GDP is measured in constant terms at 2017 PPP.

Figure 1. Components of the NEXSTEP methodology



In addition to the above-mentioned targets, the SDG 7 goal also includes target 7.A – promote access, technology and investments in clean energy, and target 7.B – expand and upgrade energy services for developing countries. These targets are not within the scope of NEXSTEP.

1.3. Nationally Determined Contribution

Nationally Determined Contributions represent pledges by each country to reduce national emissions and are the stepping-stones to the implementation of the Paris Agreement. Since the energy sector is the largest contributor to GHG emissions in most countries, decarbonizing energy systems should be given a high priority. Key approaches to reducing emissions from the energy sector include increasing renewable energy in the generation mix and improving energy efficiency.

In its NDC document, Thailand has pledged to reduce GHG emission by 30 per cent (unconditional) compared to BAU, and 40 per cent (conditional) with international support, compared with BAU by 2030. Furthermore, Thailand has committed to achieving carbon neutrality by 2050 and net zero GHG emissions by 2065, which represent enhanced mitigation efforts in various sectors.

1.4. NEXSTEP methodology

The main purpose of NEXSTEP is to help design the type and mix of policies that would enable the achievement of the SDG 7 targets and the emission reduction target (under NDCs) through policy analysis. The tool helps modelling energy, emissions and economics to analyse a range of policies and options for their suitability. This tool is unique in a way that no other tools look at developing policy measures to achieve SDG 7. One key feature of this tool is the back-casting approach to energy and emissions modelling, which is important in planning for SDG 7 where the trajectory is developed backwards from the (known) 2030 targets to the present day. Figure 1 shows components of the methodology.

1.4.1. Energy and emissions modelling

The NEXSTEP analysis begins by developing a model of the energy system for each scenario, defining the technical options in terms of the final energy (electricity and heat) requirement for 2030, possible generation/supply mix, emissions and the size of investment required. The energy and emissions modelling component uses the Low Emissions Analysis Platform (LEAP) tool.[4] This proprietary software is widely used by many countries to develop scenarios for the energy sector, policy analysis and develop NDC targets.

4 Developed by the Stockholm Environment Institute. Available at https://leap.sei.org/

1.4.2. Economic analysis

The second step builds on the selection of appropriate technologies through an economic optimisation process which identifies the least-cost energy supply options for the country. A comparative assessment of selected power generation technologies is done using the Levelized Cost of Electricity (LCOE) as an economic indicator. This provides policymakers with insights into the costs and benefits of the economically attractive technology options, allowing better allocation of resources and better-informed policy decisions. While the economic analysis has been kept to a simple level, it contains enough information to support policy recommendations in this Road Map. Some key cost parameters used in this analysis are: (a) capital cost, including land, building, machinery, equipment and civil works; and (b) operation and maintenance cost, comprising fuel, labour and maintenance costs.

1.4.3. Scenario analysis

The scenario analysis evaluates and ranks scenarios, using the Multi Criteria Decision Analysis (MCDA) tool, with a set of criteria and weights assigned to each criterion. Although the criteria considered by the MCDA tool can include the following, stakeholders may wish to add/remove criteria to suit the local context:

- Access to clean cooking fuel;
- Energy efficiency
- Share of renewable energy;
- Emissions targets in 2030;
- Alignment with the Paris Agreement;
- Fossil fuel subsidy phased out;
- Price of carbon;
- Fossil fuel phase-out;
- Cost of access to electricity;
- Cost of access to clean cooking fuel;
- Investment cost of the power sector;
- Net benefit from the power sector.

This step is performed using the NEXSTEP online portal,[5] as a means to suggest the best way forward for the countries by prioritizing the scenarios. Stakeholders can update this scenario ranking using a different set of criteria and their weights. The top-ranked scenario from the MCDA process is used to inform the Government on the best possible energy transition pathway for the country.

1.5. Data sources

The primary source of data collection has been from government databases and reports. Some data have been collected directly from government agencies through formal letter of request from the Ministry of Energy (MoE). In a few instances where government data were unavailable, such as resource potential data, research papers and analyses have been consulted. The final dataset has been presented to, and approved by MoE.

5 Available at https://nexstepenergy.org/

2. Country overview

2.1. Demographic and macro-economic profile

Thailand is located in South-East Asia and bordered by Cambodia to the east, Malaysia to the south, Myanmar to the north-west and the Lao Peoples' Democratic Republic to the north-east. It shares a maritime border with Viet Nam, Indonesia and India. The country occupies a total area of 513,120 km2 and has a 3,219-kilometre coastline.

In 2021, Thailand had a population of 66.17 million people, with an estimated 22.62 million households, which amounted to an average of 2.9 persons per household.[6] The annual population growth rate is around 0.1 per cent. Thailand's population is projected to increase and reach a peak around 2030, before starting to decline gradually (MoNRE, 2022). The urbanization rate in 2021 was around 42.8 per cent.[7] The country's capital, Bangkok, is the most populous city with more than 10 million people.

Thailand's GDP in 2021 was estimated at US$ 505.5 billion. The GDP growth has been heavily affected during 2021 and 2022 due to the impacts of COVID-19, which fell to 1.5 per cent and 2.6 per cent, respectively. According to the forecast by the Asian Development Bank (ADB), the GDP growth is expected to bounce back at 3.3 per cent in 2023 and will further rise to 3.7 per cent by 2024 (ADB, 2023).

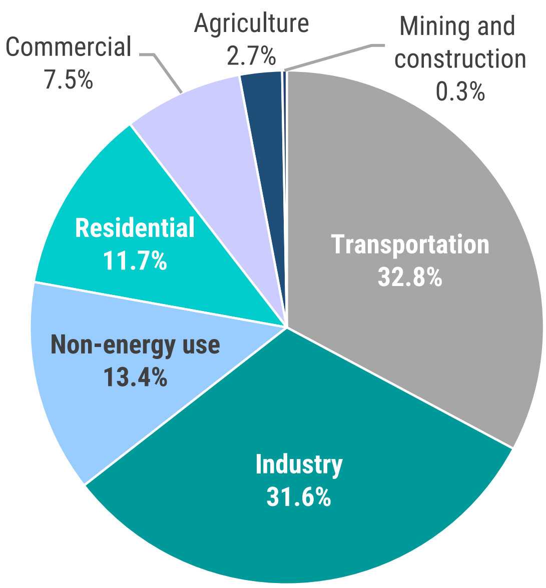
2.2. Energy sector overview

2.2.1. National energy profile in the baseline year 2021

The following details describe the estimated national energy consumption using data collected with a bottom-up approach, such as activity level and energy intensity for the different sectors. The bottom-up estimation is generally in agreement with the national energy statistics in terms of total energy supply and total final energy consumption by fuel type. The baseline year, 2021, has been chosen based on the latest year for which all data points are available.

Energy demand: In 2021, the total final energy consumption (TFEC) was around 83.3 Mtoe (figure 2). Most of the demand came from the transport sector (32.8 per cent), followed by the industry sector (31.6 per cent). The third-largest consumption was for non-energy use, estimated at 13.4 per cent or 11.1 Mtoe. The residential sector consumed 11.7 per cent, the commercial sector, 7.5 per cent and the agricultural sector, 2.7 per cent.

Figure 2. Total final energy consumption by sector in 2021



6 Based on the data from National Statistical Office provided by national consultants.
7 Based on the data from Population and Housing Report: Housing Authority of Thailand provided by national consultants.

In terms of fuel usage in TFEC, oil products contributed the highest amount (43.3 per cent) followed by electricity (20.7 per cent). The transport sector, which operated predominantly with internal combustion engine vehicles, was the main consuming sector for oil products with additional biodiesel (1.7 per cent) and ethanol (0.8 per cent). Natural gas and coal accounted for 15.7 per cent and 7.7 per cent of energy demand, respectively. In terms of biomass, modern biomass use was around 7 per cent while traditional biomass use was around 3.1 per cent.

Within the transport sector, 89.3 per cent of energy, or 24.4 Mtoe, was consumed by road transport. The remaining went to the rail transport (0.1 Mtoe), marine transport (1.4 Mtoe) and aviation sector (1.4 Mtoe). Within the road transport category, 41.3 per cent was used for freight trucks and 39 per cent of energy was used by passenger cars. Motorcycles accounted for 13.9 per cent and buses accounted for 4.6 per cent of energy demand. The remaining was for motor tricycles, taxis, tractors and mini buses.

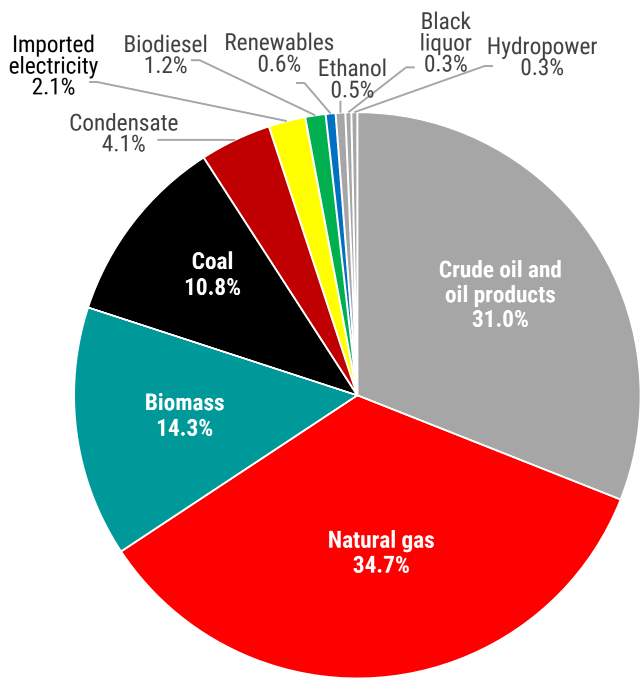
There are three energy-intensive industries in Thailand, which are (a) food and beverages, (b) glass, cement and non-metallic industries, and (c) chemical and synthetic products. These industries consumed 28.9 per cent, 25.3 per cent and 16.8 per cent of industrial energy demand, respectively. The remainder was consumed in textile and leather, machinery and transport equipment, iron and steel, pulp and paper, wood and wood products, and other processing industry.

In the residential sector, almost one-third of energy was consumed for cooking purposes (3.1 Mtoe). Household industry activity, such as clothes dyeing and brick-making, consumed around 2 Mtoe of energy demand. Around 4.7 Mtoe was utilized by: power household appliances; refrigeration, 46.5 per cent; air conditioners; 16.3 per cent; electric fans, 12.9 per cent; lighting, 10.1 per cent. The remaining 14.2 per cent was used for television, washing machines, iron and other appliances.

In the commercial sector,[8] shopping malls accounted for 64.7 per cent of the energy demand, followed by hotels at 15.3 per cent. Private offices and government buildings consumed 6.6 per cent of commercial energy demand. The remainder was used by health-care facilities, educational institutions and worship centres.

Primary energy supply: The total primary energy supply (TPES) in 2021 was around 124.5 Mtoe (figure 3). The energy supply mix was as follows:

Figure 3. Total primary energy supply by sector in 2021



8 The commercial sector analysis is based on floor space occupied by the sector and the energy intensity per square metre.

crude oil and oil products, 31 per cent; natural gas, 34.7 per cent; biomass[9] and waste, 14.3 per cent; coal, 10.8 per cent; condensate, 4.1 per cent; renewables, hydropower, biodiesel and ethanol, 2.6 per cent; imported electricity, 2.1 per cent; and other, 0.3 per cent. The total installed electrical generation capacity in 2021 was 53.2 GW.[10] Total electricity generation was 184.4 TWh,[11] where thermal power plants accounted for 85.9 per cent of power generation in 2021 while the remainder came from renewable energy.

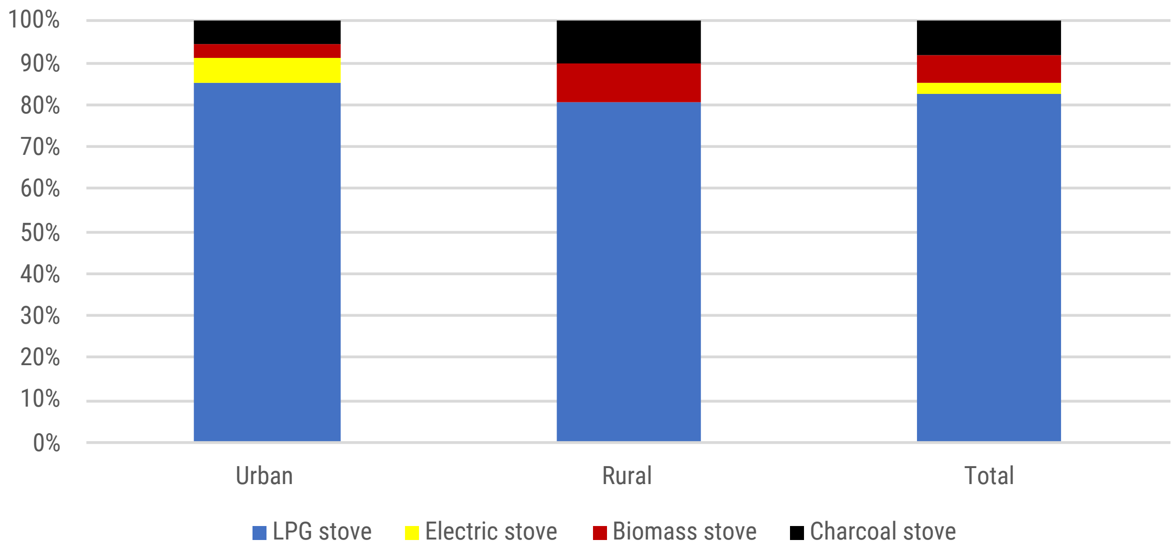
Electricity generation: Total installed power generation capacity in 2021 was 53.2 GW.[12] In terms of capacity mix, natural gas technologies (CCGT, gas steam turbine and gas cogeneration) accounted for 62.3 per cent of the capacity, followed by coal, 13.3 per cent. In terms of capacity, renewables accounted for 24.2 per cent of capacity (biomass, 8.1 per cent, hydro, 7.7 per cent, solar, 5.6 per cent and wind, 2.8 per cent). Total domestic[13] electricity generation in 2021 was 184.4 TWh, when thermal power plants accounted for 85.9 per cent of power generation while the remainder came from renewable energy.

2.2.2. Status of SDG 7 targets in the base year 2021

Access to modern energy: Thailand has made significant progress towards achieving universal access to electricity. The rate of electrification in Thailand was 99.8 per cent in 2021. Thailand is very much on track to achieve universal access to electricity by 2030. Access to clean cooking fuels and technologies measured 85 per cent in 2021. The remaining 15 per cent of the population, which corresponds to 3.38 million households, still relied on polluting charcoal and biomass stoves as their primary cooking technology. Overall, liquefied petroleum gas (LPG) stoves were the most dominant primary clean cooking technology, with an estimated share of 82.5 per cent, followed by a small proportion of electric cooking stoves. Figure 4 shows the distribution of different cooking fuels and technologies in 2021.

Renewable energy share in the total final energy consumption (TFEC): Renewable energy delivered approximately 15.6 per cent of TFEC in 2021, which is equivalent to 16.9 per cent of TPES.

Figure 4. Clean cooking access share



9 Including fuelwood, paddy husk, bagasse, agricultural residue and biogas.

10 Based on the data from power plant data base Office of the Energy Regulatory Commission, provided by national consultants.

11 Excluding imports.

12 Based on the data from power plant database Office of the Energy Regulatory Commission, provided by national consultants excluding imports.

13 Power generation within Thailand boundaries, excluding imports.

This includes traditional biomass usage in the residential sector. If the traditional biomass is excluded, the renewable share was 11.7 per cent of TFEC. While endowed with an abundance of renewable potential, Thailand has a high reliance on fossil fuels (i.e., oil products) to meet its stationary and mobile fuel demands.

Energy intensity: Energy intensity under SDG 7.3 is defined as the TPES in megajoules per US dollar of gross domestic product in terms of power purchase parity in 2017. Thailand's energy intensity in 2021 was estimated to be 4.3 MJ/USD_{2017}.

In addition, the Government of Thailand also measures energy intensity as the final energy consumption in thousand tonnes of oil equivalent per billion Baht. This method is slightly different from the one defined and measured under SDG 7.3. Thailand measures energy intensity in terms of final energy consumption, which was 6.94 ktoe/billion Baht, whereas energy intensity under SDG 7 is measured in terms of primary energy supply. Therefore, these two values cannot be directly compared.

GHG emissions: The energy sector emissions, from the combustion of fossil fuel, were calculated based on IPCC Tier 1 emission factors assigned in the LEAP model and expressed in terms of 100-year global warming potential (GWP) values. GHG emissions from the energy sector were estimated at 224.4 $MtCO_2$-e in 2021. Emissions from power generation were the largest at 86.1 $MtCO_2$-e. This is followed by the transport sector at 75.6 $MtCO_2$-e, rising from direct fuel combustions in internal combustion engines. Industrial sector emissions were around 46.9 $MtCO_2$-e. The residential sector accounted for 6.8 $MtCO_2$-e coming from fuel combustions for cooking and home industry activities. The remaining emissions are attributable to commercial, agriculture, and other sectors.

2.2.3. National energy policies, plans, strategies and institutions

Thailand's energy sector is managed by several stakeholders. These include the Ministry of Energy, the Energy Regulatory Commission (ERC), the state-owned utility Electricity Generation Authority of Thailand (EGAT), the national oil company PTT Public Company, Ltd., and two distribution companies – the Provincial Electricity Authority (PEA) and Metropolitan Electricity Authority (MEA). There are also independent power producers (IPPs) and small power producers (SPPs) which support EGAT in generating electricity.

The MoE is responsible for the policy and strategy formulation, strategic planning, management and coordination of the energy sector. The Ministry is split into four departments, including the Department of Alternative Energy Development and Efficiency (DEDE) and the Energy Policy and Planning Office (EPPO). EPPO has responsibility for preparing the Power Development Plant (PDP) together with EGAT and the ERC. The ERC is the independent organization that is responsible for regulating the operations of the energy industry.

Thailand's energy sector development is guided by several national policies and articles of legislation. These have been used as guiding references for the NEXSTEP modelling in order to better understand the country context and to develop recommendations in adherence to the Government's overarching direction. Where applicable, the currently implemented and adopted policies or regulations are considered in the current policy scenario, in order to identify gaps in achieving the SDG 7 targets.[14] The key policies and strategic documents consulted are detailed below.

- **Thailand's Energy Efficiency Plan (EEP) 2022-2037 under the National Energy Plan** sets out an energy intensity reduction target of 36 per cent by 2037 and 40 per cent by 2050 compared to the 2010 baseline. It sets out several compulsory measures and voluntary measures in achieving this target with a total savings of 35,497 ktoe by 2037 (table 1).
- **Ministerial Regulation Prescribing Type or Size of Building and Standard, Criteria and Procedure in Designing Building for Energy Conservation B.E. 2563 (2020)** mandates an energy-efficient design for all new buildings with a total floor area in all stories of 2,000 square metres or more. It is applicable to nine types

14 Only policies with concrete measures are considered in the scenario modelling for the current policy scenario. plan/strategy policy documents without concrete measures enforced are not considered but are compared with scenario result findings.

Table 1. EE target under the draft of EEP2022-2037 according to strategy

Strategies	Energy saving target (ktoe)
Compulsory strategies	
Implement energy management standards in designated factories/buildings	5,764
Compulsory energy standards (energy code) (factory, building, residential, agriculture)	937
Energy conservation measures in the road transport sector	1,650
Promotional strategies	
Equipment performance benchmarks and labelling	3,568
Financial incentive and energy services companies (ESCO) model	4,904
Promotion of innovation (IOT, smart technology, big data, AI)	317
Transport energy conservation (EV, land, water, air, rail)	15,341
Energy conservation in agriculture (smart farming, switch to machinery)	660
Conserving energy in the residential sector (energy conservation house, smart home)	1,754
Increasing the efficiency of equipment in renewable energy systems (biomass boiler, biomass burner, generator, solar heat)	322
Implementing` the energy efficiency standard for energy producers and distributors (EERS).	280

of buildings – hospitals, education institutions, condominiums, offices, convention halls, department stores, hotels, entertainments and theatre.

- **Minimum Energy Performance Standards (MEPS)** have been implemented for refrigerators and air conditioners since 2005 and 2011, respectively (IEA, 2020; IEA, 2017). MEPS for washing machines was announced in August 2021. In addition, voluntary certification is available for several types of electrical equipment through the Energy Efficiency Labelling No. 5 Program and for several non-electrical equipment through the Energy Efficiency Labelling Programme.
- **Thailand's Alternative Energy Development Plan, 2018-2037 (AEDP 2018)** (Ministry of Energy, 2018a) aims to promote the development of renewable energy production in the country and sets out a goal to increase the share of renewable energy and alternative energy in final energy consumption (excluding non-energy use) to 30 per cent by 2037.
- **Thailand biofuel mandate** stipulates a minimum biodiesel blending of 7 per cent from 2014 onwards, which was increased to 10 per cent in 2020 (for compatible vehicles) (USDA, 2021). For gasoline vehicles, ethanol blending will be increased to 20 per cent (E20) by 2027. However, in order to set primary diesel and

gasoline in the long term, the revised oil plan 2023-2037 is expected to be launched in 2024 and is currently awaiting public consultation.

- **Thailand's Power Development Plan, 2018-2037 (PDP 2018 Revised Version)** (Ministry of Energy, 2020) is to improve energy efficiency and enhance energy security in the country, while setting goals for new power production capacity. The PDP 2022-2037 is currently under public consultation.
- **Thailand's** (The Government of Thailand, 2022) intends to reduce its GHG emissions unconditionally by 30 per cent from the projected BAU level by 2030. The conditional target is to reduce emissions by 40 per cent from the projected BAU level by 2030, subject to adequate and enhanced access to technology development and transfer, financial resources and capacity-building support.
- **Thailand Long-Term Low Greenhouse Gas Emission Development Strategy** (MoNRE, 2022) outlines key mitigation actions that Thailand will undertake striving towards carbon neutrality by 2050 and net zero GHG emissions by 2065, which represent enhanced mitigation efforts in various sectors.

2.2.4. National energy resources and potentials

Thailand's natural gas reserves were estimated at 10.3 trillion standard cubic feet (TSCF) in 2021 (Statista, 2022b). Most of the reserves were located offshore, with many drilling wells located in the Gulf of Thailand. Gas is the main fuel used for electricity generation and industrial use. Thailand's gas demand has nearly doubled, yet gas production has declined in recent years. Consequently, the country now imports a large proportion of its gas demand.

Thailand has oil reserves of 243 million barrels (Statista, 2022a). The country has been a net importer, due to a production decline caused by depletion of mature production wells, the limited development of new production wells and declining investment. In terms of coal, the reserve is around 1,063 million tons (BP, 2019). Coal is mainly consumed in power generation and industry. It is also heavily used in cement and paper production.

Despite having hydropower resources, not many hydropower projects have been developed. The Government encourages local communities to develop small-scale hydropower projects. In addition to hydropower, Thailand has substantial experience with solar photovoltaics (PV) and wind technologies. There are plans to further increase solar PV deployment within the next few years. The country has high potential for utility-scale solar PV (ground-mounted and floating PV) as well as solar rooftop deployment, thanks to high solar irradiance. The daily average of solar insolation was around 17.6 MJ/m2 (Ministry of Energy, 2018a). There is also a considerable wind energy resource potential in Thailand, particularly in the north-eastern region. In most parts of the country, the average wind speed at the hub height of 90 metres is expected to be around 4 to 5 metres per second, generally considered too low to be commercially feasible. In the north-eastern region, however, the average wind speed is 6 to 7 metres per second (Ministry of Energy, 2018a). There has been increasing development of bio-energy and waste for energy production. Table 2 presents a SWOT analysis of renewable energy resources in Thailand.

Table 2. SWOT analysis of renewable energy resources in Thailand

	Strength	Weakness	Opportunites	Threats
Hydro energy	• Endowed with water resources • Already established technology	• Seasonal variability	• Player in the market is already available	• Disturbance in biodiversity • Long development time for large hydro
Solar energy	• Abundant resource availability • Already established technology	• Challenges in identifying suitable land area for large scale solar plants	• Huge potential to meet the supply and demand gap • Reduction in GHG emissions	• High capital cost
Wind energy	• Low to moderate potential • Sparsely distributed potential and very geographic specific	• Limited availbality of suitable sites with adequate wind speeds	• Windy areas in northeast region • Reduction in GHG emissions	• High capital cost
Biomass and waste energy	• Availability of crop residues and wastes	• May have issue with food security if not managed propoerly	• Opportunity to retrofit old thermal power plant	• Very high capital cost

3. Modelling assumptions

This section presents an outline of the scenarios considered by NEXSTEP, together with the key demographic and macro-economic assumptions used in modelling Thailand's energy system.

3.1. Scenario definitions

NEXSTEP is designed for scenario analysis, using the LEAP modelling system to enable energy specialists to model energy system evolution based on current energy policies. The baseline year 2021 was chosen, as it is the most recent year with sufficient data information for modelling. In the NEXSTEP model for Thailand, five scenarios have been developed. These include three core scenarios: (a) business-as-usual (BAU) scenario; (b) current policy scenario (CPS); and (c) Sustainable Development Goal (SDG) scenario. In addition, (d) Carbon Neutrality by 2050 and (e) Net Zero Emissions by 2065 scenarios have been developed to present technological options and policy measures that would be required for Thailand to transition beyond 2030.

3.1.1. BAU scenario

This scenario hypothetically projects the energy demand and emissions trajectory based on historical improvement and in the absence of any new actions or policies. While this scenario is not a practically true scenario, since there will be policies and plans implemented along the way, it is helpful in comparing the emission trajectories. In this scenario, the final energy demand is met by a fuel mix reflecting the current shares in TFEC, with the trend extrapolated to 2030.

3.1.2. Current policies scenario

Inherited from the BAU scenario, this scenario considers initiatives implemented or scheduled to be implemented during the analysis period of 2021-2030 in establishing its baseline performance, with reference to the SDG 7 and NDC targets as well as national targets for energy efficiency improvement and renewable energy share. Otherwise, the energy intensities from different demand sectors are assumed constant throughout the analysis period. Only policies with concrete measures are considered in this scenario. Plans/strategies/policies that are unlikely to be implemented are not considered but are compared with scenario results and findings later in this Road Map.

3.1.3. SDG scenario

The SDG scenario builds on the current policy scenario to provide recommendations for achieving the SDG 7 targets. This scenario aims to achieve the SDG 7 targets, including universal access (100 per cent) to electricity and clean cooking fuel, substantially increasing the renewable energy share and doubling the rate of energy efficiency improvement. For clean cooking, different technologies (electric cooking stoves, LPG cooking stoves and improved cooking stoves) have been assessed, with subsequent recommendation on the uptake of the most appropriate technology. Energy intensity has been modelled to help achieve the SDG 7 target. It also allows the achievement of the country's unconditional NDC target by 2030.

3.1.4. Beyond 2030 scenario

Like the SDG scenario, the beyond-2030 scenarios also aim to achieve the SDG 7 targets. In addition, these scenarios look at increasing the socio-economic and environmental benefits for the country from raising its ambition beyond the SDG 7.3 target and meeting its conditional NDC target.

- **Carbon Neutrality by 2050 scenario:** This scenario explores technological interventions, timeframe of implementation of different measures and technologies, and policy framework that would be needed to successfully achieve Thailand's carbon neutrality plan by 2050.

- **Net Zero Emissions by 2065 scenario:** Similar to Carbon Neutrality by 2050, this scenario explores technological interventions, timeframe of implementation of different measures and technologies, and policy framework that would be needed to successfully achieve Thailand's Net Zero Emissions plan by 2065.

3.2. Assumptions

COVID-19 posed a negative impact on the energy demand in Thailand, which saw negative growths in 2020 and 2021. The MoE suggested adjusting the energy demand forecast to compensate for the COVID-19 impacts by considering the historical pre-COVID data and the 2022 energy demand data (as shown in figure 5) to ensure better accuracy in the projection. As can be seen, the energy data for 2022 shows a positive rebound and is expected to return to normal trend in 2023.

The energy demand is estimated by using the activity level and energy intensity in the LEAP model. The demand outlook throughout the NEXSTEP analysis period is influenced by factors such as annual population growth and annual GDP growth. The assumptions used in the NEXSTEP modelling are further detailed in Annex II, while table 3 provides a summary of key modelling assumptions for the three main scenarios (i.e., BAU, CPS and SDG scenarios).

Figure 5. Adjustment for COVID-19 impacts to energy demand trend

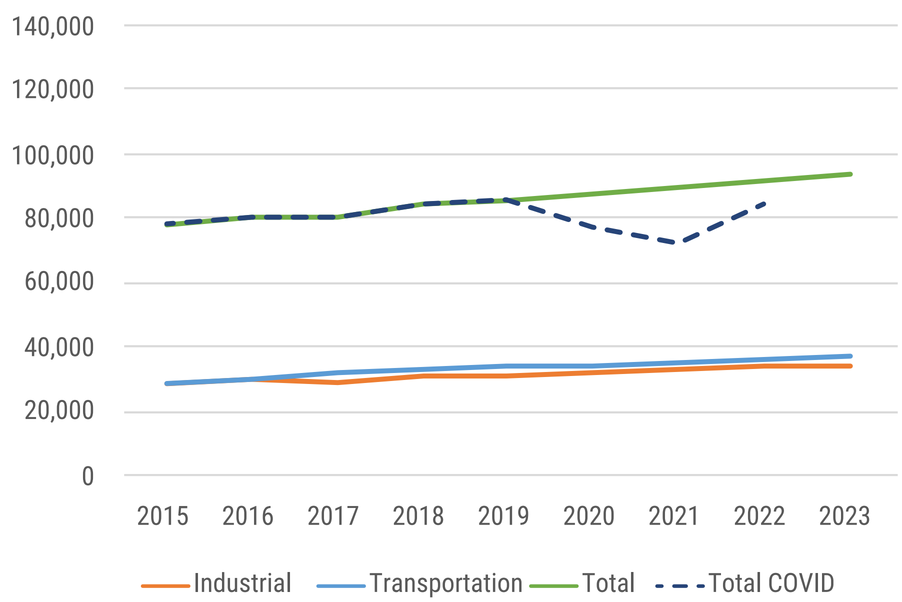


Table 3. **Important factors, targets and assumptions used in NEXSTEP modelling**

Parameters	Business as usual scenario	Current policy scenario	Sustainable Development Goal scenario
Economic growth	2021 to 2022 (2.6per cent); 2022 to 2023 (3.3per cent), 2023 to 2024 (3.7per cent), 2024 forward (3.7per cent)[15]		
Population growth	0.16 per cent per annum, reaching a peak in 2030, and decreasing at a rate of 0.26 per cent per annum[16]		
Urbanization rate	42.8 per cent in 2021, growing to 48.4 per cent in 2030[17]		
Commercial floor space	Assumed annual energy consumption increasing at the same growth as GDP		
Industrial activity	Industrial activities are assumed to grow at the same rate as GDP between 2021 to 2030 and adjusted for COVID-19 impacts for 2021-2022.		
Transport activity	Passenger transport activities and freight transport activities are assumed to have grown at the same rate as per capita GDP growth and adjusted for COVID-19 impacts for the 2021-2022.		
Residential activity	The appliance ownership for electrical appliances is projected to grow at a rate like the growth in GDP per capita.		
Access to electricity	100 per cent access to electricity is assumed to have achieved in 2022		
Energy efficiency	Projected based on the historical penetration rate between the 2000-2020 period.		100 per cent clean cooking access rate to achieve the SDG 7 target.
Power plant	Additional energy efficiency measures not applied	Improvement based on current policies	Global target of energy intensity adopted

15 Based on the projection (ADB, 2023).

16 Calculated based on the population projection in the LT-LEDS document (MoNRE, 2022).

17 This assumes that the urbanization rate grows at an annual rate of 1.4 per cent, with reference to the national historical urbanisation growth from 2010 to 2020.

4. Energy transition outlook in the current policy scenario

This section presents key results of modelling under the NEXSTEP's current policy scenarios, focusing on impacts in key areas of the economy and the energy sector.

4.2. Energy demand

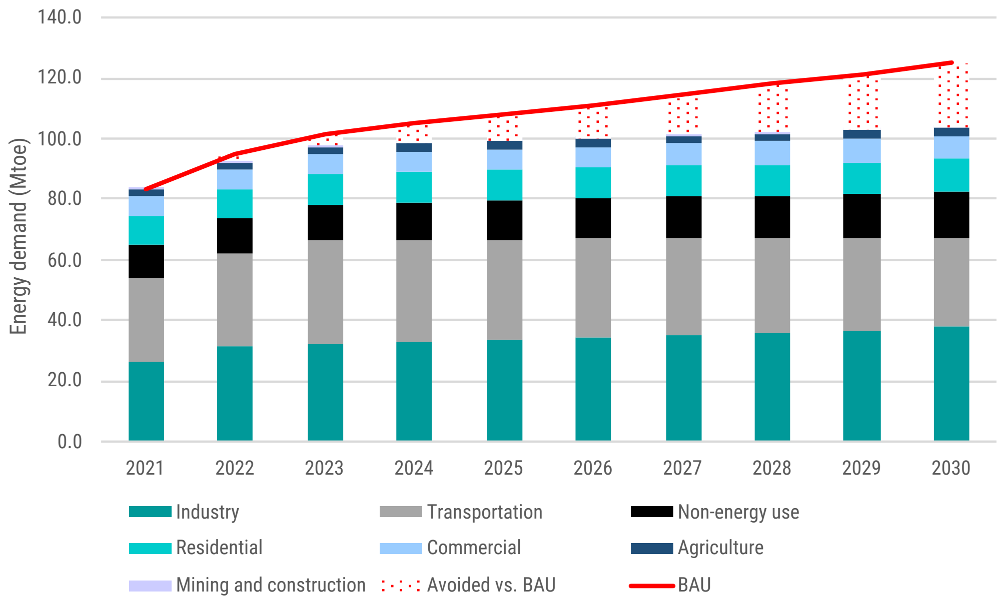
Under the current policy setting, the demand for total final energy is expected to increase from 83.3 Mtoe in 2021 to 104.1 Mtoe in 2030, an average annual growth rate 2.2 per cent. In 2030, the industry sector will surpass the transport sector to become the largest energy-consuming sector at 36.2 per cent, while the transport sector share will be 28.6 per cent. The non-energy use consumption will be 14.6 per cent followed by the residential sector at 10 per cent. The commercial and agricultural sector will account for 7.3 per cent and 2.9 per cent of energy demand, respectively. Figure 6 shows the forecast of the TFEC by sector under the CP scenario. The sectoral energy efficiency measures are described further below.

4.1.1. Industry sector

The industrial sector will surpass the transport sector to dominate Thailand's TFEC, with a 36.2 per cent share in 2030. It will consume 37.7 Mtoe in 2030, an annual growth of 4.1 per cent, up from 26.4 ktoe in 2021. Within the industrial sector, it is projected that 30.1 per cent of energy in 2030 will be consumed by glass, cement and non-metal industries. Food and beverages will account for 26.1 per cent followed by chemical and synthetics products at 16 per cent. The remaining 27.8 per cent will be consumed across nine industries, including machinery and transport equipment, and iron and steel industries.

The Government has put in place the energy efficiency plan targeting a 12.4 Mtoe energy reduction in the industrial sector between 2021 and 2037. Several energy efficiency measures are being implemented in the industry sector, including the energy management standards and energy code which are compulsory measures. The designated factories are required to develop an energy management system and inspection reports. In addition, promotional measures, such as equipment standards and labelling as well as financial incentives and ESCO model, are being implemented in the industrial sector (Ministry of Energy, 2018b).

Figure 5. Energy demand outlook in the current policy scenario 2021-2030



4.1.2. Transport sector

The transport sector will consume 29.8 Mtoe in 2030, an annual growth of 0.9 per cent, up from 27.4 Mtoe in 2021. The Government has put in place an energy efficiency plan targeting a 17 Mtoe energy reduction in the transport sector by 2037. Within the transport sector, land transport will account for 91 per cent transport energy demand in Thailand. To manage the growing energy demand in the transport sector and reduce corresponding emissions, the Government has put in place the electric vehicle policy of 30 per cent by 2030 targeting passenger cars, motorcycles, buses as well as freight trucks, and an increase in the biofuel mix ratio in the road transport sector (20 per cent for ethanol and 10 per cent for biodiesel). The rail transportation system in the city is also being developed to promote a travel mode shift from personal cars to public transportation systems, while simultaneously promote both cycling and walking to access public transport system. In addition, a double-track and high-speed rail system have been developed for intercity transportation. In terms of freight transportation, the double-track railway system and container yards (CY) are also being developed in order to shift freight transport from road to rail.

Although water transport and aviation consume less than 10 per cent of energy demand, the Government also has plans to develop infrastructure to support efficiency improvement in water transport as well as sustainable aviation fuel blending. In addition, the Government can implement a Ship Energy Efficiency Management Plan (SEEMP) for all shipping companies. SEEMP can be described as an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner (IMO, 2019). It allows shipping operators to track and improve operational and fleet performance with the aid of the Energy Efficiency Operational Indicator (EEIO) as a voluntary monitoring tool.

4.1.3. Residential sector

Energy demand in the residential sector will increase from 9.8 Mtoe in 2021 to 10.4 Mtoe in 2030, with an annual growth of 0.7 per cent. The low annual growth rate value is expected due to the low population growth combined with the energy efficiency improvement in the residential sector. In terms of fuel, electricity will be the main energy source by 2030 at 56.6 per cent, followed by biomass and charcoal at 24.6 per cent and LPG at 18.8 per cent. LPG, biomass, and charcoal are used mainly for cooking purposes. Electricity will be used for refrigeration (45.5 per cent), air conditioners (17.8 per cent), electric fans (11.9 per cent) and lighting (10.2 per cent). In the residential sector, the Government has targeted a total saving of up to 1.7 Mtoe during 2021-2037 through programmes such as equipment standards and labelling, energy codes, efficient and smart home system as well as Internet-of-Things (IoT).

4.1.4 Commercial and agricultural sector

Total energy consumption in the commercial sector will increase from 6.2 Mtoe in 2021, at an average annual growth of 2.3 per cent, to 7.6 Mtoe in 2030. The Government will enforce energy management standards and energy codes as compulsory measures. In addition, promotional measures, such as equipment standards and labelling as well as financial incentives, and the ESCO model will be implemented in this sector. Shopping malls, hotels and offices will account for a total of 86.8 per cent of the energy demand. Under the building code, buildings with areas larger than 2,000 m^2 must consider their envelope system, electric lighting system, air-conditioning system, water heating appliances, renewable energy system, and whole building energy.

The agricultural sector will consume 3 Mtoe of energy in 2030, an annual increase of 3.3 per cent from 2.2 Mtoe in 2021. The Government targets

Table 4. Energy efficiency measures and energy demand reduction opportunities in the CP scenario compared to the BAU scenario by 2030 and 2037

Sector	Measure	Energy demand reduction (ktoe)	
		2030	2037
Residential	Compulsory energy standards (energy code) Equipment performance benchmarks and labelling Energy conservation (Smart home system, IoT)	770	1,775
Commercial	Implement energy management standards in designated factories/ buildings Compulsory energy standards (energy code) Equipment performance benchmarks and labelling Fiscal incentive and ESCO model	872	3,553
Industry	Implement energy management standards in designated factories/ buildings Compulsory energy standards (energy code) Equipment performance benchmarks and labelling Fiscal incentive and ESCO model	6,238	12,441
Transport	Energy conservation measures in the road transport sector (including B10, E20) Electric vehicles 30@30 Mode shifting: encouraging cycling and bicycling, double track and new line development, water transport infrastructure development.	12,963	17,055
Agriculture	Smart farming and machinery switching	296	708
Total		**21,139**	**35,531**

a 0.7 Mtoe demand reduction during 2021-2037 through smart farming and switching to machinery. Table 4 summarizes energy efficiency measures modelled in the current policy scenario and corresponding energy reduction opportunities in different sectors.

4.2. Energy supply outlook

Primary energy supply

In the current policy scenario, TPES is forecasted to increase from 124.5 Mtoe in 2021 to 140.1 Mtoe in 2030. The fuel shares in 2030 (figure 7) is projected to be natural gas and condensate 56 Mtoe (40 per cent), crude oil and oil products 41.9 Mtoe (29.9 per cent), biomass 21.8 Mtoe (15.6 per cent), coal 13 Mtoe (9.3 per cent), biofuel 2.9 Mtoe (2.1 per cent), imported electricity 1.5 Mtoe (1.1 per cent), hydropower 0.4 Mtoe (0.3 per cent) and other renewables 2.1 Mtoe (1.5 per cent). The increase in biomass shares is due to the current AEDP plan to replace some natural gas and coal in the industry sector by biomass, which will help Thailand to achieve a 30 per cent renewable share target under final energy consumption.

Electricity generation

Thailand has an ambitious plan to accelerate the transition to cleaner energy supply. The NEXSTEP analysis for Thailand uses data from the revised power development plan to model the current policy scenario for electric power generation outlook. In

Figure 7. Total primary energy supply by fuel type in 2030 in the CP scenario

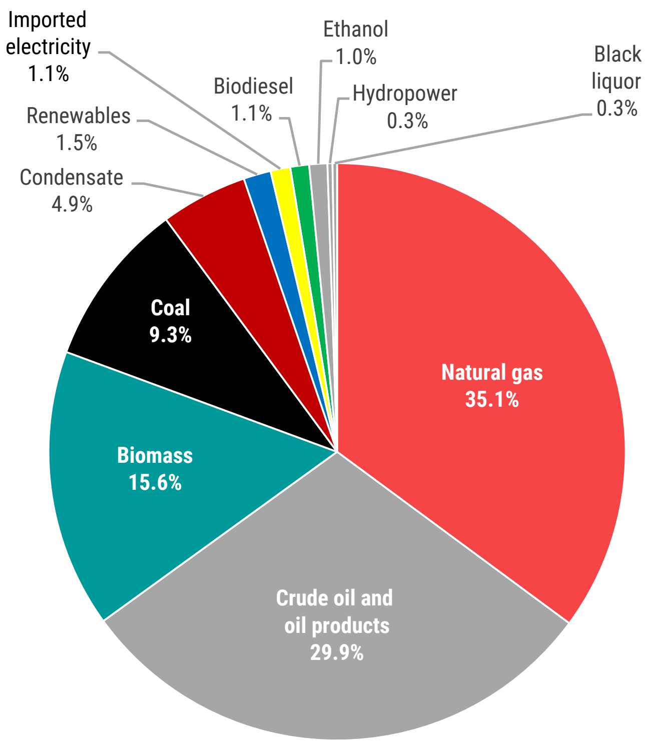
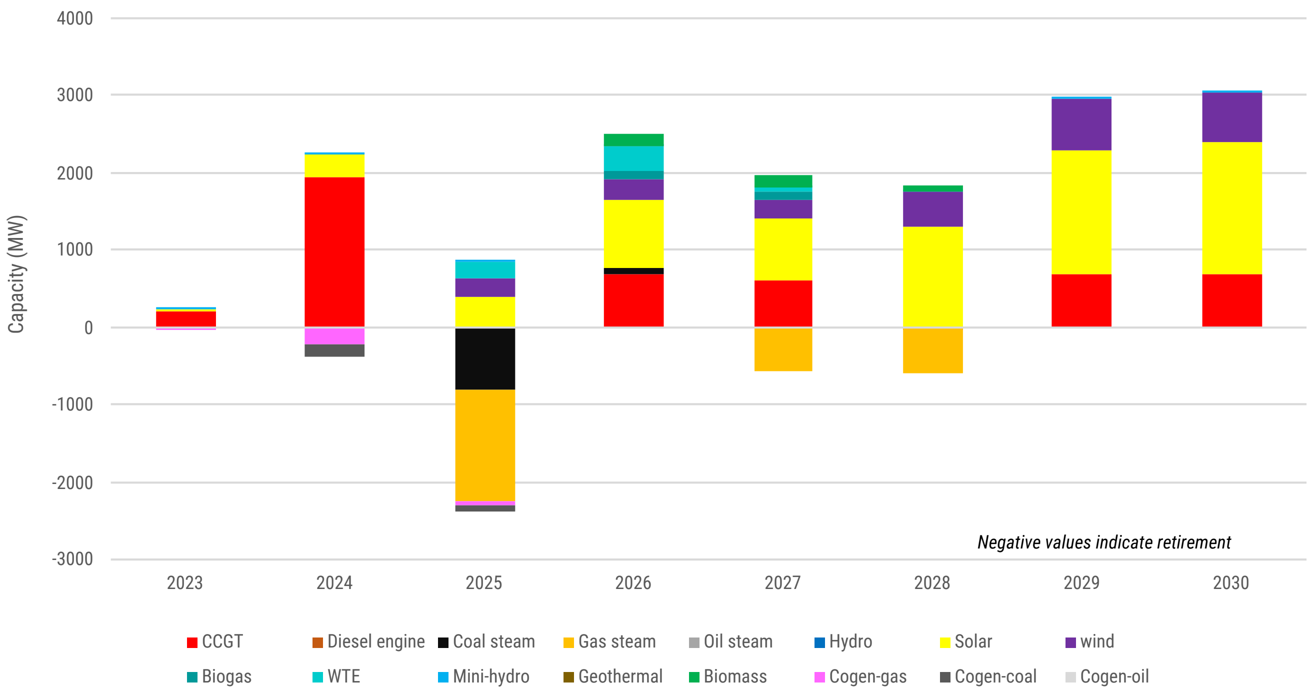


Figure 8. Power capacity expansion and retirement plan 2023-2030



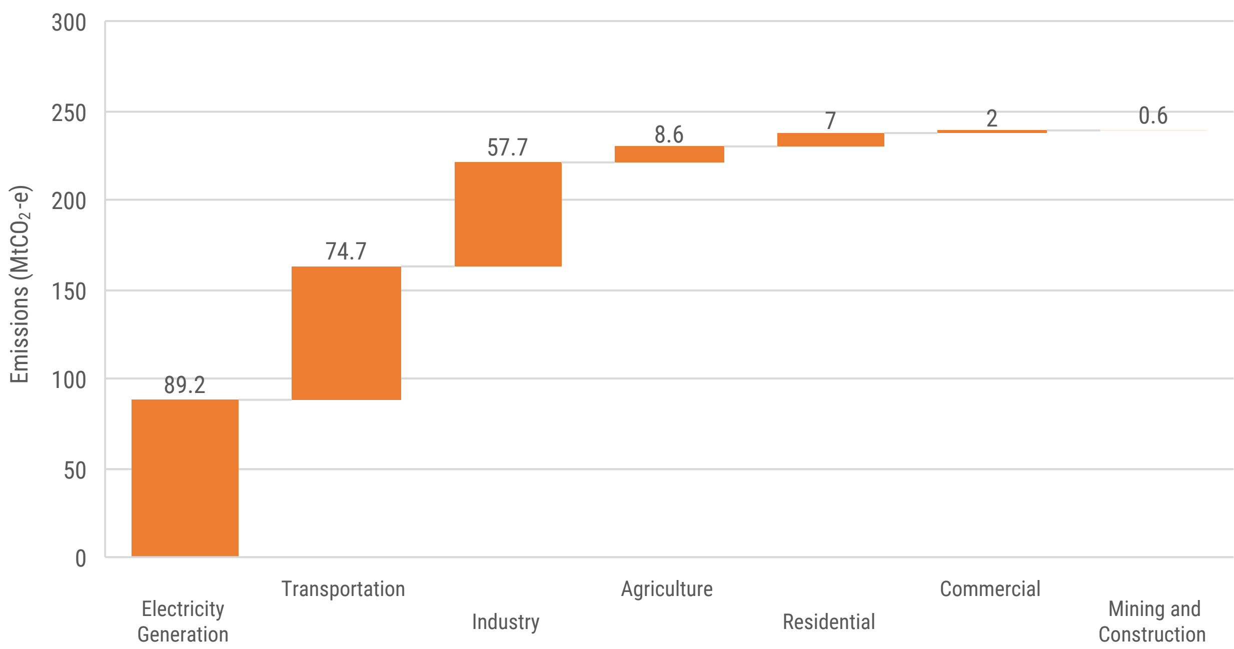
the current policy scenario, an additional 10.8 GW renewable-based power plant will be added to the power sector domestically up to 2030, on top of 5.5 GW combined heat power, while some steam turbines will retire (figure 8).

In 2030, the installed power generation capacity for Thailand is forecast to be 65.8 GW. Fossil fuel will continue to dominate installed capacity at 64 per cent and the renewables share will increase to 36 per cent. Electricity generation is expected to rise from 184.4 TWh in 2021 to 263.6 TWh[18] in 2030. The renewable energy share of electricity supply will increase from 14.1 per cent in 2021 to 18.1 per cent in 2030. The total electricity requirement (considering both final energy demand as well as transmission and distribution losses) in the CP scenario by 2030 would be 281.6 TWh.

4.3. GHG emissions

GHG emissions are projected to reach 239.7 $MtCO_2$-e by 2030, which is a decrease of 32.5 per cent compared to the BAU scenario in which emissions are expected to be 355.1 $MtCO_2$-e by 2030. This reduction is attributable to the Government's plan for energy efficiency measures and renewable energy. Most emissions will come from electricity generation (37.2 per cent), followed by the transportation sector (31.2 per cent) and industry sector (24.1 per cent). Figure 9 shows the emissions distribution by sector in 2030.

Figure 9. Distribution of emissions by sector in 2030 in the CP scenario



18 Excluding imports.

5. SDG scenario: An assessment of SDG 7 targets and indicators

This section begins with a concise overview of the energy demand projections under the SDG scenario. Later, the results are evaluated against the SDG 7 and NDC targets, along with other relevant indicators. This evaluation is based on the outputs from the NEXSTEP analysis, aiming to spotlight any policy gaps in Thailand's current energy policies. To conclude, the future energy supply outlook is presented.

5.1. Energy demand outlook

In this scenario, TFEC increases to 90.5 Mtoe in 2030, which is a 13.6 Mtoe reduction compared to the current policy scenario. This reduction is due to additional energy efficiency modelled to ensure the achievement of the SDG 7.3 target. In 2030, the industry sector will have the largest share of TFEC at 33.3 Mtoe (36.7 per cent), followed by the transport sector at 26.8 Mtoe (29.6 per cent). Demand for non-energy use will be 11.4 Mtoe (12.6 per cent). Residential and commercial sectors will account for 8.8 Mtoe (9.7 per cent) and 7 Mtoe (7.7 per cent), respectively. The agriculture, mining and construction sectors together will account for 3.3 Mtoe (3.7 per cent). Figure 10 shows the total final energy consumption by scenario in 2030.

5.2. SDG 7 targets

5.2.1. Access to electricity

The electrification rate in Thailand was 99.8 per cent in 2021, and many organizations have reported that the electricity rate in Thailand already reached 100 per cent in recent years (World Bank, 2020; ASEAN-German Energy Programme, 2021). Even though there is a possibility that a small share of unregistered households have no access to electricity, it is still very likely that Thailand will achieve universal access to electricity by 2030. In such a case, the NEXSTEP analysis proposes that decentralized renewable electricity systems, such as solar mini-grids and solar home systems, could be provided to the unconnected households. The ease of implementation, compared to extending the grid infrastructure, should allow the 100 per cent electrification target to be reached.

5.2.2. Access to clean fuels and technologies for cooking

Thailand has made progress towards clean cooking, increasing from 57 per cent in 2000 to 85 per cent in 2021. This has been possible due

Figure 10. Comparison of energy demand between BAU, CPS and SDG scenarios

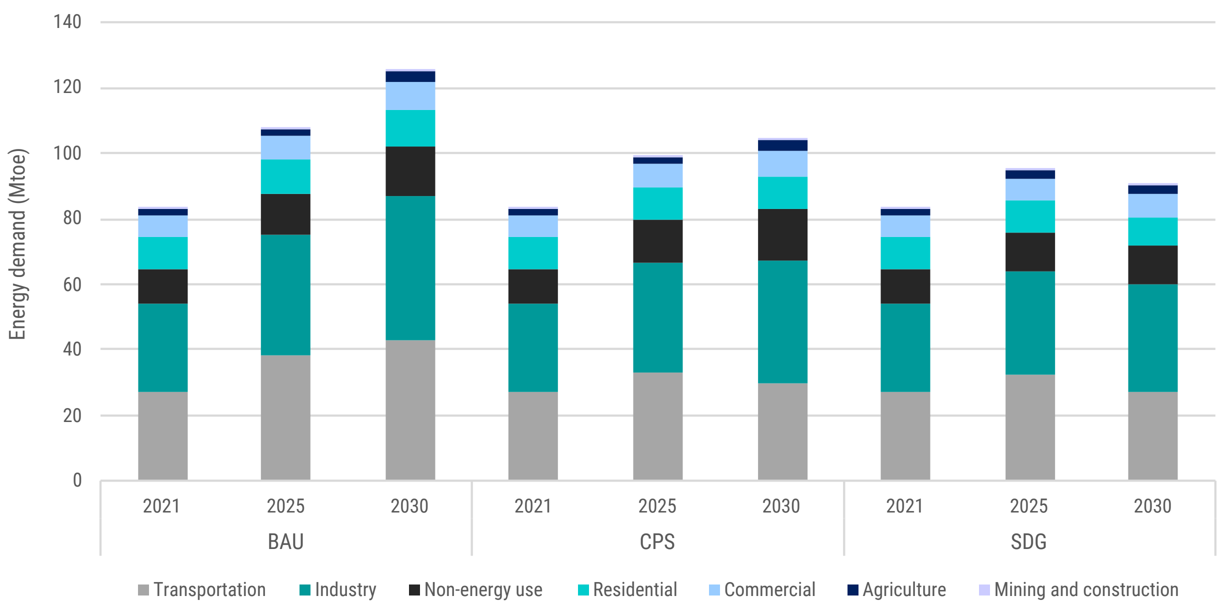
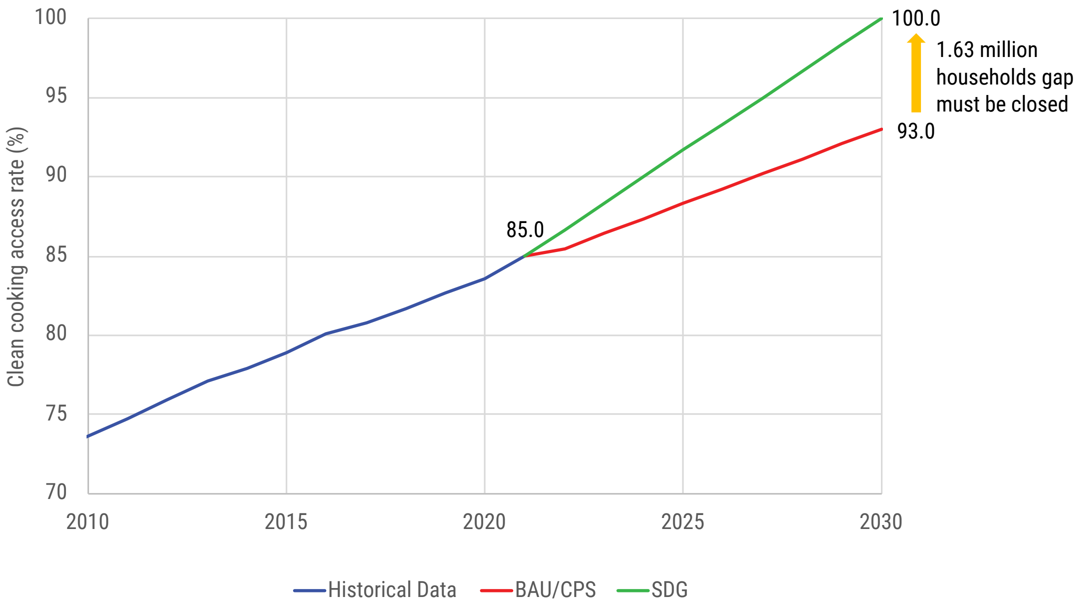


Figure 11. Thailand's access to clean cooking in the BAU/CPS and SDG scenarios



to the High Efficiency Cookstove Development and Manufacturing Project or High Efficiency Cookstove (Mahasetthi Cooking Stove) programmes during 2008-2011. However, as fuel and cooking gas have become more expensive, the progress has become slower (Akahoshi, Zusman Onmek and Wangwongwatana, 2022. As of 2021, 15 per cent of people relied on polluting cooking technologies, specifically biomass and charcoal. Under the current policy scenario, access to clean cooking fuels and technologies will reach 93 per cent in 2030, leaving 1.6 million households relying on inefficient and hazardous cooking fuels and technologies. Under the SDG scenario, the clean cooking access rate is set to achieve universal access (100 per cent) by 2030 (figure 11).

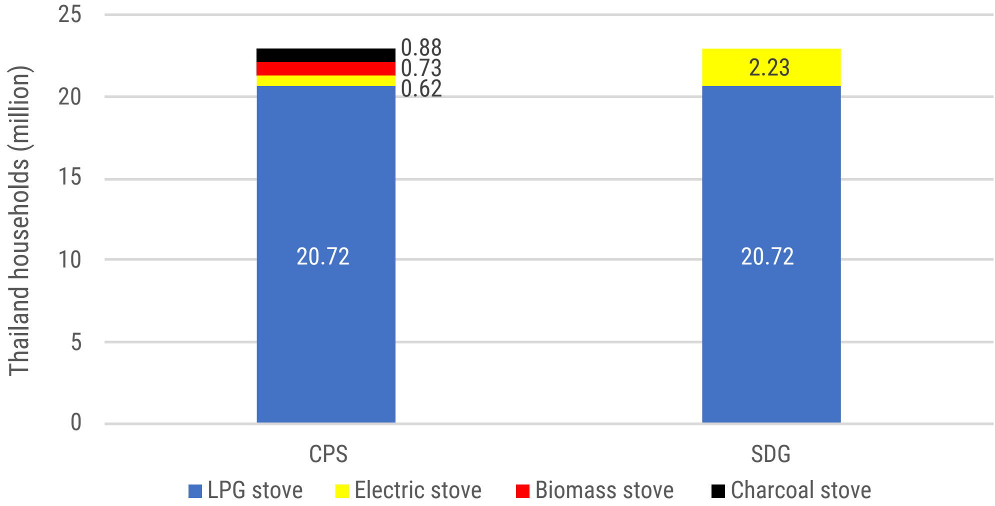
The NEXSTEP analysis indicates that electric cooking stoves would be the most appropriate solution for Thailand to connect 1.6 million households by 2030 due to cost and environmental effectiveness, since the technology has been available in the country (figure 12). The annualized cost of electric cooking stoves will be around US$165 while the LPG cooking stoves will be around US$177. With this measure, the share of households with LPG stoves will be around 90.3 per cent while those with electric stoves will be around 9.7 per cent by 2030 under the SDG scenario. This will prepare Thailand for carbon neutrality by 2050 and the avoided LPG can be utilized for a petrochemical process that would provide better economic value. LPG stoves, however, can play an intermediary role in the area where electric cooking stoves may not be suitable for households using off-grid electricity systems, as the appliance requires substantial power supply capacity. Box 1 explains the basis for evaluation of clean cooking technologies. Annex IV summarizes the cost and technical assumptions used in the economic analysis.

5.2.3. Renewable energy

SDG 7.2 does not have a quantitative target but encourages a "substantial" increase of the renewable energy share in TFEC. The share of renewable energy in TFEC in 2030 will be 10.7 per cent in the business-as-usual scenario, which is expected to grow to 18.7 per cent, in the current policy scenario (figure 13). This increase is largely driven by the biofuel mandate and the increase in the renewable energy share in power generation in the revised PDP 2018-2037 and AEDP 2018-2037. The renewable energy share in TFEC is further increased to 25.7 per cent in the SDG scenario, resulting from increased energy efficiency measures as well as switching from biomass-based cooking stoves to electric cooking stoves.

In addition, the Government of Thailand also measures renewable target as the renewable share in the final energy consumption (excluding the non-energy use). This method is slightly different from the one defined under SDG 7. As per this definition, the renewable energy share in

Figure 12. Share of clean cooking technologies by 2030 under CPS and SDG scenarios



Box 1. Evaluation of clean cooking technologies

Electric cooking stoves

Electric cooking technology is classed as Level 5 in the World Bank Multi-Tier Framework (MTF) for indoor air quality measurement. Electric cooking stoves are more efficient than other cooking stoves, including gas stoves. Electric cooking stoves can generally be divided into two types – solid plate and induction plate. While solid plate cooking stoves use a heating element to transmit radiant energy to the food and reach about 70 per cent efficiency, induction plate cooking stoves use electromagnetic energy to directly heat pots and pans, and can be up to 90 per cent efficient.

Improved cooking stoves

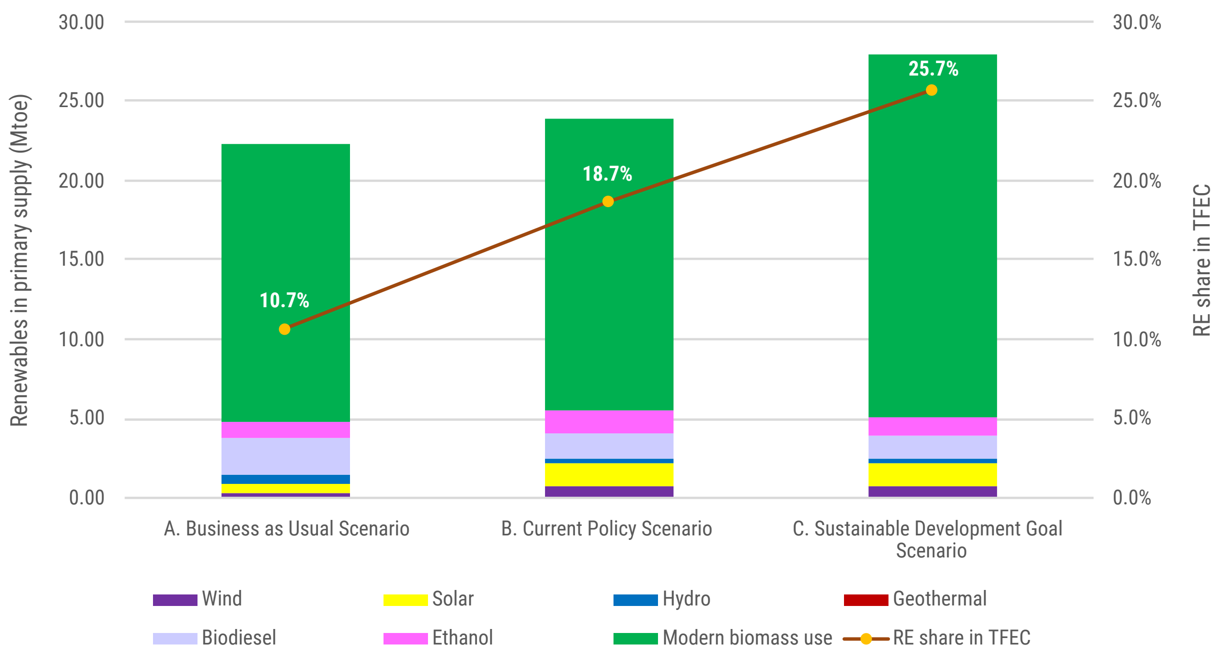
ICS programmes initially require strong advocacy to promote adoption, after which they require ongoing follow-up, monitoring, training, maintenance and repairs in order to facilitate continuing usage. In addition, based on the World Health Organization (WHO) guidelines[19] for emissions for clean cooking, only certain types of ICS technology comply, particularly when considering the fact that cooking stove emissions in the field are often higher than they are in laboratory settings used for testing. Tier 3+ ICS, which meets the WHO clean cooking guidelines, has the potential to reduce GHG emissions and provide socio-economic and health benefits, when it is promoted in carefully planned programmes.

LPG cooking stove

LPG is constrained due to fuel import dependency and supply chain challenges. LPG cooking stoves generate lower indoor air pollution compared to ICS. They are classified as Level 4 in the World Bank Multi-Tier Framework (MTF)[20] for cooking exposure and reduction of indoor air pollution by 90 per cent compared to traditional cooking stoves.

19 See defining clean fuels and technologies at https://www.who.int/tools/clean-household-energy-solutions-toolkit/module-7-defining-clean
20 See https://www.esmap.org/mtf_multi-tier_framework_for_energy_access

Figure 13. Renewable energy in TPES and TFEC in 2030



Note: RE share in this graph refers to the estimation methodology as per SDG 7.2.

the final energy consumption will be 21.9 per cent for CP scenario and 29.4 per cent for the SDG scenario in 2030.

An assessment of renewable energy until 2037 indicates that Thailand is on track to achieving the AEDP renewable target of 30 per cent under both the CP and SDG scenarios.

5.2.4. Energy efficiency

The Government of Thailand measures energy intensity as the final energy consumption in thousand tonnes of oil equivalent per billion Baht. This method is different from the one defined/ measured under SDG 7 therefore, as such, these two values cannot be directly compared. As per Thailand's own measuring units, energy intensity in 2030 is estimated to be 6.25 ktoe/billion Baht in the CP scenario and 5.56 ktoe/billion Baht in the SDG scenario.

Thailand is on track to achieving this target of 36 per cent energy intensity reduction to 5.47 ktoe/ billion Baht by 2037.

Under the SDG 7.3 targets, energy intensity is defined as the total primary energy supply (TPES) in megajoules per US$ of gross domestic product in terms of power purchase parity in 2017. Under the CP scenario, Thailand's energy intensity in 2030 was estimated to be 3.5 MJ/USD_{2017}, a reduction from 4.3 MJ/USD_{2017} in 2021 (2.1 per cent EE improvement rate between 2021 and 2030).

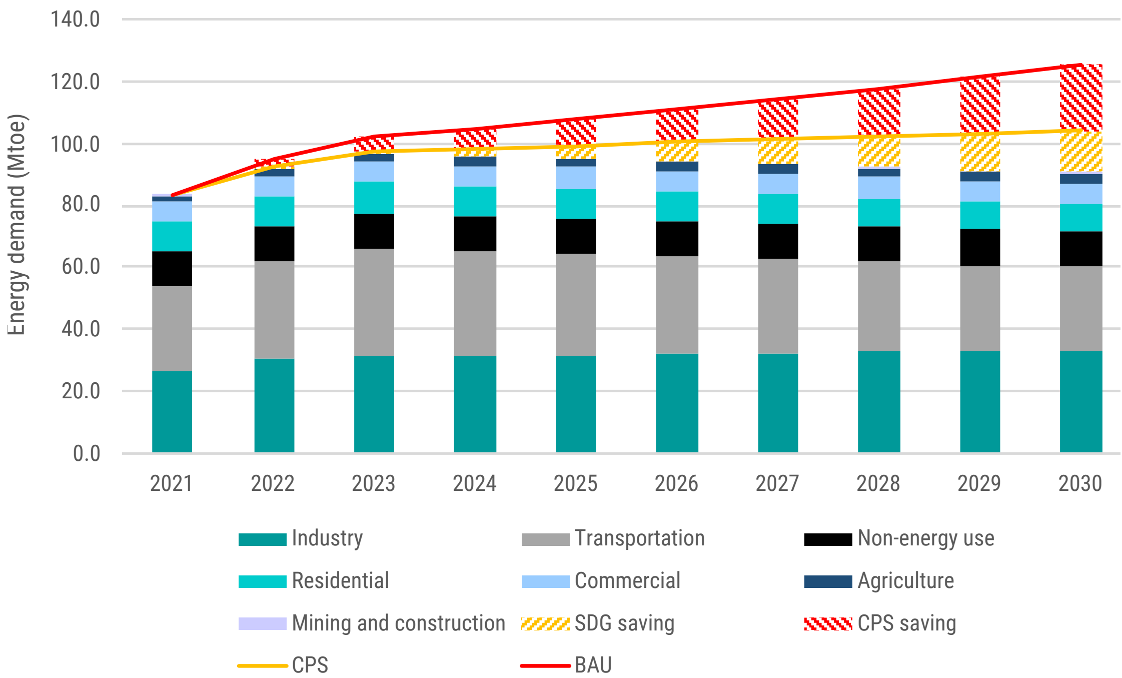
NEXSTEP analysis finds that Thailand can further reduce the energy intensity to 3.1 MJ/USD_{2017}, to align with the global energy efficiency target of 3.4 per cent annual improvement for SDG 7. This requires an additional 13.6 Mtoe of energy demand reduction compared with the CP scenario, as shown in table 5. This can be achieved by accelerating (bringing forward the implementation timeframe) several measures already planned in Thailand.

Figure 14 shows additional energy-saving opportunities under the SDG scenario, compared to the CP scenario.

Table 5. Energy saving in the SDG scenario compared to CPS

Sector	Measure	Energy saving potential in 2030 (ktoe)
Residential	• Phasing-out of inefficient cooking technologies by efficient electric cooking stove (e.g., induction type) to achieve a 100 per cent clean cooking access. • Phasing-out of inefficient use of traditional biomass for small-scale household industry (e.g., brick making, cloth dying, etc) using a more efficient burning technology with the utilization of modern biomass. • Equipment standards and labelling are suggested to be made a compulsory target in the residential sector to have a higher adoption of energy efficient equipment.	1,600
Commercial	• Accelerating the implementation of energy management standards in designated factories/buildings. • Making equipment performance benchmarks and labelling as a compulsory strategy.	678
Industry	• Accelerating the implementation of energy management standards in designated factories/buildings. • Making equipment performance benchmarks and labelling as a compulsory strategy.	4,462
Transport	• Accelerating the implementation of mode shifting in passenger transport.	3,030
Non-energy use	• Improve industrial process to reduce the requirement of raw materials.	3,809
Total		**13,577**

Figure 14. Energy saving potential in different sectors and sub-sectors under the SDG scenario compared to the CP scenario



5.3. Energy supply outlook

Primary energy supply

In the SDG scenario, the TPES is forecasted to increase from 124.5 Mtoe in 2021 to 131.4 Mtoe in 2025, and decrease to 124 Mtoe in 2030. The fuel shares in 2030 are projected as: natural gas and condensate, 46.6 Mtoe (37.6 per cent); crude oil and oil products, 37.9 Mtoe (30.6 per cent); biomass, 23.1 Mtoe (18.6 per cent); coal; 9.5 Mtoe (7.7 per cent); biofuel, 2.5 Mtoe (2 per cent); imported electricity, 1.6 Mtoe (1.3 per cent); hydropower, 0.4 Mtoe (0.3 per cent); renewables, 2.1 Mtoe (1.7 per cent); and other fuel, 0.3 Mtoe (0.2 per cent). The 16.1 Mtoe supply reduction compared with the CP scenario comes from the additional energy efficiency improvements as discussed in the previous section. In addition, since the electricity demand decreases, the fuel consumed in power generation declines as well.

Electricity generation

In 2030, the installed power generation capacity would be similar to the CP scenario at 65.8 GW (figure 15). Although fossil fuel will still dominate electric supply at 64 per cent, renewables share will increase to 36 per cent of the installed capacity. In the SDG scenario, electricity generation (excluding imports) is expected to be 233.8 TWh in 2030, where renewable energy will account for 20.5 per cent.

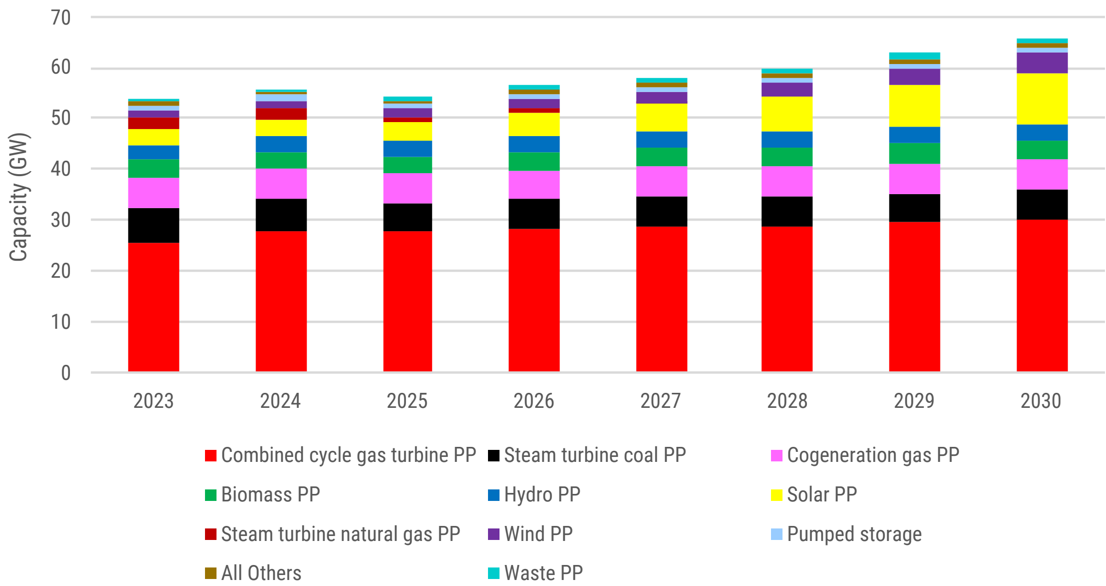
5.4. Nationally determined contribution targets

Emissions from the combustion of fossil fuel are calculated based on IPCC Tier 1 emission factors. For the combustion of biomass and biomass products, the carbon emissions are not attributed to the energy sector, but are accounted for in the agriculture, forest and land-use change (AFOLU))[21] as per the accounting system suggested by IPCC. Nevertheless, the emissions of other GHGs, such as methane and nitrous oxide, are included in the total emissions in the energy sector.

Emission analysis in this study suggests that the BAU emission in 2030 will be 355.1 $MtCO_2$-e This is slightly different to what is forecast in the NDC document.[22] This difference is primarily due to the changes in the predicted economic and population growth of the country. Thailand has committed to reducing GHG emissions in the energy sector by 30 per cent unconditionally (without international aid) and 40 per cent conditionally.

Thailand will be able to achieve the unconditional NDC target by 2030. Although total emissions are expected to grow from 224.4 $MtCO_2$-e in 2021 to

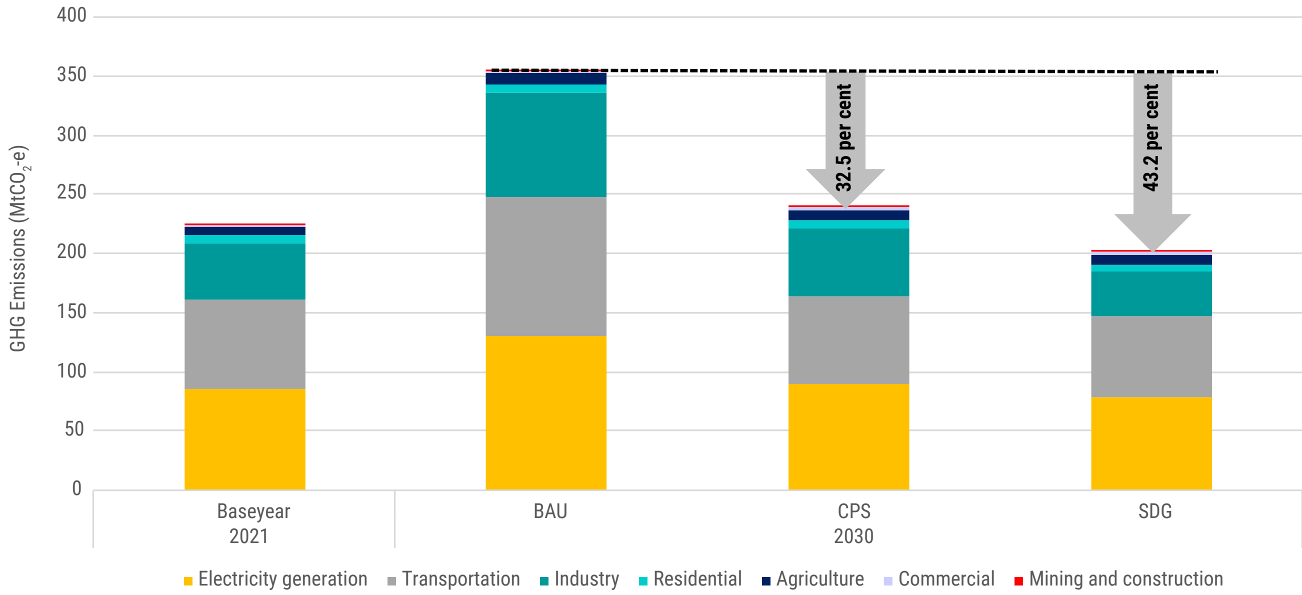
Figure 15. Power plant installed capacity 2023-2030



21 The AFOLU sector is not within the scope of NEXSTEP.

22 The BAU emissions in 2030 will be 555 $MtCO_2$-e for the whole economy. Assuming a 69.06 per cent share of energy emissions (using same proportion as 2018), it is predicted that emission from the energy sector will be 383.3 $MtCO_2$-e.

Figure 16. Emission trajectories for different main scenarios



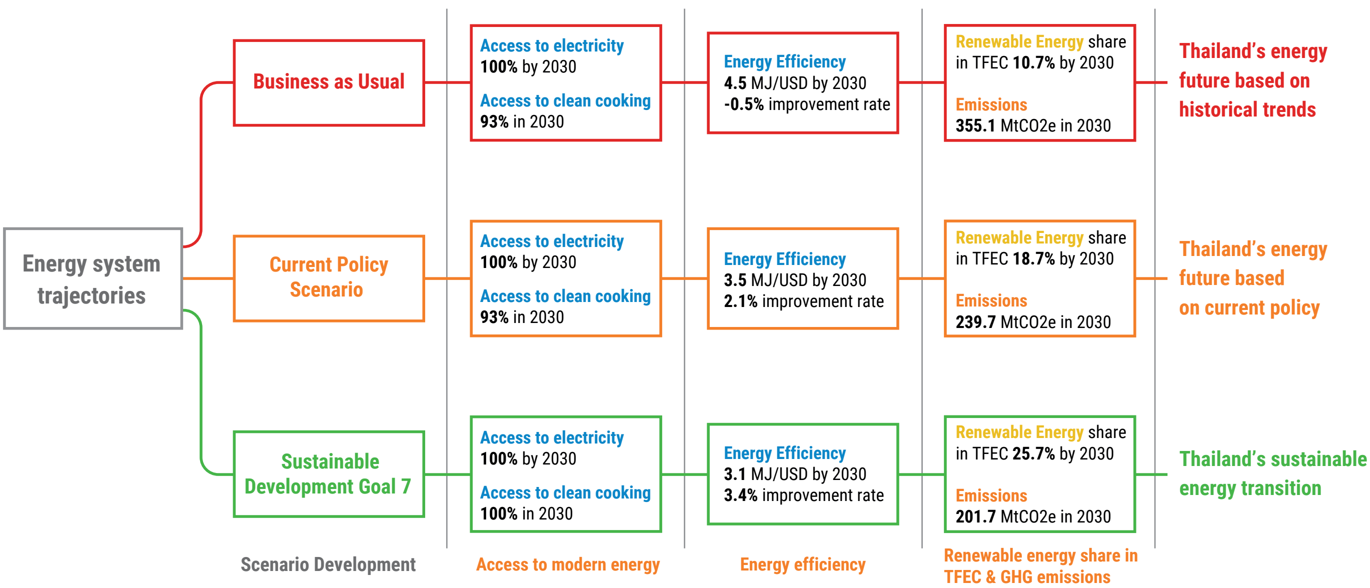
239.7 $MtCO_2$-e in 2030 (figure 16), there will be a 115.4 $MtCO_2$-e (32.5 per cent) reduction compared with the BAU scenario. The decrease in GHG emissions, relative to the BAU scenario, is due to the higher renewable share in electricity supply as per the PDP, higher renewable share in heat and biofuel mix based on AEDP, and significant energy efficiency saving under EEP.

Thailand can further enhance its efforts to achieve the conditional NDC target by accelerating the implementation of energy saving measures in order to align with the global improvement target of 3.4 per cent discussed in the previous section.

In the SDG scenario, total emissions are expected to further decrease to 201.7 $MtCO_2$-e by 2030, corresponding to a 153.4 $MtCO_2$-e (or a 43.2 per cent) reduction compared with the BAU scenario.

Thailand's efforts must be appreciated since the current policies are ambitious enough to increase the renewable share, improve the energy efficiency, and even reach the unconditional NDC target. An improvement of the clean cooking access is still required and this can be considered to be enforced in the updated national energy policy. Figure 17 summarizes the SDG 7 indicators from three different main scenarios.

Figure 17. Summary of SDG 7 indicators for different main scenarios



6. Going beyond SDG 7 with ambitious scenarios

The SDG scenario, as discussed in the previous chapter, sets out various strategies for facilitating an economy-wide, energy-efficiency improvement in alignment with the 2030 Agenda for Sustainable Development and the Paris Agreement. It also identifies appropriate technology options in advancing sustainable energy transition in Thailand. The measures that have been discussed in the previous chapter have allowed an energy demand reduction of 13.6 ktoe and emission reduction of 27.9 $MtCO_2$-e in the SDG scenario, relative to the current policy scenario by 2030. These allow a GHG emission reduction sufficient to meet even the conditional NDC target and a modest increase in the renewable energy share in TFEC. Transitioning beyond 2030, the two additional scenarios have been developed in line with Thailand's announcement for carbon neutrality by 2050 and net zero emissions by 2065. These scenarios aim to assess the potential for achieving these ambitious goals, identify technological interventions, define the timeframe of implementation of different measures and suggest policy recommendations to help put Thailand's energy sector on the right path.

6.1. Strategy overview

Achievement of these two targets, particularly the Net Zero Emissions target, will require decarbonization of the energy sector, which is best done in the following two steps: (a) decarbonizing the power sector; and (b) switching all energy sources to electricity. Helpfully, the energy system of Thailand is well-positioned for an accelerated decarbonization of its energy system as some required net zero technologies, such as electric cooking stoves and electric vehicles, are readily available. With reference to the Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS) document (MoNRE, 2022), several sectoral strategies have been considered for decarbonizing the energy sector as outlined in table 6.

Table 6. Sectoral strategies for decarbonization of the energy sector

Sectors	Overview	Strategies for decarbonization
Power	Share of RE in 2030 is expected to be 25.7 per cent and the remaining is fossil fuel-based generation.	• Switching to 74 per cent renewables-based electricity generation by 2050. • Implementation of BECCS to capture carbon from biomass-based power generation. • Application of CCS/CCUS technologies in the remaining fossil fuel-based technologies.
Residential	LPG, biomass and electricity are the key energy sources.	• Further energy efficiency improvement of electrical appliances. • Switching LPG and biomass to electric cooking stoves.
Commercial	LPG and electricity are the key energy sources.	• Further energy efficiency improvement of electrical appliances. • Shifting from LPG to electricity-based technologies. • Consider solar water heating systems for water heating.
Industry	LPG, biomass and electricity are the key energy sources.	• Further energy efficiency improvement of electrical appliances. • Switching non-electrical appliances to electric. • Utilization of biomass and solar thermal technologies for heating. • Possible use of green hydrogen to replace fossil fuel-based heating system in heavy industries.
Transport	Petroleum oil products are the key energy sources.	• Switching to electric vehicles for road transport. • Use of fuel cell technology for long-haul transports • Increasing fuel efficiency in other transports e.g., marine transport.
Agriculture	Diesel, gasoline and electricity are the key energy sources.	• Electrification of end-use technologies such as tractor, threshing and irrigation.

6.2. Carbon neutrality by 2050 Scenario

To achieve its carbon neutrality in 2050, Thailand needs to focus on reducing carbon emissions from the energy sector. Building on the SDG scenario and extending the timeframe to 2050, this scenario suggests some additional measures, as shown in table 7, to align the energy sector with the 2050 goal of carbon neutrality.

With these measures, the total energy demand is expected to increase from 90.5 Mtoe in 2030 to 110.3 Mtoe in 2050. However, this will be a reduction of about 19.7 Mtoe relative to the SDG scenario (figure 18). The industrial sector consumption will remain the largest at 50.7 per cent, followed by the non-energy use at 14.3 per cent. The transport sector will account for 13.6 per cent, the commercial sector at 9 per cent, and the residential sector at 7.6 per cent.

In terms of energy efficiency, this scenario will further reduce energy intensity since the country is on track to reach the 36 per cent energy intensity reduction target by 2037 and 40 per cent target by 2050 under the CP scenario. This is due to the implementation of the national Energy Efficiency Plan as presented in figure 19.

Despite requiring a lower amount of energy compared to the SDG scenario by 2050, the electrification of the energy system in this scenario will require an additional 60.4 TWh electricity. A decarbonized electricity supply is also required to complement the hastened adoption of electricity-based technologies, such as electric vehicles and electric cooking stoves, in order to realise the greatest potential of electrification. The LT-LEDS document presents the fact that the share of renewable electricity is estimated to be 74 per cent of total electricity generation in 2050 in order to achieve carbon neutrality in 2050. NEXSTEP estimated that 18.5 GW CGGT will still be required in the energy system to achieve the 74 per cent RE target. The capacity of solar will be around 101.3 GW, wind will be around 9.4 GW, and bioenergy (including waste) will be 8.7 GW.

In the carbon neutral scenario, the emission peaks in 2025 and starts to decline gradually until 2040 and then drops sharply in 2050 due the

Table 7. Additional measures to align the energy sector with the carbon neutrality goal

Sectors	Additional measures
Residential and commercial	• Gradually increasing electric cooking to 100 per cent by 2050. • Switching to the most efficient electrical devices available in the market, particularly for lighting, refrigeration, air conditioning, and electric fans. • Expanding energy efficiency in building code to all types of buildings.
Industry	• Replacing coal, natural gas, and oil products in the industry sector with electricity, biomass, and/or biofuel up to 60 percent by 2050. • Introduction of carbon removal technology to capture the emission from the industry sector by 40 per cent.
Transportation	• Phasing down ICE vehicles from around 70 per cent in 2030 to 31 per cent in 2035 and zero per cent in 2050, particularly passenger cars, motorcycles and buses. • Phasing down ICE trucks from around 70 per cent in 2030 to 50 per cent in 2050. • Converting 30 per cent oil product operated boats to electric boats by 2050
Agriculture	• Replacing all diesel pumps for irrigation with solar pumps.
Power	• Phasing down coal power plants from 2040 onwards and fully phasing out by 2050. • Increasing renewable energy generation to 68 per cent by 2040 and 74 per cent by 2050. • Introduction of bio-energy carbon capture and storage (BECCS) to capture CO_2 emissions from biomass-based power generation technologies. • Introduction of additional carbon removal technology to capture the emissions from the power sector by 50 per cent in 2050 and the emissions from the industry sector by 40 per cent.

Figure 18. Comparison of total final energy demand in 2050 by sector

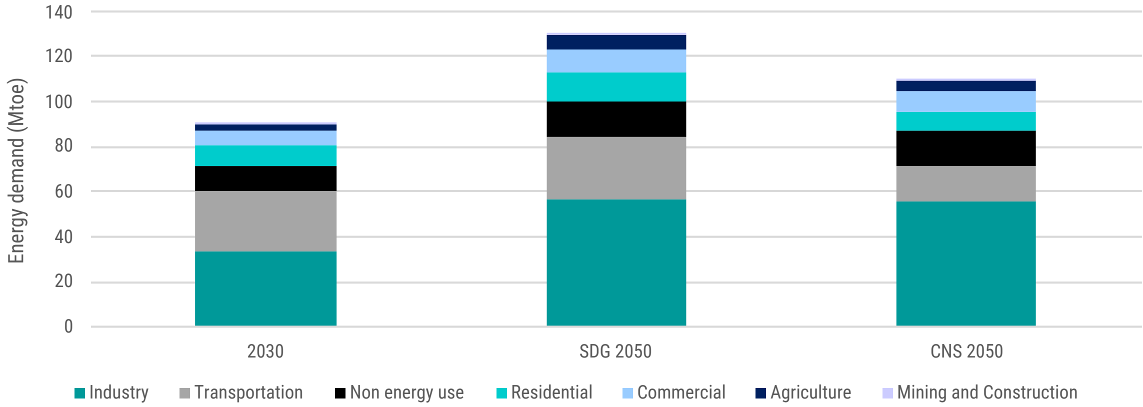
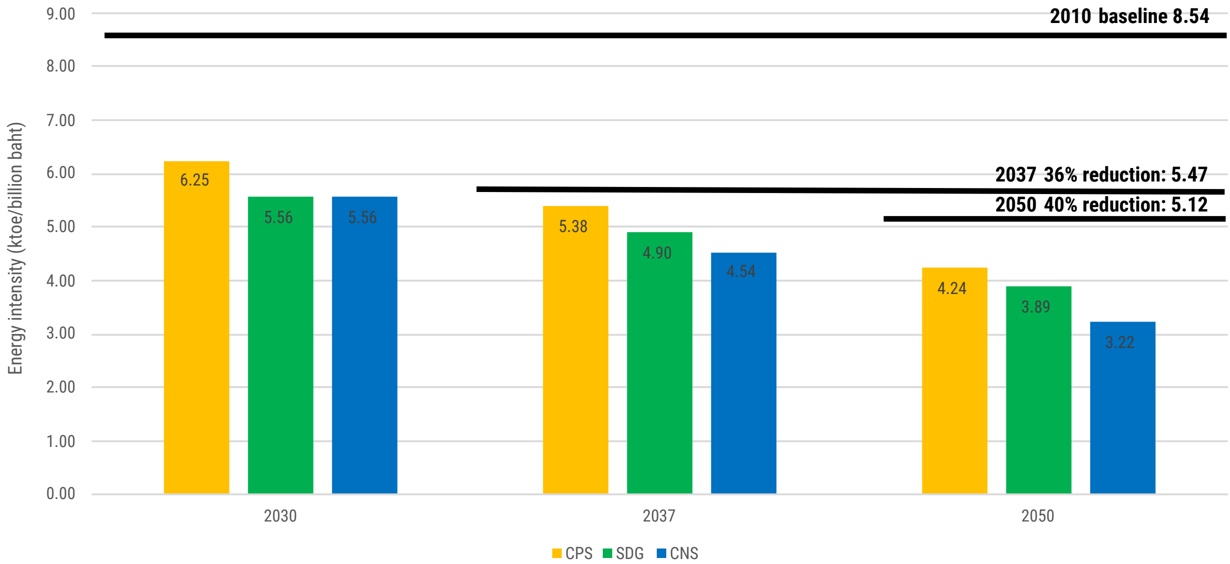


Figure 19. Comparison of total final energy demand in 2050 by sector



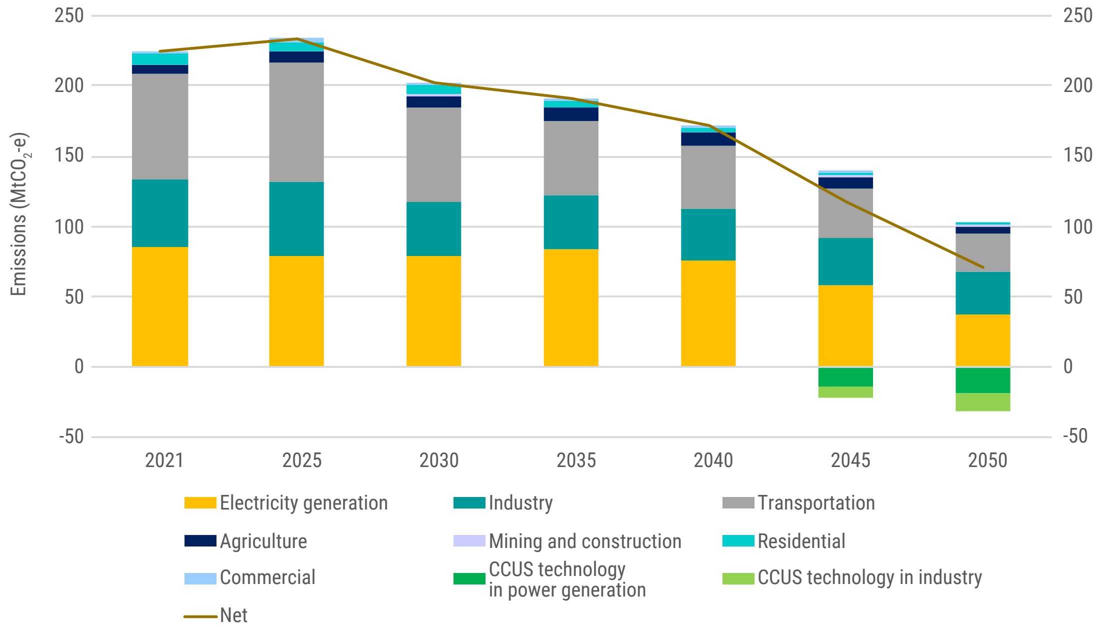
implementation of several measures discussed above. In 2050, electricity generation will emit 37.9 $MtCO_2$-e from the combustion of natural gas in the CGGT plants. On the demand side, the industry sector will emit 29.9 $MtCO_2$-e from the combustion of biomass and biofuel. The transportation sector will still emit 27.8 $MtCO_2$-e from the utilization of IC engines for the remaining unelectrified transport system. Additional carbon removal technology will need to be introduced from 2035 to capture emissions from the power and industry sectors. NEXSTEP suggests that capturing emissions from the power sector by 50 per cent in 2050 and emissions from the industry sector by 40 per cent will help the net emissions from energy sector to reach only 71 $MtCO_2$-e by 2050 (figure 20). It is expected that the remaining emissions will be sequestrated by the LULUCF sector to help achieve carbon neutrality.

6.3. Net Zero Emissions by 2065 Scenario

Building on the carbon neutral scenario and extending the timeframe to 2065, this scenario suggests the following additional measures to align the energy sector with the 2065 goal of net zero emissions.

1. Phasing out of ICE trucks and switching to 100 per cent electric in 2065.
2. Replacing coal, natural gas and oil products in the industry sector with electricity, biomass and/or biofuel to a 100 per cent share by 2050.
3. Increase renewable energy generation to 100 per cent by 2065.
4. Introduction of additional carbon removal technology to capture the emission from the power sector by 75 per cent in 2055, and the remaining emission from the industry and transport sectors by 100 per cent in 2065.

Figure 20. GHG emission in the Carbon Neutral by 2050 Scenario



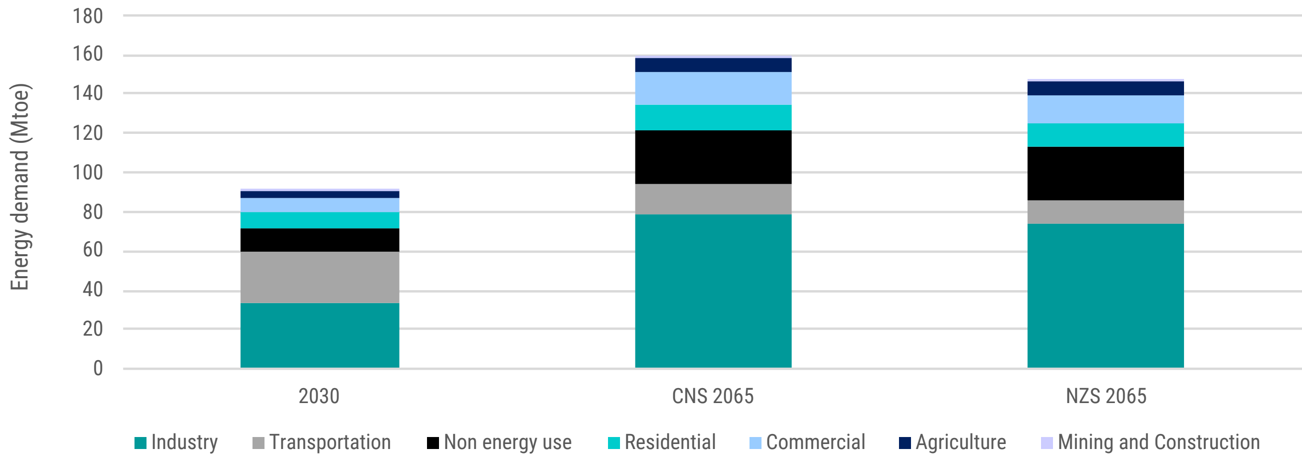
The total energy demand is expected to increase from 90.5 Mtoe in 2030 to 147.3 Mtoe in 2065; however, there will be a reduction of about 12.5 Mtoe relative to the SDG scenario (figure 21). The industrial sector consumption will remain the largest at 50.6 per cent, followed by non-energy use at 18.4 per cent. The commercial sector will account for 9.7 per cent, followed by the residential sector (8 per cent), and the transport sector (7.6 per cent).

Since most efficient technologies have been implemented in the Carbon Neutral Scenario, these above measures will not significantly reduce energy demand compared with the Carbon Neutral Scenario in 2065. The bulk of the additional energy demand reduction will come from 100 per cent fuel switching in industries. NEXSTEP identified that replacement of oil products by biodiesel, coal by biomass, and natural gas by electricity will be a more appropriate strategy in the long term. Since hydrogen is not commercially available and the technology has various unknown variables, NEXSTEP has not performed a quantitative analysis of hydrogen for implementation in Thailand. Further investigation is needed to identify the techno-economic potential of hydrogen (see box 2).

Increased ambition in transport electrification will also be critical in the net zero emission scenario. It is expected that electric freight trucks will reach 100 per cent by 2065. Electrification of water transport may also be a required strategy to reduce emissions from both domestic and international maritime transport (see box 3). The electrification of the energy system in this scenario will require 661.3 TWh electricity. NEXSTEP estimated that the capacity of solar PV would be 269.3 GW, wind will be around 9.4 GW, and bioenergy (including waste) will be 8.7 GW by 2065 in order to fully decarbonize the power system.

In both ambitious scenarios, there will be a high penetration of intermittent renewable energy. Therefore, addressing challenges associated with integrating intermittent renewable energy sources into the grid will be critical. Development of grid infrastructure will be the part of Thailand's energy transition plan. By investing in upgrading and expanding the transmission network, including strengthening interconnections with neighbouring countries, Thailand can strengthen its energy supply security. Furthermore, the adoption of smart grid technologies, as planned under the Smart Grid Development Master Plan (EPPO, 2015) in Thailand, will help to prepare the infrastructure to accommodate high penetration of variable renewable energy supply. Furthermore, these advanced systems will empower the grid to effectively manage and balance RE sources by improving grid monitoring, control and communication methods. Finally, adoption of the demand side management (DSM) concept, as part of the smart grid technology, will be essential. DSM is the concept of allowing users to monitor

Figure 21. Comparison of total final energy demand in 2065 by sector



Note: In this figure the. CNS timeframe has been extended to 2065 to compare the energy demand between two ambitious scenarios.

Box 2. Hydrogen gains global interest, but application is still limited

Green hydrogen, created using renewable electricity, has garnered great interest globally. Various government policies have been introduced that directly or indirectly promote the adoption of renewable hydrogen as a means to achieve environmental and climate objectives. It is driven by an increasing interest in using renewable heat in large industry sectors. For example, five countries (Australia, Brazil, South Africa, Spain and Sweden) have road maps that include green hydrogen in the industry sector (REN21, 2023)

The implementation of green hydrogen, however, is still limited due to high production costs and the need for associated infrastructure. IEA (2019) reported that producing hydrogen from low-carbon energy is still costly at the moment despite the declining costs of renewables. IEA analysed that the cost of hydrogen production from solar PV and wind in the ASEAN region will be around 3 US$/kg. The development of hydrogen through electrolysis may also require a significant amount of water and electricity. IEA estimated that if all current dedicated global hydrogen production was produced through water electrolysis, this would result in an annual electricity demand of 3,600 TWh – and water requirements would be 617 million cubic metres. The widespread hydrogen adoption is also being held up due to the slow development of hydrogen infrastructure. Planning and coordination between governments and industries are required to address refuelling station problems in the future.

Despite its challenges, Thailand has been proactive in planning for the utilization of hydrogen in its energy system. The Government is currently developing a Hydrogen Economy Roadmap* for hydrogen production and consumption in the country. Research and pilot projects will be conducted from 2023 until 2030 to study business models, test the pipeline system and its storage, and develop regulation and standards. The commercial development is expected to start from 2031 where utilization of 20 per cent hydrogen as a mixed fuel for natural gas may be considered in power plants. Fiscal incentives will be put in place while simultaneously there will be improvement of pipeline system (up to 20 per cent) and development of around 70 refuelling stations. In the long term, a market platform and carbon trading mechanism will be developed to support the domestic hydrogen industry from 2041. In addition, subsidy phase out and price mechanism will be promoted to establish the market. It is expected that hydrogen's mixing proportion will be increased up to three-quarters in the power sector, and hydrogen will replace LPG and residual oil in the industry within the radius of the gas grid network. In the transport sector, fuel cells will be considered for power train and buses.

**This Information is based on a draft study paper under the project "Strategic Plan for Hydrogen Development in the energy Sector" by EPPO.*

Box 3. Framework to set GHG emissions reduction targets for international marine transport

In July 2023, the International Maritime Organization (IMO) updated their target on international maritime transport (IMO, 2023), as follows:

1. **Carbon intensity of international ships to decline through further improvement of energy efficiency in new ships;**
2. **Carbon intensity of international shipping to decline.** This is to be achieved by reducing CO2 emissions per transport work as an average across international shipping, by at least 40 per cent by 2030, compared with 2008;
3. **Uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to increase.** Uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5 per cent, striving for 10 per cent, of the energy used by international shipping by 2030; and
4. **GHG emissions from international shipping to reach net zero.** GHG emissions from international shipping are to peak as soon as possible and to reach net-zero GHG emissions by or around, i.e., close to 2050, taking into account different national circumstances, while pursuing efforts towards phasing them out as called for in the Vision consistent with the long-term temperature goal set out in Article 2 of the Paris Agreement. There will be two indicative check points for international shipping to reach net-zero GHG emissions: 2030 (by at least 20 per cent, and striving for 30 per cent); and 2040 (by at least 70 per cent, striving for 80 per cent).

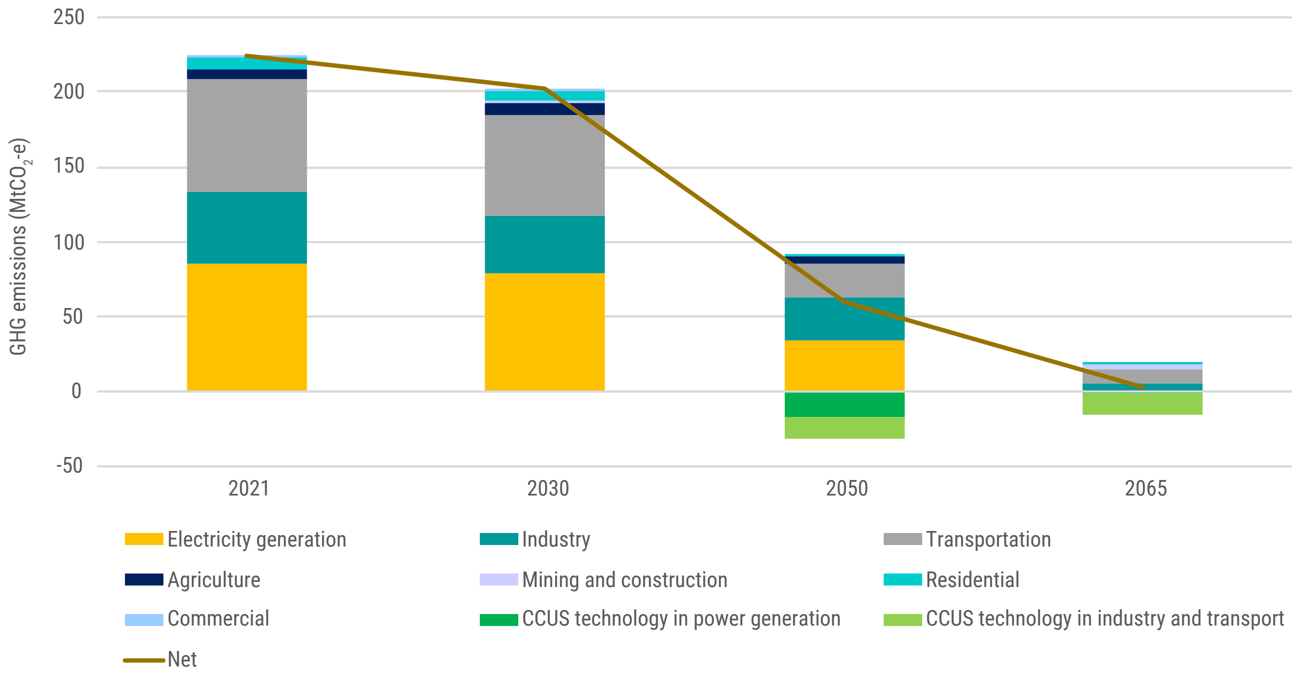
International marine transport is not within the scope of this analysis due to the difficulties in separating the emission sources between two international ports. Secondly, such analysis required much data from both the conventional system and new technologies/systems, including their cost/financial data. Given that the new system is not ready yet and that Thailand does not have any infrastructure to serve this new system, data gathering could not be possible. As such, ESCAP and the Marine Department jointly agreed to focus only on domestic marine transport.

However, NEXSTEP suggests that the implementation of a Ship Energy Efficiency Management Plan (SEEMP) would help Thailand achieve the first objective in reducing the energy intensity. Achieving target 3 would require switching to alternative fuel, e.g., electric system. Other pathways that can be considered is the use of other cleaner fuels like LNG. It is noted that LNG could be a transitional source of energy until a more feasible solution is found. As we progress towards net zero emissions by 2050 (IMO target), other alternative fuels will need to be sourced and used. IRENA (2023) identified that indirect use of clean electricity through synthetic fuels, such as green hydrogen, e-methanol and e-ammonia, may help reduce emissions by international maritime transport by 60 per cent in 2050. One important note is that Thailand does not manufacture any large cargo ships – it imports from large ship manufacturers in the Republic of Korea, China and Japan. Therefore, the technological innovation in these countries will dominate the pathways towards cleaner marine transport system in Thailand.

their energy consumption while taking peak energy demand into account. This continuous monitoring and management of energy consumption aim to improve system reliability while lowering energy costs. By using this strategy, utilities can control electricity demand by incentivising customers to modify their energy consumption patterns during peak hours or reduce their overall energy consumption.

There will be a significant emission reduction in the net zero 2065 scenario. This is because of (a) full implementation of fuel switching, and (b) fully decarbonising the electricity supply. Due to certain limitations to implementing measures in the transport and industry sectors, however, a small number of emissions would still be produced in those sectors. Therefore, carbon sinks, such as reforestation or forest management, or other carbon capture technologies should be considered to absorb the remaining carbon emissions. In the net zero emission scenario, it is expected that carbon removal technology will cover 100 per cent of the remaining emission in the energy sector so that the net emission will reach zero (figure 22).

Figure 22. GHG emission in the Net Zero Emissions by 2065 Scenario



7. Economic analysis and financing options

Sustainable green transition in the energy sector offers financial benefits in the long term. This could entail financial incentives to promote efficient vehicles or efficient household appliances. It should be noted that the transport, residential, commercial and industrial sectors have a high GHG mitigation potential, with which most scenarios are cost-effective in the long term. For example, mode shifting in the transportation sector and energy management standard in industries would provide the highest saving with high abatement potential. Nonetheless, cost savings can be expected due to the reduced usage of expensive imported oil products.

Under the promotional sector measures, Thailand is stressing the role of ESCOs to promote energy efficiency. Thailand has previously demonstrated leadership in this approach by establishing a "revolving fund" for energy conservation and efficiency. ESCOs can borrow funds from financial institutions at an interest rate lower than commercial rates, over an extended repayment period (see box 4).

The LT-LEDS document (MoNRE, 2022) presented the fact that the share of renewable electricity is estimated to be 74 per cent of total electricity generation in 2050 in order to achieve carbon neutrality in 2050 (MoNRE, 2022). This might seem a challenging target since the country must (a) increase the renewable share significantly, and (2) phase out its coal power plant by 2050.

In the past, investment in coal-fired generation was a cheap and reliable, albeit polluting, method of generating electricity. This is no longer the case as renewables have matured and costs have dropped significantly. It is cheaper today to generate electricity from renewables such as solar, hydropower, wind and biomass compared to coal-fired technologies. The Levelized Cost of Electricity (LCOE) is a widely used metric in the energy industry for comparing the economic value of different electricity generation technologies. It

Box 4. Case study – Energy Efficiency Revolving Fund in Thailand

In 2003, the Government of Thailand launched the Thai Energy Efficiency Revolving Fund (EERF) as part of its Energy Conservation Programme. The EERF works to overcome barriers within the Thai financial sector in order to stimulate adequate financing for energy efficiency and reduce greenhouse gas emissions. It was aimed at strengthening the capacity of commercial banks to finance EE projects, developing the ESCO fund to enable smaller companies to access EE financing, and works with the Bureau of Investment to provide tax/duty exemptions for EE products. The establishment and implementation of the Revolving Fund has been successful in supporting initial investments in energy efficiency and creating a self-sustained market by encouraging the involvement of commercial banks in this area. This fund was initiated in 2003 to attract investments in energy efficiency, create confidence of entrepreneurs and promote ESCOs as a vehicle to improve energy efficiency. The fund was made available by DEDE with financial support from the Ministry of Energy. The total budget for five phases of the fund was US$ 245.10 million. Phase 5 of the fund operated from June 2010 to May 2013. During the first phase (2003-2006), the fund was made available to commercial banks without an interest rate; however, an interest rate of 0.5 per cent was introduced in Phase 2 and was continued at the same rate through to Phase 5. Facility owners, ESCOs and project developers are eligible to borrow from this fund for a maximum of seven years for EE and Renewable Energy (RE) projects. Single loan size was capped at about US$ 1.56 million and an interest rate of 4 per cent. Until 2013, 295 project proposals were received (60 per cent EE projects and 40 per cent RE projects) for a total investment of US$ 498.7 million, of which US$ 226 million was contributed from this fund and the remainder supported by financial institutions (Achavangkool, 2014)

calculates the unit cost of electricity (US$/MWh or cents/kWh) over the lifetime of the project, including capital, operating and financing costs. LCOE is measured using the lifecycle cost of a system and therefore balances out the disparity where some technologies have a high capital cost but low operating cost, whereas the other technologies have low capital cost and high operating cost.

NEXSTEP has calculated LCOE for Thailand (figure 23) using cost figures presented in Annex 3. This makes LCOEs entirely reflective of the national context of Thailand. The LCOE component analysis highlights renewable electricity generation technologies, e.g., solar photovoltaic (5.2 cents/kWh), onshore wind (7 cents/kWh), hydro (7.9 cents/kWh) and biomass (8.8 cents/kWh) are cheaper than coal-fired generation technologies today in Thailand. The given LCOE for renewable energy is without energy storage consideration. Box 5 shows the impact of battery energy storage system (BESS) on LCOE.

As mentioned above, 18.5 GW CGGT will still be required in the energy system in 2050. The capacity of solar will be around 101.3 GW, wind will be around 9.4 GW, and bioenergy (including waste) will be 8.7 GW. The investment costs required in power generation will be US$ 158 billion until 2050 with a net benefit of around US$ 760 billion.

The capacity of solar will further increase to around 269.3 GW in order to fully decarbonize the energy system by 2065 under the net zero emission scenario. In this scenario, the investment cost will be US$ 361 billion (on an average annual investment of about US$ 8 billion) with net benefit of a US$ 1,414 billion.

There are a few pathways that the country may explore, in collaboration with citizens and/or private investors, in order to achieve a net-zero carbon power supply objective. One workable solution and the recent policy instrument that can be considered is the renewable energy auction. This approach is likely to substantially decrease the cost of electricity supply through a competitive pricing bidding and therefore, return a greater net benefit. Recent auctions, e.g., the 60 MW solar PV auction in Cambodia, have achieved $0.0387 per kWh.

A renewable energy auction, also known as a "demand auction" or "procurement auction", is essentially a call for tenders to procure a certain capacity or generation of renewables-based electricity. The auction participants submit a bid with a price per unit of electricity at which they are able to realize the project. The winner is selected on the basis of the price and other criteria, and a power purchase agreement is signed. The auctions have the ability to achieve deployment of renewable electricity in a well-planned, cost-efficient and transparent manner. Most importantly, it makes the achievement of targets more precise than would be possible by other means, such as a Feed-in-Tariff (FiT).

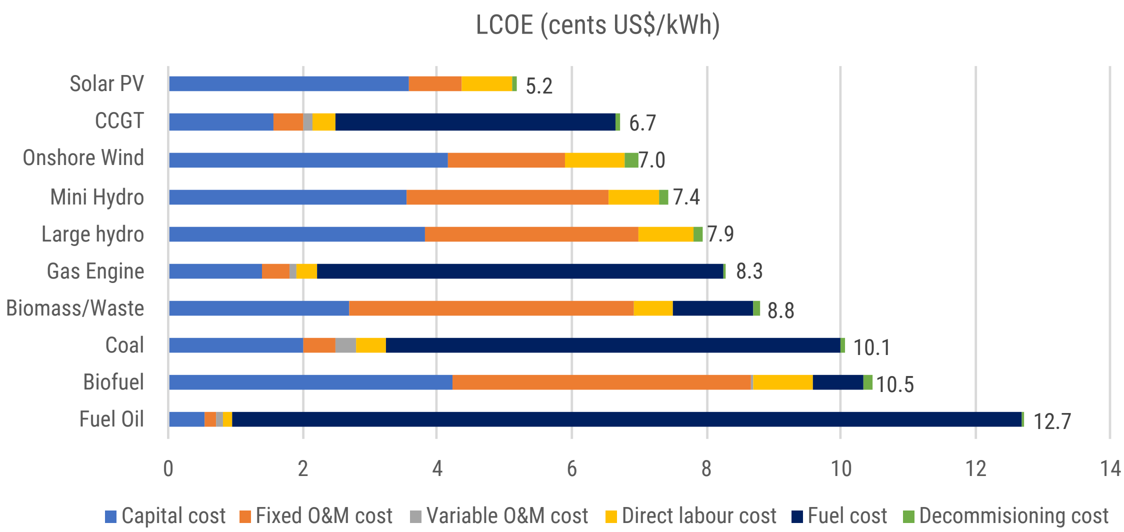
Auctions are flexible and they allow Governments to combine and tailor different design elements to meet deployment and development objectives. Unlike FiTs, where the Government decides on a price, auctions are an effective means of discovering the price appropriate to the industry, which is the key to attracting private sector investment. In addition, an auction provides greater certainty about future projects, and is a fair and transparent procurement process. However, the administrative and logistic costs associated with auctions are very high unless multiple auctions are undertaken at regular intervals. Further details of designing renewable auctions can be found in box 6.

Another consideration for the long term is internalizing externalities. The challenges associated with accurately estimating the externalities of fossil fuel energy technologies have continued to result in unfair comparisons with renewables. If the external costs of fossil fuel systems are considered, energy generation from renewables would have been equal, if not lower, to that of conventional energy systems. The external costs arise from pollution and environmental degradation caused by the extraction of fossil fuel resources, indoor and outdoor air pollution and the negative economic impacts of extreme weather events caused by global warming, such as its impact on agricultural yields.

Carbon pricing is recognized around the world as an effective policy tool to facilitate sustainable energy transition. The external cost of carbon emissions paid by society should be shifted towards the producers and consumers responsible for producing pollution-causing goods, by directly setting a price on carbon emissions. There are two main mechanisms for carbon pricing – emission trading schemes (cap and trade) and carbon taxation. Emission trading systems place a cap on CO_2-e emissions and allow participants to trade an allowance of CO_2-e emissions under the cap. The mechanism results in a wealth transfer from high emission to low emission technology proponents, increasing the attractiveness of low-emission technology investments. Carbon taxes simply put a price on the GHG emissions or on the carbon content of fuels. Governments may choose to treat this as a revenue stream or hypothecate these funds to use them as a wealth transfer mechanism.

Figure 26 shows the indicative marginal abatement cost (MAC) curve for all sectors in Thailand. The MAC curve follows the measures proposed in the SDG scenario and uses the BAU scenario as the reference baseline. It is reflected from the MAC curve that most renewable generation has

Figure 23. Comparison of levelized cost of electricity

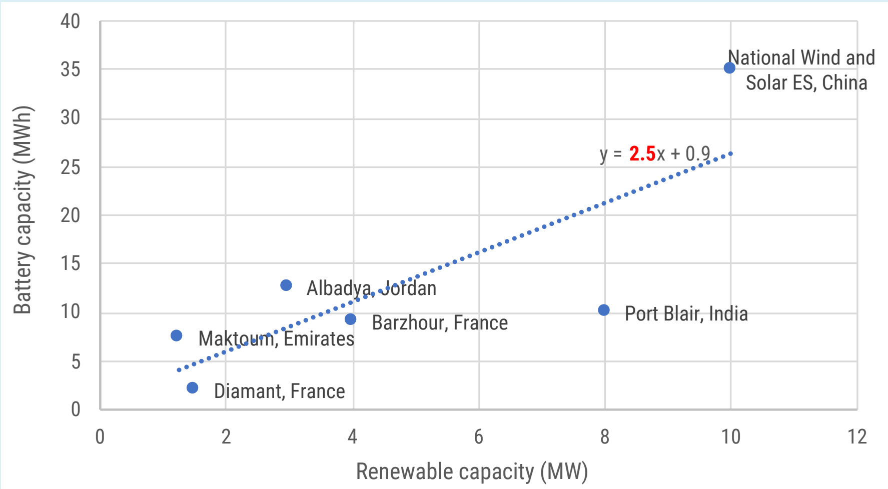


Box 5. LCOE of electricity generation with battery energy storage system

A battery energy storage system will have a critical role in a fully decarbonized energy system. However, calculating battery capacity requirement for the national level is impractical since the ratio between battery capacity and solar capacity varies, depending on the size and location of the project. For example, the Port Blair project in India has a ratio between battery capacity and renewable capacity of 1.25 (8 MW/10 MWh Li-ion). However, the Maktoum project in the United Arab Emirates has a battery capacity and renewable capacity of around 6 (1.25 MW/ 7.5 MWh). In France, the Diamant and the Barzhour projects have different factors despite being installed in the same country. Therefore, storage capacity is better estimated at the project level. Because of its inherent difficulties, NEXSTEP analysis has avoided estimated specific storage capacity at the national level. Instead, it has estimated a ratio between battery and renewable capacity, which is expected to be around 2.5 as shown in figure 24.

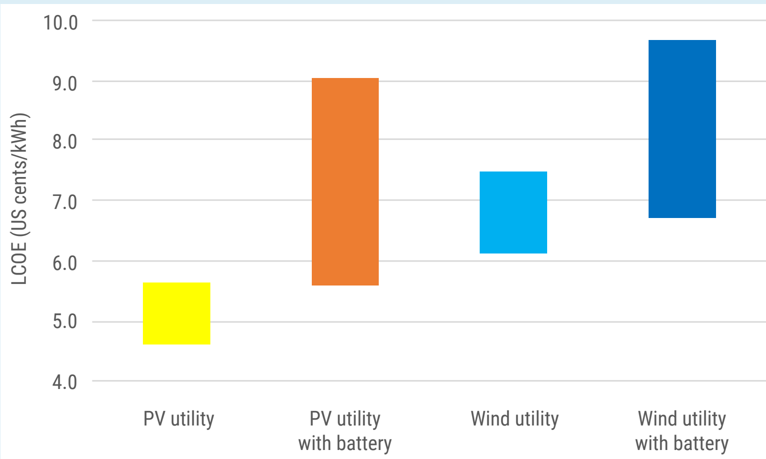
Using this factor, NEXSTEP has estimated the LCOE of a utility-scale renewable project with and without storage (figure 25). Without storage, the LCOE of utility-scale solar photovoltaic will range from 4.6 to 5.6 cents/kWh, while the LCOE of utility-scale onshore wind will range from 6.1 to 7.5 cents/kWh. With storage, the LCOE of utility-scale solar photovoltaic will range from 5.6 to 9 cents/kWh, while the LCOE of utility-scale onshore wind ranges from 6.7 to 9.7 cents/kWh, depending on the storage capacity. The higher the battery size, the higher the LCOE. Therefore, finding the optimum battery sizing will be critical for the development of renewables with BESS projects.

Figure 24. Relationship between battery capacity and renewable capacity



Note: Data are taken from Beltran, Cardo-Miota, Segarra-Tamarit and Pérez, 2021.

Figure 25. LCOE comparison with and without batteries for Thailand



a positive cost, since high capital expenditure is generally required for new renewable power capacities. Solar PV has a lower abatement cost per tonne of CO2 compared to wind and biomass. The abatement costs for solar PV, wind and biomass are US$ 2/tCO_2-e, US$ 15/tCO_2-e and US$ 18/tCO2-e.

In today's market, there is no consistency in carbon price, and it is therefore very difficult to choose a carbon price that will suit the national context. The World Bank's State and Trend of Carbon Pricing 2022 report (World Bank, 2022b) suggests that a minimum carbon price of US$ 50-US$ 100 per ton of is needed by 2030 to cost-effectively reduce emissions in line with the temperature goal of the Paris Agreement. In Singapore, the carbon tax rate will be increased to US$ 18/tCO_2-e in 2024 and 2025, and US$ 33/tCO2e in 2026 and 2027, with a view to reaching US$ 37-59/tCO2e by 2030. An indicative price of US$ 20/tCO_2-e would make the proposed measures attractive. This is an indicative price to demonstrate how a price on carbon would support the proposed transformation of the energy sector.

A price on carbon can close the investment gap in the long term. For example, the investment gap in the power sector between the current policy and carbon neutrality scenarios will be US$ 112 billion until 2050. It is estimated that the remaining emissions from the power sector (the balance that will remain after implementing all measures, including increasing renewable energy, improving energy efficiency and implementing CCUS) will be 2.2 billion tCO_2-e cumulatively up to 2050. Therefore, a carbon price of US$ 51.5 can entirely cover the investment gap (figure 27). Further in-depth investigation should be performed, involving subject matter experts and stakeholders, to identify the price suitable for Thailand.

Finally, active engagement and collaboration among stakeholders from both the public and private sectors will lead to the overall success of the energy transition process. Bringing together utilities, government agencies, renewable energy developers and technology providers will facilitate the sharing of expertise, resources and best practices.

Box 6. Key design principles of a renewable auction

It is imperative that an auction be appropriately designed to (a) avoid the risk of underbuilding and project delays, and (b) allow sufficient competition among different levels of bidders in order to drive down the cost. IRENA suggests the following key design elements:

- Auction demand. Governments need to clearly indicate the scale or size of each auction, the preferred technology (technology neutral of a specific technology), auction frequency, and the upper and lower limits of projects size and price.
- Pre-qualification. A strict or high pre-qualification for bidders will leave out the smaller entities, while a relaxed pre-qualification may undermine the quality of the project and increase the administrative costs. Governments need to make a trade-off, depending on the project size and other development objectives.
- Selection criteria. Commonly two selection criteria are used: (a) the lowest bid where only the lowest bidder will win; and (b) lowest bids plus other objectives where, in addition to the price, other objectives such as local content and jobs are taken into consideration.
- Payment modalities. The pay-as-bid model is good to minimize the cost. However, the marginal cost payment model, where the same price (selected based on the highest cost winner) is paid to all winners is also practised.
- Penalties for non-compliance. There could be cases where the developer either delays the project or fails to complete. To avoid such cases, penalties should be in place. There are two modes of penalty. In the monetary penalty, money will be deducted from bidder's "bond", or the price of energy will be reduced for a delayed completion. A form of non-monetary penalty can be the exclusion of the bidder from future auctions.

Figure 26. Marginal abatement cost curve

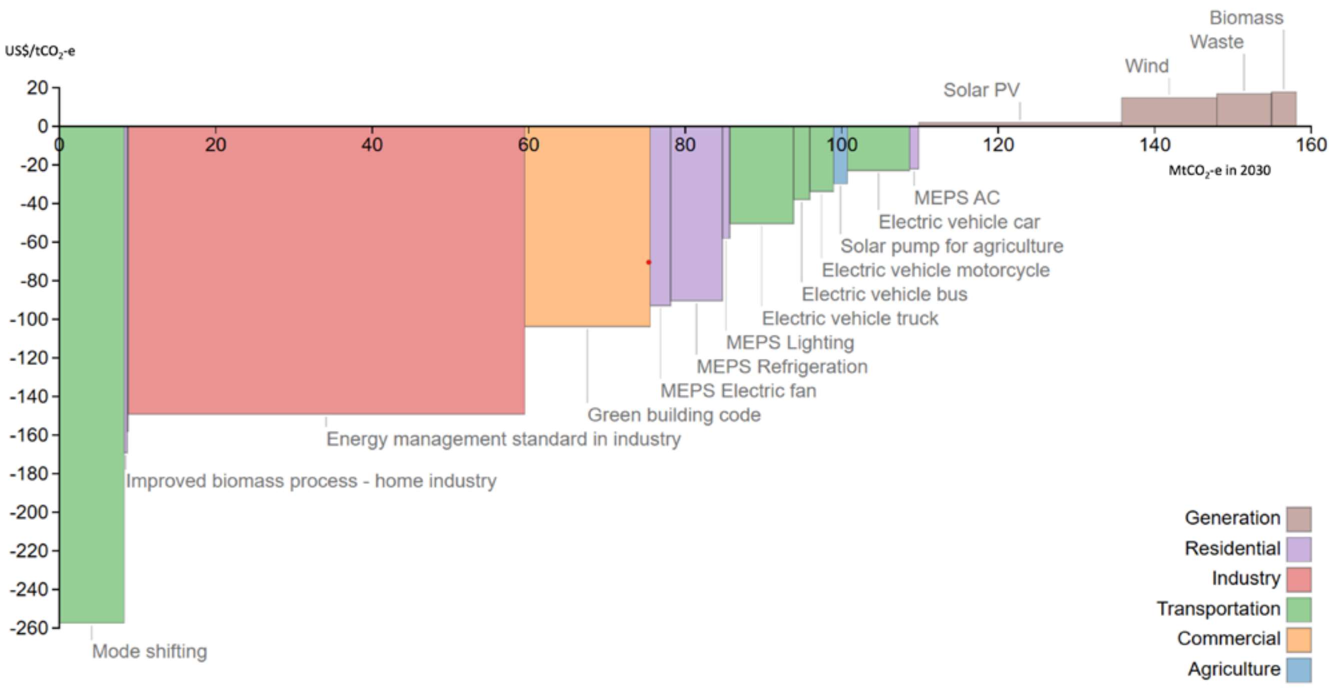
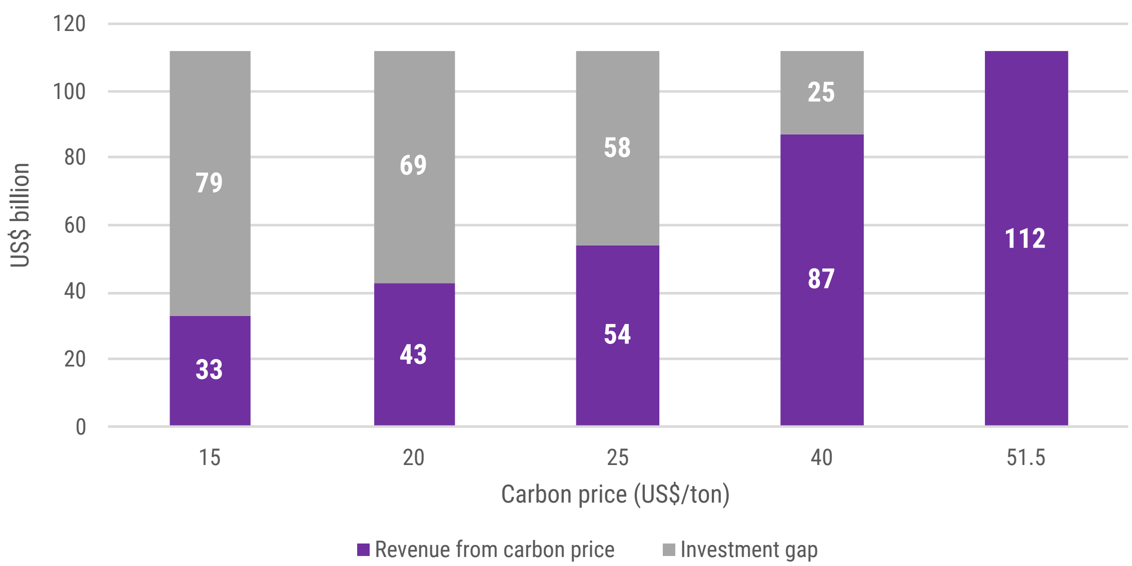


Figure 27. Indicative carbon price to close the investment gap in 2050



8. Policy recommendations

8.1. Scenario evaluation

The current policy, SDG and ambitious scenarios have been evaluated and ranked, using the Multi-Criteria Decision Analysis (MCDA) tool, with a set of 12 criteria and weights assigned to each criterion (table 8). While the criteria and weights have been selected based on expert judgement, ideally the process should use a stakeholder consultation. If deemed necessary, this step can be repeated using the NEXSTEP tool in consultation with stakeholders, where the participants may want to change weights of each criterion. The following factors have been considered to assume comparative weights across the set of criteria, where the total weight needs to be 100 per cent:

(a) Universal access to electricity to be achieved;
(b) Universal access to clean cooking fuel to be achieved;
(c) Renewable energy share in the total final energy consumption to increase;
(d) Energy efficiency improvement should be doubled, and where there is an economic benefit, it should be further enhanced;
(e) The unconditional NDC target should be achieved. Where possible, the conditional target should be achieved if it is economically viable;
(f) Total investment should be kept low, but the net benefit should be high. This was done by assigning both indicators the same weight to ensure that a scenario is chosen on the value-for-money basis; and
(g) Carbon pricing should be introduced to encourage investments in clean energy.

Table 9 shows the summary of results obtained through this evaluation process. The scenario evaluation suggests that the "Net Zero Emissions by 2065" scenario is the highest-ranked energy transition pathway for Thailand since there will be a significant energy efficiency improvement, renewable share increase and emission reduction; most importantly, it would set the course of the energy sector to achieve the goal of net zero emissions. Therefore, Thailand should begin developing/aligning strategies and plans in line this scenario, which will also ensure the achievement of all SDG 7 targets as well as NDC conditional target.

Table 8. Criteria with assigned weights for MCDA

Criterion	Weight
Access to clean cooking fuel	10%
Energy efficiency	10%
Share of renewable energy	11%
Emissions targets in 2030	10%
Alignment with Paris Agreement	10%
Fossil fuel subsidy phased out	5%
Price on carbon	5%
Fossil fuel phase-out	5%
Cost of access to electricity	7%
Cost of access to clean cooking fuel	7%
Investment cost	10%
Net benefit from the power sector	10%
Total	**100%**

Table 9. Scenario ranking based on MCDA

Scenarios	Weighted scores	Rank
Net Zero Emissions 2065	56.5	1
Carbon Neutral Scenario 2050	52.3	2
SDG scenario	47.6	3
Current policy scenario	31.1	4
Business-as-usual scenario	20.0	5

8.2. Revisiting existing policies

Thailand's current energy policies have been evaluated based on the outputs from the LEAP model, in order to highlight any revisions required to achieve the SDG 7 and NDC targets by 2030. These are summarized in table 10.

8.3. Policy recommendations

8.3.1. Promote electric cooking stoves to provide a sustainable solution to achieving universal access with multifold benefits

Universal access to clean cooking solutions should be a key priority in Thailand and it needs to be included in the energy policy. The NEXSTEP analysis suggests the remaining clean cooking gap in Thailand should be closed with the promotion of electric cooking stoves. Electric cooking stoves are a prime solution to achieving universal access to clean cooking by 2030, and will support the achievement of carbon neutrality and net zero emission scenarios with no added burden on fuel imports.

Electric cooking stoves are more efficient than other cooking stoves, including gas stoves. Electric cooking stoves have cheaper annualised cost compared to LPG cooking stoves, making it more affordable for households. The annualized cost of electric cooking stoves will be US$165 while the LPG cooking stove will be US$177. It is estimated that a cumulative investment of US$ 265 million will be required to distribute electric cooking stoves to 1.63 million households by 2030.

8.3.2. Accelerating the implementation of energy efficiency strategies by 2030 to align with global improvement target

Energy efficiency policies across sectors can help achieve substantial energy savings by reducing the need for investment in energy infrastructure, fuel costs and vulnerability to fossil fuel prices. It is great to know that the Government of Thailand is on track to achieve the target of 36 per cent energy intensity reduction by 2037. However, with a little more effort to accelerate the enforcement and the implementation timelines for some of the EE measures will help to achieve the SDG 7 target for energy efficiency as suggested below.

Achievement of the SDG 7 target of 3.1 MJ/US$ by 2030 (3.4 per cent annual improvement rate) will require additional reduction of TFEC by 13.6 Mtoe compared to the CP scenario. To achieve this target, the Government should consider accelerating the implementation of energy management standards, energy code, equipment performance benchmarks and labelling, and mode shifting by 2030. Since this strategy will further help Thailand to achieve the conditional NDC targets, additional streams of funding from international body might be required.

8.3.3. Adopt multi-sectoral approach to raise the renewable energy target in the long term by fuel switching and electrification.

Thailand is also on track to achieve a 30 per cent renewable share in the final energy consumption by 2037. This Road Map suggests

Table 10. Assessment of SDG7 and NDC targets

Category	Existing policy	Policy evaluation	NEXSTEP analysis
Access to electricity	Not applicable since Thailand has achieved universal access to electricity.	Thailand has achieved 100 per cent universal access to electricity.	There may be some unregistered households that still have no access to electricity. In such minor cases, solar mini-grids and solar home systems could be considered.
Access to clean cooking	Not available.	The NEXSTEP analysis projects that Thailand may only reach a 93 per cent clean cooking access rate as per the historical improvement trend.	In consideration of comments from stakeholders, NEXSTEP analysis suggests bridging the remaining gap with electric cooking stoves as the most appropriate clean cooking solution.
Renewable energy	Thailand's Alternative Energy Development Plan 2018-2037 (AEDP 2018) aims to promote the development of renewable energy production in the country and sets out a goal to increase the share of renewable energy and alternative energy in total final energy consumption (TFEC) to 30 per cent by 2037. Thailand's Power Development Plan 2018-2037 (PDP 2018 Revised Version) aims to improve energy efficiency and enhance energy security in Thailand, while setting goals for new power production capacity. The PDP 2022-2037 is currently under public consultation.	Thailand is on track to achieve 30 per cent renewable share in FEC (TFEC excludes non-energy use). The share of renewables in TFEC is projected to be 25.1 per cent in the CP scenario due to the increase of planned renewable power capacities under the PDP as well as the increasing share of renewable for heat under the AEDP scenario.	The renewable energy share in TFEC will further increase to 28.6 per cent in the SDG scenario. This increase is attributable to phasing out of inefficient traditional biomass and kerosene stoves with electric cooking stoves. This increase is also contributed by the additional measures in the energy efficiency.
Energy efficiency	Thailand's National Energy Plan 2022-2037 (NEP 2022 draft) sets out an energy intensity reduction target of 36 per cent by 2037 and 40 per cent by 2050 compared to the 2010 baseline. It sets out several compulsory and voluntary measures to achieve this target with a total savings of 35,497 ktoe by 2037.	Thailand is on track to achieve the target of 36 per cent energy intensity reduction by 2037. However, the CP scenario will not achieve the suggested global energy efficiency improvement target of 3.4 per cent or 3.1 MJ/USD_{2017} in 2030. It is projected that the energy intensity will be 3.5 MJ/USD_{2017} in 2030.	The energy intensity is further reduced to 3.1 MJ/USD_{2017} in 2030 under the SDG scenario, which meets the global energy efficiency target. Achievement of this target requires phasing out inefficient cooking technologies, accelerating the implementation of energy management standards in designated factories/buildings, accelerating mode shifting in transport sector, and making equipment performance benchmarks and labelling as well as financial incentive and ESCO model as a compulsory strategy.

Category	Existing policy	Policy evaluation	NEXSTEP analysis
Emission reduction	Thailand's Updated Nationally Determined Contribution (The Government of Thailand, 2022) – Thailand intends to reduce its GHG emissions unconditionally by 30 per cent from the BAU baseline by 2030 and by 40 per cent subject to adequate and enhanced access to technology development and transfer, financial resources and capacity-building support.	Thailand is on track to achieve the unconditional target of 30 per cent emission reduction by 2030.	Thailand will further achieve the conditional target of 40 per cent emission reduction by 2030 because of the additional measures in the demand sector to improve its energy efficiency.

that policymakers should raise the ambition further to align with the carbon neutrality and net zero emissions scenarios. NEXSTEP identified that bio-energy will be an important strategy for Thailand to replace the heat demand compared to hydrogen due to the current uncertainties in the hydrogen market. Further in-depth investigation should be performed, involving subject matter experts and stakeholders, to identify the techno-economic potential of hydrogen in Thailand. In addition, progress towards second-generation and third-generation biofuels such as algae is the key. Investment is required in research and development to reach commercial potential.

Electrification of the transport system will also be critical for Thailand. A vigorous adoption of electric vehicles (EVs), for example, would reduce the demand for oil products. Another advantage of EVs is their ability to absorb excess renewable energy. With specialised networks and large numbers of EVs plugged into the grid at any one time, there is the possibility to use the combined stationary battery capacity as an element of load levelling. To promote the investments, Thailand has set financial and tax incentives as well as safety standards so that the country can become the centre of EV manufacturing in ASEAN.

8.3.4. Decarbonize the power sector by investing in renewable energy to help achieve net zero emissions target

As Thailand moves towards net zero emissions by 2065, stopping new investment in coal-fired power generation is essential to meet the long-term targets. Policymakers should cancel any coal-fired capacity addition and plan the retirement of existing coal-fired power plants. The importance of early action cannot be overstated. A schedule for the planned retirement of existing coal-fired power plants should be defined and forced-retired as quickly as possible to reach zero coal power plant by 2050. In the past, investment in coal-fired generation was a cheap and reliable, albeit polluting, method of generating electricity. This is no longer the case as renewables have matured and costs have dropped significantly. It is cheaper today to generate electricity from renewables such as solar, hydropower, wind and biomass compared with coal-fired technologies. Strategies, such as renewable auctions and carbon pricing, can be considered to provide revenue streams for investing renewable energy generation in a fully decarbonized energy system.

8.3.5. Develop a green financing policy

Accelerating green financing is critical to achieving the proposed sustainable energy transition. Policymakers need to work with central banks, regulatory authorities and investors to examine the possibility of developing a green finance policy or fund to help close the investment gap. Another option is green bonds to mobilize resources from domestic and international capital markets to finance climate solutions. Renewable energy technologies have relatively high financing costs in developing countries, which reflects their unattractive risk/return profile. This is because of their long-term horizon, high initial capital costs (including high infrastructure cost), unfavourable policy for grid access, illiquid equipment and project risks. Policymakers can reduce high financing costs by using two methods – de-risking and direct incentives. De-risking has two basic forms – policy de-risking instruments that reduce risk, and financial de-risking instruments that transfer risk. Direct incentives are direct finance transfers or subsidies to low carbon investments. The United Nations Development Programme for De-risking Renewable Energy Investment (United Nations Development Programme, 2021) is an important guide for policymakers in developing strategies to reduce risks in renewable energy investment. In addition, setting up a carbon price and a carbon trading scheme should be considered to help close the investment gap, particularly for the carbon neutrality and net zero emissions scenarios. It is suggested that the Government should establish the carbon trading scheme and provide necessary training to build the capacity of the private sector.

8.4. Building back better in the recovery from COVID-19

Energy plays a key role in the process of building better from the COVID-19 pandemic. There are two important dimensions of energy that must be considered.

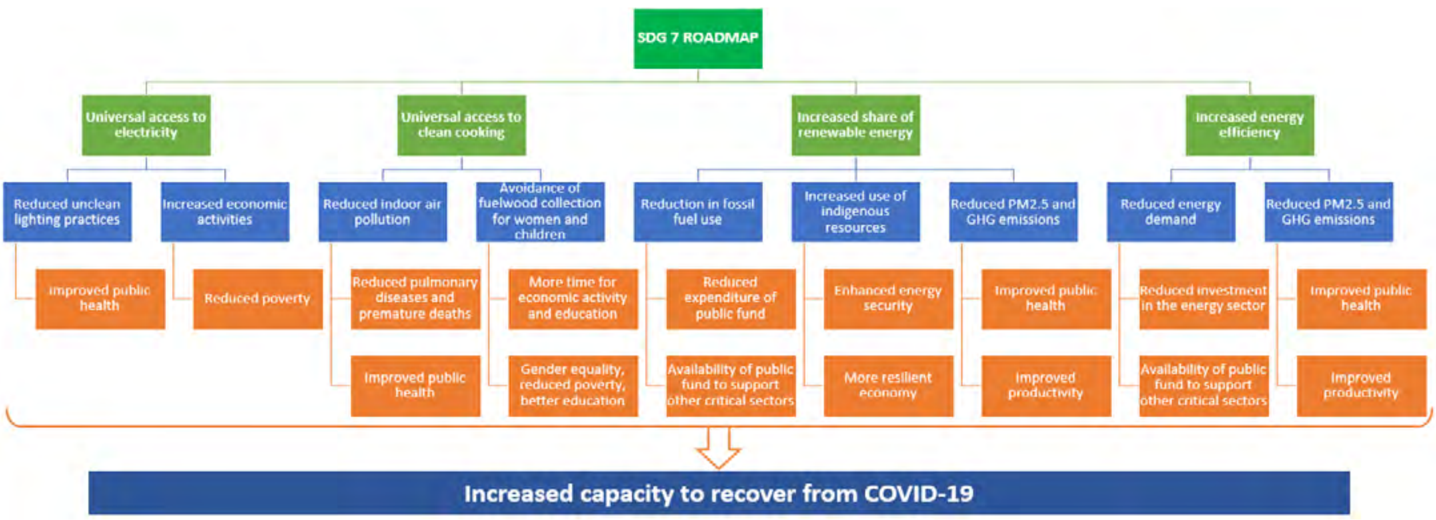
First, energy enables a range of essential services to be delivered – supporting health-care facilities, supplying clean water for essential hygiene, enabling communication and IT, and off-grid renewables refrigeration for vaccine storage. These services are only possible with reliable affordable supplies of energy and are essential in boosting the resilience of the country.

Second, where countries are seeking to revive their economies after the downturn triggered by the COVID-19 pandemic, investing in sustainable energy offers opportunities to generate economic activity and create jobs.

The COVID-19 pandemic has caused social and economic disruption globally, and Thailand was no exception. With the Government of Thailand's effective COVID-19 health strategies, according to WHO (2023), there have been 4,757,049 confirmed cases of COVID-19 with 34,471 deaths (as of 20 September 2023). A total of 139,279,946 vaccine doses have been administered (as of 22 June 2023). Notwithstanding, the country's GDP contracted by 6.1 per cent in 2020 (World Bank, 2023). While grappling with the devastation caused by the pandemic, Thailand should not lose sight of its progress and ambitions towards achieving the SDG targets. Thailand should take the opportunity to build back better from this crisis, in order to become more resilient to face future challenges such as climate change.

The SDG 7 roadmap has identified several key areas that will assist policymakers in strengthening policy measures to help recover from the COVID-19 impact while maintaining the momentum to achieving the 2030 Agenda for Sustainable Development and the Paris Agreement. Figure 28 presents how the SDG 7 Road Map will help to increase the capacity of Thailand to better recover from COVID-19.

Figure 28. SDG 7 Road Map will increase the capacity of Thailand to recover from COVID-19



8.4.1. Accelerating access to clean and modern energy services

Access to clean and modern energy services is essential in helping rural populations combat challenges related to COVID-19. Relying on traditional and hazardous technologies for cooking increases their susceptibility to the effects of the virus-related pandemic in future. Ongoing research is finding relationships between air pollution and the incidence of illness and death due to COVID-19.

Thailand had around 15 per cent of the population or around 3.4 million households that lacked access to clean cooking fuel in 2021. Women and children disproportionately bear the greatest health burden from polluting fuels and technologies in homes as they typically labour over household chores such as cooking and collecting firewood, and spend more time exposed to harmful smoke from polluting stoves.

One potential medium-term impact of COVID-19 could be decreased investment in energy access, as national budgets come under strain and priorities shift. WHO has warned about the severity of health impacts arising from the exposure to traditional use of biomass for cooking and space heating, and is encouraging policymakers to adopt measures to address this challenge. By 2019, around 7,449 people had died per year due to household air pollution-related diseases in Thailand.[23]

The SDG 7 roadmap has identified technical options for connecting the remaining population to cleaner fuel for cooking and heating. The benefits resulting from this measure, in the form of reduced mortality and health impact outweigh the needed investment to advance the clean cooking rate and clean heating rate to reach 100 per cent. According to the World Bank (World Bank, 2022), the cost of health damage from PM2.5 exposure due to households' air pollution in Thailand is around US$6.6 billion per year, which is significantly higher compared to the cumulative cost of providing clean cooking technologies of US$ 265 million.

8.4.2. Savings from the energy sector will help to build other sectors

The NEXSTEP analysis identifies that there are ample opportunities for Thailand to save energy under the current practices. Several of these measures also provide cost savings and strengthen the country's energy security, making it less susceptible to fuel supply and price shocks. Savings from this improvement can help investment in other sectors, such as health, social protection and stimulus, which are critical in responding to and recovering from the COVID-19 pandemic.

The electrification of the transport sector provides multiple additional benefits (in addition to energy saving), including the reduction of expenditure on importing petroleum products and reducing local air pollution. Such measures are very important to solidifying the pathway to recovery from COVID-19 and building back better.

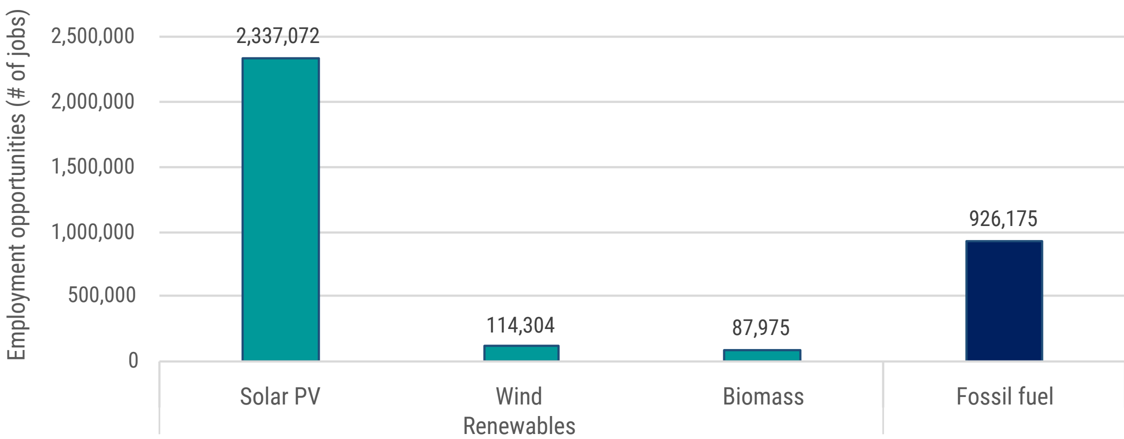
8.4.3. Long-term recovery planning to build back better while ensuring sustainable growth

Deployment of clean energy systems requires much less lead time than fossil fuel counterparts. Moreover, clean energy can create three times

23 The Global Health Cost of PM2.5 Air Pollution (World Bank, 2022)

more jobs for the same amount spent on fossil fuel. Under the net zero scenario, an additional 269.3 GW solar power plant, 9.4 GW wind, and 8.7 GW bioenergy/waste plant are required. This will require an investment cost of around US$ 322.8 billion for solar power plants, US$ 15.2 billion for wind, and $11.5 billion for bioenergy/waste plants by 2050. The average job creation for solar PV, wind, and bioenergy generation are around 7.24, 7.52, and 7.65 per million US dollars respectively (Garrett-Peletier, 2017). In contrast, Garrett-Peletier (2017) found that only 2.65 full-time equivalent jobs are created per million US dollars of spending in fossil fuels. Therefore, these renewable investments will provide employment opportunities to around 2.54 million people compared with only around 0.93 million people employment opportunities generated from the same amount of investment in fossil fuel (figure 29).

Figure 29. Comparison of the number of jobs created by renewable energy and fossil fuels



9. Conclusion and the way forward

The 2030 Agenda for Sustainable Development and Paris Agreement provide a common goal for all countries to achieve sustainability and climate objectives. Achieving the SDG 7 and NDC targets is not an easy feat, but it will help to create a more sustainable and resilient society. This Road Map has presented a number of different scenarios together with their technical feasibility, investments, benefits, challenges and opportunities to inform policymakers of different pathways to energy transition. NEXSTEP has also looked beyond just achieving SDG 7 targets and explored the full potential of the country in relation to decarbonizing its power sector and assessing the potential to advance towards net zero by 2065.

Thailand has achieved universal access to electricity. On the other hand, much needs to be done to achieve universal access to clean cooking by 2030. A coordinated approach is therefore much desired from the private and public sectors in advancing the clean cooking gaps in order to provide clean technologies to the remaining population. For example, electric cooking stoves, which build on commonly used practices, should be promoted to reduce fuel consumption and household indoor pollution.

Thailand is on track to achieve its energy intensity reduction target by 2037. Opportunities exist in the residential, industrial, transport and commercial sectors to save more energy through the implementation of energy efficiency measures. The transportation and industry sectors provide the biggest energy saving potential and should be the main focus, as these sectors have the largest share of Thailand's energy consumption, particularly via mode shifting, fuel switching, energy management standards and energy codes. Thailand has the potential to increase its ambition beyond what is needed under the current policy scenario. Increased efforts can help achieve the global energy efficiency improvement target of 3.4 per cent annually. This can be achieved by accelerating the implementation of some targets under compulsory and promotional measures to be achieved by 2030. Moreover, increasing the energy efficiency measures will help Thailand achieve even the conditional NDC target.

Thailand is also on track to achieve the renewable energy target under final energy consumption by 2037. Improvement of energy efficiency and increasing modern renewable energy will further increase the renewable energy share. The promotion of electric cooking stoves and electric vehicles in the long term will require a substantial amount of electricity in the future. Diversification of generation sources using solar PV, wind and bioenergy would help the country to fulfil the increasing demand as well as improve energy security. The scenario analysis using the MCDA tool suggests that the net zero emissions scenario is the highest ranked scenario for navigating the energy sector towards 2065. In addition to achieving the SDG 7 targets, this scenario will also enable Thailand to exploit its full potential for emission reduction in the long term as well as fulfil the commitment made in COP 26.

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Annexes

I. National Expert SDG 7 tool for energy planning methodology

The analysis presented in this national Road Map is based on the results from the National Expert SDG 7 Tool for Energy Planning (NEXSTEP) project. NEXSTEP is an integrated tool for assisting policymakers in making informed policy decisions that will help in achieving SDG 7 and NDC targets by 2030. The SDG 7 and NDC targets are integrated in the LEAP energy model and back-casted from 2030, since the targets for 2030 are already defined.

Annex table 1. Targets and indicators for SDG 7

Target	Indicators	2020	2030
7.1. By 2030, ensure universal access to affordable, reliable, and modern energy services.	7.1.1. Proportion of population with access to electricity.	99.8%	100%
	7.1.2. Proportion of population with primary reliance on clean fuels and technology for cooking.	85%	100%
7.2. By 2030, increase substantially the share of renewable energy in the global energy mix.	7.2.1. Renewable energy share in total final energy consumption.	10.7% (excluding traditional biomass)	25.7%
7.3. By 2030, double the global rate of improvement in energy efficiency.	7.3.1. Energy intensity measured as a ratio of primary energy supply to gross domestic product.	4.3 MJ/US$ (2017) PPP	3.1 MJ/US$ (2017) PPP

SDG 7.2. Renewable Energy

Methodology: Share of renewable energy in total final energy consumption, where TFEC is total final energy consumption, ELEC is gross electricity production and HEAT is gross heat production.

$$\%TFEC_{RES} = \frac{TFEC_{RES} + \left(TFEC_{ELEC} \times \frac{ELEC_{RES}}{ELEC_{TOTAL}}\right) + \left(TFEC_{HEAT} \times \frac{HEAT_{RES}}{HEAT_{TOTAL}}\right)}{TFEC_{TOTAL}}$$

SDG 7.3. Energy Efficiency. "By 2030, double the global rate of improvement in energy efficiency", as measured by the energy intensity of the economy. This is the ratio of the total primary energy supply (TPES) and GDP. Energy intensity is an indication of how much energy is used to produce one unit of economic output. As defined by the IEA, TPES is made up of production, plus net imports minus international marine and aviation bunkers plus stock changes. For comparison purposes, GDP is measured in constant terms at 2017 PPP.

$$Primary\ energy\ intensity = \frac{Total\ Primary\ Energy\ Supply\ (MJ)}{GDP\ (USD\ 2017\ PPP)}$$

$$CAGR = \left(\frac{EI_{t2}}{EI_{t1}}\right)^{\frac{1}{(t2-t1)}} - 1$$

where EI_{t1} is energy intensity in year t1 and EI_{t2} is energy intensity in year t2.

Base period improvement rate for Thailand (1990-2010): -0.7 per cent (negative sign means that the energy intensity increased during the given period).

SDG 7.3. improvement rate for Thailand (suggested global improvement rate): 3.4 per cent.

II. Key assumptions for NEXSTEP energy modelling

(a) General parameters

Annex table 2. GDP, PPP and growth rate

Parameter	Value
GDP (2021)	US$ 505.5 billion
PPP (2021, constant 2017 US dollar)	US$ 1,222.7 billion
Growth rate	2021 to 2022 (2.6%); 2022 to 2023 (3.3%), 2023 to 2024 (3.7%), 2024 forward (3.7%)

Annex table 3. Population, population growth rate and household size

Parameter	Value
Population (2021)	66,171,439
Population growth rate	0.16% per annum, reaching a peak in 2030, and decreasing at a rate of 0.26% per annum
Number of households (2021)	22,624,354
Household size (constant throughout the analysis period)	2.92

(b) Demand-side assumptions

(i) Transportation

- Land transport consumption is estimated using the vehicle statistics, load factor, annual travel mileage and estimated fuel economy as shown in annex table 4. The factors are based on vehicle statistics compiled by the local consultant.
- Land transport activities in 2021 are estimated to have been 638.26 billion passenger-kilometres and 274.62 billion tonne-kilometres. The growth in both passenger transport and freight transport activities is assumed as growing at the following rate: 2021 to 2022 (18%); 2022 to 2023 (16%); 2023 forward (2.3%).

Annex table 4. Passenger-km and tonne-km distribution

Passenger transport	% share of vehicles by fuel type	Annual travelled mileage (km)	Fuel consumption	% share of passenger-km
Passenger car	Gasoline – 38.3%	5,723	7.3 km/l	48.1%
	Diesel – 56%		12.1 km/l	
	LPG – 3.2%		3.5 km/l	
	CNG – 1.3%		8.1 km/l	
	Electric – 1.2%		5 km/kWh	
Private motor tricycle	Gasoline – 67.8%	5,723	9.1 km/l	0.004%
	Diesel – 0.4%		15.1 km/l	
	LPG – 29.2%		3.7 km/l	
	CNG – 0.2%		8.6 km/l	
	Electric – 2.4%		5 km/kWh	
Motorcycle	Gasoline – 99.9%	1,785	9.2 km/l	9.8%
	Electric – 0.1%		5 km/kWh	
Taxi	Gasoline – 5.6%	5,723	5.2 km/l	0.3%
	Diesel – 3.6%		7.1 km/l	
	LPG – 29.6%		2.1 km/l	
	CNG – 60.4%		4.8 km/l	
	Electric – 0.8%		5 km/kWh	
Taxi motor tricycle	Gasoline – 7.5%	5,723	9.1 km/l	0.1%
	Diesel – 0.1%		15.1 km/l	
	LPG – 85.8%		3.7 km/l	
	CNG – 5.4%		8.6 km/l	
	Electric – 1.2%		5 km/kWh	
Bus	Gasoline – 3%	65,256	5.2 km/l	41.1%
	Diesel – 78.3%		8.4 km/l	
	LPG – 2.7%		2.1 km/l	
	CNG – 15.8%		4.8 km/l	
	Electric – 0.2%		5 km/kWh	
Minibus	Gasoline – 20.4%	65,256	5.2 km/l	0.2%
	Diesel – 79.6%		8.4 km/l	
Tractor	Diesel – 100%	1000	6.1 km/l	0.1%
Other	Diesel – ~100%	5,723	10.1 km/l	0.3%
Freight transport	**No. of vehicles**	**Annual travelled mileage (km)**	**Fuel consumption**	**% share of tonne-km**
Freight truck	Diesel – 96.8%	95,650	8.4 km/l	100%
	Gasoline – 0.1%		5.5 km/l	
	LPG – 0.1%		4.8 km/l	
	CNG – 3.0%		2.1 km/l	

(ii) Residential

- The residential sector is further divided into urban and rural households. Urban households have achieved a 100 per cent electricity access rate, while rural households have achieved a 99.7 per cent electricity access rate. The overall clean cooking rate was 85 per cent in 2021. The breakdown is shown in annex table 5.

Annex table 5. Cooking distribution in urban and rural households[24]

Stove type	Energy intensity (GJ/household)	Urban	Energy intensity (GJ/household)	Rural
LPG stove	4.0	85.1%	4.2	80.6%
Electric stove	3.0	5.8%	-	-
Biomass stove*	15.9	3.8%	16.8	9%
Charcoal stove*	13.9	5.3%	14.7	10.4%

*This is assumed as unclean fuel/technology.

- The residential appliance ownership data and energy use intensity in the baseline year were provided by the local consultant. The appliance ownership is projected to grow at a rate similar to the growth in GDP per capita. The average electrical demand per owning household for the different appliances are assumed to be constant throughout the analysis period, unless further energy efficiency measures are implemented.

Annex table 6. Residential appliance baseline assumptions

Appliance	Electricity intensity (kWh/HH/year)	Ownership – urban	Electricity intensity (kWh/HH/year)	Ownership – rural
Lighting	258.7	100%	242.5	99%
Air conditioner	1,482.6	45%	741.3	26%
Refrigerator	1,227.3	90%	1,227.3	94%
Television	98.4	92%	90.9	94%
Electric heater	171.5	26%	114.3	18%
Electric fan	311.7	99%	323.6	99%
Washing machine	58.5	67%	58.5	73%
Iron	202.1	86%	179.6	78%

(iii) Industry

- The industry sector is differentiated into nine subcategories. The fuel consumption by industry subcategories is as detailed in annex table 7.
- The industrial GDP is assumed to grow at a rate similar to the national GDP growth rate. The energy intensity is assumed constant throughout the analysis period in the absence of energy efficiency interventions

24 The clean cooking access rate is indicated as 85 per cent (World Health Organization, 2022). The energy intensity is based on assumptions provided by the local consultant.

Annex table 7. Fuel consumption by industry subcategories in 2021

Industry	Fuel consumption (ktoe)					
	Coal	Oil products	Biomass	Natural gas	Electricity	Total
Food and beverages	463	1,142	3,674	195	2,143	**7,617**
Chemical and synthetic products	158	533	632	2,046	1,064	**4,433**
Glass, cement, and non-metals	4,523	300	436	920	490	**6,669**
Iron and steel	26	282	-	385	673	**1,366**
Pulp and paper	825	126	56	64	201	**1,272**
Textile, leather, and leather products	357	64	17	67	130	**875**
Machinery and transport equipment	-	220	1	318	1,486	**2,025**
Wood and other products	-	102	385	1	207	**695**
Other processing industry	15	1,125	26	145	91	**1,402**
Total	**6,367**	**3,894**	**5,227**	**4,141**	**6,725**	**26,354**

(iv) Commercial sector

- The total annual energy consumption in the commercial sector was 5,599 ktoe in 2021. It is projected to grow at an annual rate similar to the national GDP growth rate.
- The commercial sector is further differentiated into four categories, and the energy consumption by categories are as shown in annex table 8.

Annex table 8. Commercial sector fuel consumption in 2021

Category	Floor space (million m^2)	Fuel consumption (toe)			
		Natural gas	LPG	Electricity	Total
Private offices and Government buildings	31.33	0.02	12.49	397.61	410.12
Shopping malls	239.54	0.02	10.86	3,982.93	3,993.81
Hotels	39.97	0.69	403.92	545.29	949.9
Health facilities	5.66	0.11	63.89	82.67	146.67
Educational institution	15.3	-	0.71	98.59	99.31
Worship centres and other	25.04	0.15	90.12	492.56	582.84
Total	**356.84**	**1.00**	**582.00**	**5,599.65**	**6,182.65**

(v) Other sectors

- The remaining demand is used for agriculture and non-energy use. The consumption growth is projected to grow at the same as the national GDP growth rate.

Annex table 9. Consumption by other sectors in 2021

Category	Fuel consumption (ktoe)					
	Coal	Natural gas	Oil products	Electricity	Biomass	Total
Agriculture	-	-	2,200	34	-	2,234
Non-energy use	-	3,388	3,090	-	-	6,428

III. Power technologies cost and key assumptions

The cost parameters considered for the power technologies are as follows:

Annex table 10. Power technologies key assumptions

Technology	Efficiency	Maximum availability	Investment cost (US$/kW)	Fixed O&M (US$/kW-year)	Variable O&M (US$/MWh)
CCGT	46%	68%	950	12.94	1.31
Steam turbine (Coal)	54%	75.1%	2,100	24.56	3.07
Steam turbine (gas)	34%	5.8%	950	12.94	1.31
Co-generation (coal)	40%	74%	600	24.56	3.07
Co-generation (gas)	31%	74.3%	600	12.94	0.41
Solar	100%	18.3%	1,212	12.12	-
Wind	100%	25.3%	1,939	38.78	-
Biogas	12%	22.7%	3,818	190.91	-
Waste	24%	62.7%	2,272	284.09	-
Biomass	12%	33.8%	2,424	181.82	-
Mini-hydro	100%	38.2%	3,015	120.61	-

IV. Economic analysis data for clean cooking technologies

The NEXSTEP economic model utilizes the technological and cost parameters to estimate the. annualised cost of clean cooking technologies (annex table 11). The calculation assumes an annual cooking thermal energy requirement of 3,840 MJ per household. In addition, a discount rate of 5.37 per cent is assumed.

Annex table 11. Technology and cost data for clean cooking technologies

Technologies	Efficiency[25] (%)	Lifetime[26] (years)	Stove cost (US$)	Variable O&M[27] (US$/year)	Fuel cost (US$)
LPG stove	40	7	30	10	0.73 per kg
Electric stove	84	15	37	10	0.113 per kWh

V. Summary results for the scenarios

	BAU scenario	CPS scenario	SDG scenario
Universal access to electricity in 2030	100%	100%	100%
Universal access to clean cooking in 2030	93%	93%	100%, via electric stoves
Energy efficiency in 2030	4.5 MJ/US$	3.5 MJ/US$	3.1 MJ/US$
Renewable energy share in TFEC in 2030	10.7%	18.7%	25.7%
GHG emissions in 2030	355.1 $MtCO_2$-e	239.7 $MtCO_2$-e	201.7 $MtCO_2$-e
Renewable energy share in power generation in 2030	11.4%	18.1%	20.5%
Net benefits from the power sector	US$ 224.5 billion	US$ 216.2 billion	US$ 200.4 billion
Total investment for the power sector up to 2030	US$ 16.1 billion	US$ 22.1 billion	US$ 22.1 billion

25 Sourced from: ICS – own estimation, LPG stove efficiency ranges – (World Bank, 2014), electric cooking stove (induction stove) – (IEA, 2012).

26 Sourced from: ICS – own estimation, LPG stove – (Clean Cooking Alliance, 2021), electric stove – (IEA, 2012).

27 Variable O&M is based on own assumptions.