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International Renewable Energy Agency

RENEWABLE ENERGY OUTLOOK THAILAND

Based on Renewables Readiness Assessment and REmap analysis

IRENA
International Renewable Energy Agency

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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RENEWABLE ENERGY OUTLOOK

THAILAND

Department of Alternative Energy Development and Efficiency
MINISTRY OF ENERGY

IRENA
International Renewable Energy Agency

FOREWORD
from the Minister of Energy

"Stability, Prosperity and Sustainability" is the vision that Thailand is pursuing in 2015-2020, as guided by Prime Minister Prayuth Chanocha. According to this five-year vision, the Ministry of Energy has focused on energy stability, prosperity and sustainability and has released the Thailand Integrated Energy Blueprint (TIEB), spanning 2015-2036.

The blueprint combines five key energy plans from 2015, covering power, oil, gas, energy efficiency, and alternative energy development. The Alternative Energy Development Plan (AEDP 2015) set a target to increase renewables, whether in the form of electricity, heat or biofuels, to 30% of the country's final energy consumption by 2036. This makes renewable energy one of Thailand's top energy priorities.

To achieve the AEDP 2015 target, the Ministry of Energy has put in place a number of support measures to promote renewable energy projects to the private sector and recognises the International Renewable Energy Agency (IRENA) as a solid partner in this dialogue. Thailand officially became a member of IRENA in 2015. The resulting collaboration between the Ministry of Energy and IRENA, with kind support from other Thai organisations, produced the Renewables Readiness Assessment (RRA) and REmap country analysis that form the basis of Renewable Energy Outlook: Thailand. This project is very successful contribution for Thailand on renewable energy forecast and analysis renewable energy policies.

On behalf of Ministry of Energy of Thailand, I would like to express appreciation for IRENA's efforts and support so far. I would also like to thank all the people and organisations involved in this project for their excellent co-operation and contributions. I look forward to continuing this great collaboration in the near future.

H.E. General Anantaporn Kanjanarat
Minister of Energy
Thailand

FOREWORD
from the IRENA Director-General

Thailand, like other South-East Asian nations, stands at an important crossroads in its energy sector. It faces a rise in energy demand by almost 80% in the next two decades, driven by population growth and continued economic growth. This creates a challenging situation for a country that relies on energy imports for more than half of its energy supply.

In response, Thailand has sought to enhance its energy security and meet long-term social and economic goals through improved efficiency and greater reliance on renewables. This quest has inspired others in the Association of South-East Asian Nations (ASEAN).

Renewable Energy Outlook: Thailand, prepared by the International Renewable Energy Agency (IRENA) in close collaboration with the Department of Alternative Energy Development and Efficiency (DEDE) of the Thai Ministry of Energy, evaluates three sub-sectors – power generation, thermal use and bioenergy – and identifies key challenges. It also highlights the actions needed to meet or even exceed the country's target of 30% renewables in the energy mix by 2036.

The study combines two key IRENA methodologies: the Renewables Readiness Assessment (RRA), based on country-led stakeholder consultations; and REmap, IRENA's roadmap to double renewables in the energy mix. All ten ASEAN members took part in regional REmap analysis, which highlights a realistic path to reach 23% renewables regionally by 2025. As the present study indicates, Thailand could reach 37% renewables while reducing energy costs – saving some USD 8 billion per year with the environmental and health-related costs of fossil fuels taken into account.

I wish to acknowledge the strong support provided by the Ministry of Energy of Thailand for this study. The contribution of other stakeholders and international partners has also been invaluable to provide a broader perspective. IRENA will continue to support Thailand's quest for a sustainable energy future in full partnership with the government authorities.

Adnan Z. Amin
Director-General
International Renewable Energy Agency

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ABBREVIATIONS

ACE	ASEAN Centre for Energy
AEDP	Alternative Energy Development Plan
APAEC	ASEAN Plan of Action for Energy Cooperation
ASEAN	Association of South East Asian Nations
BEV	battery electric vehicle
BF	blast furnace
bln	billion
BMTA	Bangkok Mass Transit Authority
BoI	Board of Investment
BTL	biomass to liquid
CO_2	carbon dioxide
CO	coke oven
COD	commercial operating date
CNG	compressed natural gas
CSP	concentrated solar power
DEDE	Department of Alternative Energy Development and Efficiency
DH	district heat
EEP	Energy Efficiency Plan
EGAT	Electricity Generating Authority of Thailand
EPPO	Energy Policy and Planning Office
ERC	Energy Regulatory Commission
EV	electric vehicle
FIP	feed-in premium
FIT	feed-in-tariff
IRENA	International Renewable Energy Agency
GDP	gross domestic product
HVDC	high-voltage direct current
IEEJ	Institute of Energy Economics of Japan
IPP	independent power producer
IPPU	industrial processes and product use
Lao PDR	Lao People's Democratic Republic
LCOE	levelised cost of energy
LPG	liquefied petroleum gas
MEA	Metropolitan Electricity Authority
MoAC	Ministry of Agriculture and Cooperatives
MoE	Ministry of Energy
MoNRE	Ministry of Natural Resources and Environment
MoU	memorandum of understanding
MSW	municipal solid waste
NDC	Nationally Determined Contribution
NEPC	National Energy Policy Council
OECD	Organisation for Economic Co-operation and Development

ABBREVIATIONS

O&M	operation and maintenance
PEA	Provincial Electricity Authority
PDP	Power Development Plan
PHEV	plug-in hybrid electric vehicle
PPP	purchasing power parity
PTT	Petroleum Authority of Thailand
PV	photovoltaic
REC	renewable electricity certificate
REDP	Renewable Energy Development Plan
REmap	renewable energy roadmap
RRA	Renewable Readiness Assessment
R&D	research and development
SPP	small power producer
TFEC	total final energy consumption
TIEB	Thailand Integrated Energy Blueprint
TPES	total primary energy supply
VRE	variable renewable energy
VSPP	very small power producer
WTE	waste to energy
yr	year

UNITS OF MEASUREMENT

EJ	exajoule	**Mtoe**	million tonnes of oil equivalent
GW	gigawatt	**MVA**	mega-volt ampere
GWh	gigawatt hour	**MW**	megawatt
GWth	gigawatt thermal	**MWh**	megawatt hour
ktoe	thousand tonnes of oil equivalent	**m/s**	metre per second
kV	kilovolt	**N/A**	not applicable
kW	kilowatt	**PJ**	petajoule
kWh	kilowatt hour	**toe**	tonne of oil equivalent
L	litre	**TWh**	terawatt hour
Mt	megatonne	**°C**	degree Celsius

EXECUTIVE SUMMARY

Solar PV power plant in Thailand
Photograph: Solarco Co. Ltd.

Energy security has long been a top priority for Thailand. More than half of its energy supply relies on imported energy, a proportion that is likely to increase further when its proven reserves of oil and gas are depleted, as anticipated in less than a decade, unless other indigenous energy sources are exploited. This has not only challenged security of supply, but has also had significant implications for overall energy expenditure. Additionally, the commitments that the Government of Thailand has made to reduce greenhouse gas emissions by 20-25% from the business-as-usual scenario by 2030 requires concerted actions for decarbonisation of the energy sector.

Thailand has set a new renewable energy target of 30% of total final energy consumption by 2036 in its Alternative Energy Development Plan (AEDP) 2015. This study evaluates the three sub-sectors of power generation, thermal use and bioenergy, with a focus on the identification and analysis of the key challenges to achieving the targets set out in AEDP 2015. It conducts an in-depth renewable technology assessment using the International Renewable Energy Agency (IRENA) REmap analysis tool to identify where additional potential for renewable energy lies while quantifying additional factors including cost, effects on externalities and investments.

The key findings show that Thailand has the potential to increase the share of renewable energy in final energy from the present AEDP target of 30% in 2036 to as high as 37%. The study also presents a different portfolio of technology options from those in AEDP 2015 with a minimum saving of USD 1.2 billion per year before factoring in the benefits from reduced adverse effects on health and the environment. However, to capture the benefits Thailand will need to invest significantly in its energy system over the coming two decades and consider the following findings and recommendations in addressing the challenges ahead.

- In 2036, there is a large amount of hydropower generating capacity, including 1 000 MW of pumped storage, in all scenarios. This can be used as regulating power when needed, especially in the scenario that the share of variable energy sources, such as solar photovoltaic (PV) and onshore wind power, in the power system increase substantially.

- It is important to develop a portfolio that includes a variety of different renewable energy sources in the mix that can complement each other in resource availability. This will help achieve a higher overall capacity factor and reduce the requirements for reserve capacity, and thus minimise overall system costs.

- Other options are available, for instance, matching variable renewable energy (VRE) outputs with load as much as possible using intelligent control systems, including adopting demand-side management schemes. From a long-term perspective, there might be a need to establish an auxiliary market to enable independent regulating power providers to take a more active role in different market segments, so as to ensure grid stability and reliability. Therefore, it is advisable that Thailand conducts a feasibility study of establishing a market for better utilisation of existing and potential reserve margins.

- Most of the industrial facilities that can potentially use biomass for process heat are large-scale, centralised plants operating at economies of scale, which would require large energy flows to be brought from within and across national borders. Cost-competitiveness of biomass can be maintained through an effective logistics infrastructure as consumption increases. Therefore, it is essential to support the development of biomass supply chains that ensure the delivery of reliable, high-quality and affordable biomass fuels to those industries that are willing to use them. The development of such supply chains would benefit not only heat applications, but also electricity production and, more importantly, co-generation of heat and power. The development of such supply chains could benefit multiple users of different parts of biomass feedstocks. Yet, it should be made clear that food security for both humans and livestock must remain the top priority. For this reason, the focus of further development in the AEDP should be on biomass supply chains that do not threaten food security.

- Consequently, to sustain the supply chain, there must be clear policy and legal frameworks on land tenure and use, which are the basic elements that enable long-term commitment and investment in agriculture, especially at the levels that are required to sustain a strong bioenergy sector that does not compete with food production. Second is the need to establish a fair and reasonable market environment with a clear pricing mechanism for biomass that can offer long-term purchase guarantees, based on projected demand, and to smooth out as much as possible the seasonal variation in feedstock yields. To some extent, this market environment should also factor out the commodity price volatility of the international markets. This would help minimise the negative impact of oil price volatility on farmers' finances, and in return enhance their confidence in investments in energy crops.

  Additionally, prices should in principle be stable or predictable over the long term, and should not be set too high or too low in relation to food prices. Third, a fair and sound regulatory framework should be put in place to ensure a fair distribution of the benefits between farmers and energy producers, particularly when trade is through processing collection companies (including agricultural cooperatives that are operating as a collector in some places), processing mills, and other involved businesses. Lastly, the use of new technologies for managing the feedstocks and derived products should be encouraged, for instance solid biomass pellets, provided they can meet the expected or desired quality assurance.

- Energy demand in Thailand is expected to increase by 78% by 2036, and gross domestic product (GDP) by 126%. Renewables will play an important role in meeting this demand. In the REmap Options, the two largest sources of additional potential are solar PV, increasing from 6 gigawatts (GW) to almost 17 GW, and onshore wind, doubling from 3 GW to 6 GW. Therefore, greater attention should be paid to solar PV and wind power given the huge potential they present in the analysis.

- Bioenergy remains the dominant renewable source in Thailand's end-use sectors due to its ability to be used for heat and transport fuels. The analysis shows that Thailand has huge potential to replace traditional bioenergy with modern cookstoves and biogas digesters, resulting in an increase in modern bioenergy in the residential sector and reversal of the uptake in liquefied petroleum gas (LPG) foreseen in AEDP 2015.

- Renewable thermal energy utilisation accounts for nearly two-thirds of the total increment of renewables in final energy by 2036, if the AEDP 2015 target is met as projected in the plan. The majority of this is expected to come from biomass according to the plan. Solar thermal represents "low-hanging fruit" in the end-use sectors, and can be scaled up significantly in buildings for water heating and in industry for low-temperature heating and pre-heating.

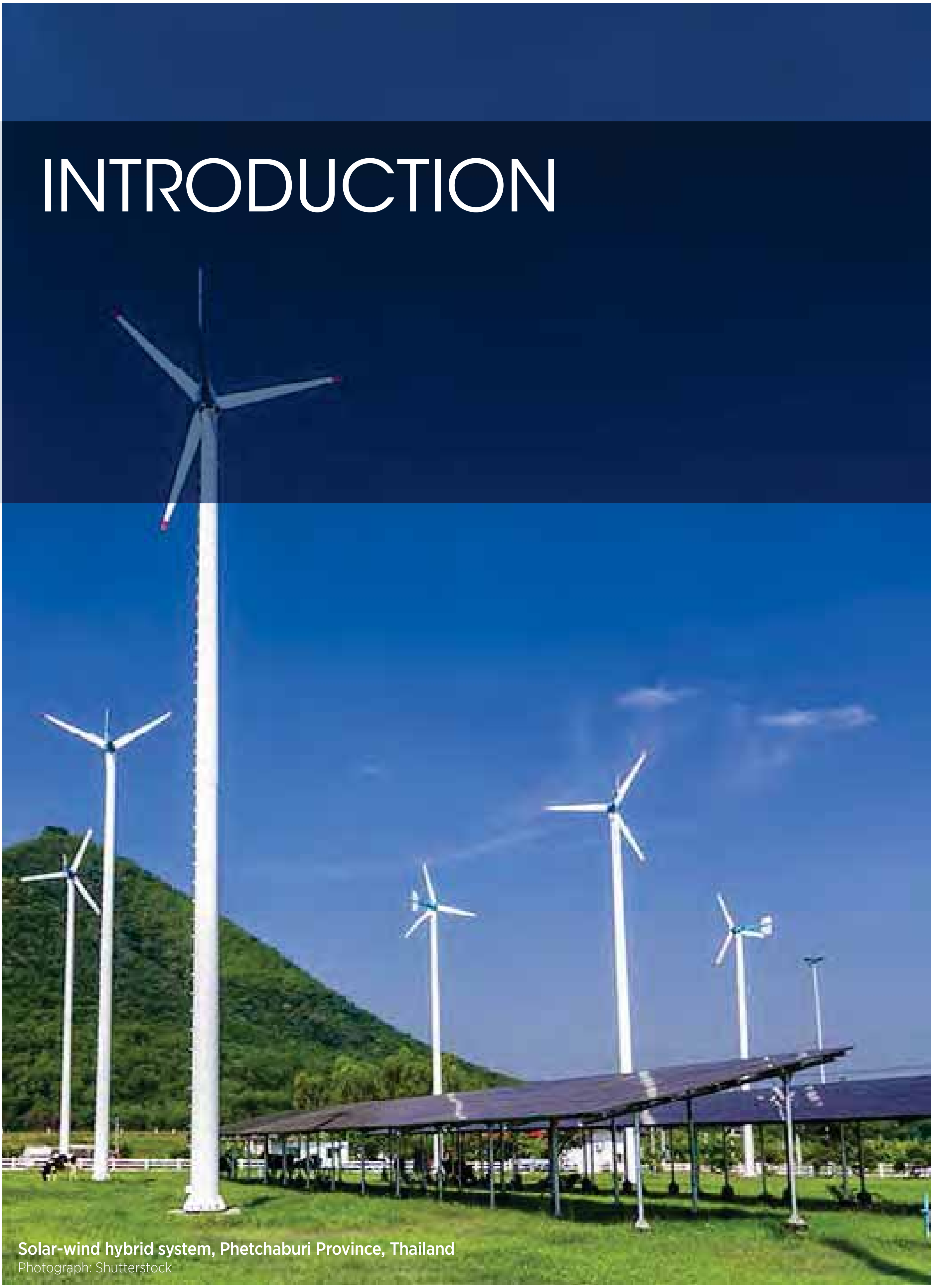
  Thailand should set the right policy framework for the effective use of renewable thermal energy, with a suite of dedicated incentive schemes as it did for promoting the use of renewable energy sources in the power and transport sectors. To achieve this, a statistical system is required that can collect and assemble the right set of energy metrics for renewable thermal energy. To this end, it is recommended that a comprehensive study is conducted to review the current data system, including the scope of technologies covered and the ways in which the data are collected, assembled, reported and analysed for renewable thermal energy.

  On the demand side, there is a need for studies to look further into the feasibility of the potential applications, followed by a promotional strategy.

- Thailand has developed a strong automobile industry. In the transport sector REmap focuses on identifying the potential of electric vehicles (EVs) and as a result the demand for electricity in the sector triples. The number of passenger EVs on the road in Thailand by 2036 would total 1.5 million and electric two- and three-wheelers would total over 3.5 million. To achieve this, Thailand should develop a better, proactive system of planning for technological and infrastructure development. EVs could have an important role as an alternative to petroleum-derived transport fuels in Thailand, but the country should avoid a swift change in policy direction.

  Thailand is advised to devise a long-term strategic development plan or roadmap for the transport sector, including vehicles, fuel types and the necessary infrastructure. For instance, Thailand could tap into electric two- and three-wheeler markets, including tuk-tuks, and establish local manufacturing capacities to deliver quality products at acceptable prices for Thai consumers. There is no competition with conventional car manufacturers in this market segment. For four wheelers, Thailand could start with the market for fixed-route transport that has a predictable range of distance, such as public buses, light freight vehicles for delivery services, and sightseeing or tour buses. Alongside the development of manufacturing capacity for EVs, Thailand should increase investment in charging facilities for EVs, including on-street charging for urban EVs and two-/three-wheelers as well as fast-charging stations, in order for the market to develop in an organic way.

INTRODUCTION



Solar-wind hybrid system, Phetchaburi Province, Thailand
Photograph: Shutterstock

01

1.1 Country background

The Kingdom of Thailand, located in Southeast Asia, is home to 68 million people in an area of 513,000 square kilometres divided into 76 provinces (excluding Bangkok, which is defined as a Special Administration Zone) with six regions, namely the Northern region (9 provinces), Southern region (14 provinces), Eastern region (7 provinces), Western region (5 provinces), Northeastern region (20 provinces) and Central region (21 provinces) (UNSD, 2016). The country is adjacent to the Lao People's Democratic Republic (hereinafter referred to as Lao PDR) in the east, Myanmar in the north and Malaysia and Cambodia in the south, making it an important corridor for the long-distance transmission of electric power.

Over the past three decades, Thailand has made remarkable progress on many fronts, including strong economic growth[1] that helped lift millions out of poverty and the country up to an upper-middle income economy.[2] During this time, the industrial and commercial sectors have rapidly evolved into major contributors of growth to gross domestic product (GDP), while the importance of agriculture has reduced in this regard (World Bank, 2016).

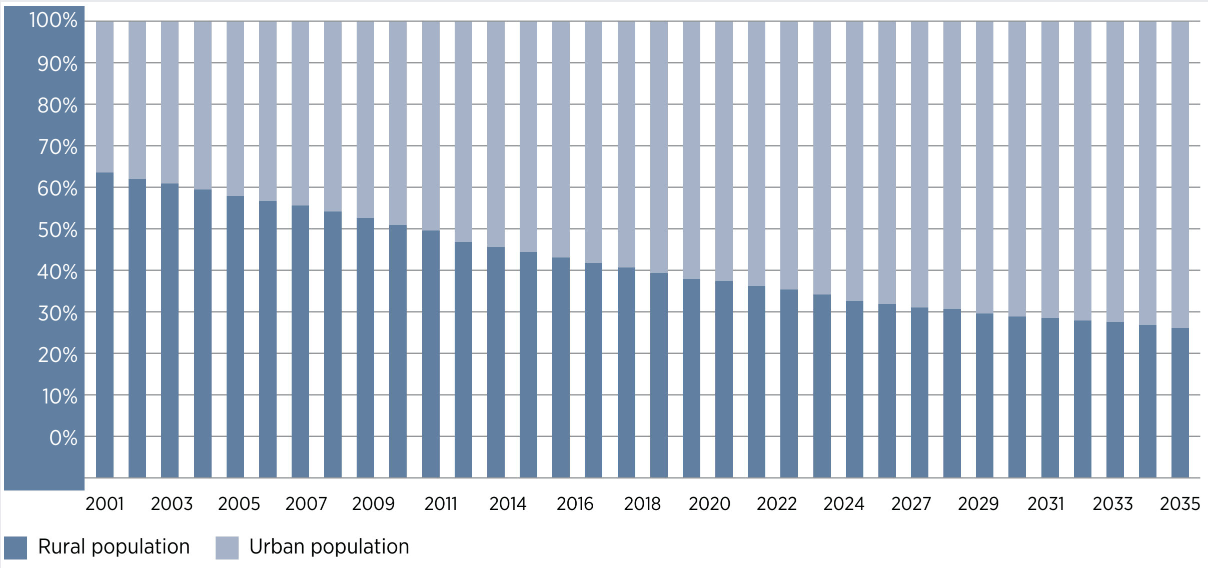
However, 11% of the population remained in poverty by 2014, according to the World Bank, the majority of whom reside in rural areas. The rural population accounts for largely half of the total population. As illustrated in Figure 1, since 2001 urbanisation has substantially increased the migration of the rural labour force into cities, driven in part by increased productivity in the agricultural sector and growing demand for labour in the industrial sector. As with other developing economies, this trend is likely to continue, should Thailand continue its efforts in industrial development. The World Bank projected that the rural population would decline to one-third of the total population by 2036 (World Bank, 2017).

[1] Except for the two financial crises, which occurred in 1998 and 2008 and affected Thailand's GDP growth rates.

[2] Poverty among the population has significantly declined from 67% in 1986 to 11% in 2014, according to the World Bank.

The industrial sector, including energy-intensive sub-sectors such as iron and steel, mining, petrochemicals and construction, provides jobs for about 20% of the labour force, constituting about 40% of GDP. However, given that the manufacturing sub-sector, including automobiles, electronics and food processing, is to a large extent export-oriented, Thailand's economy may become more vulnerable to global and regional economic situations unless its portfolios of trading partner countries and commodities can be adequately diversified.

Figure 1. Thailand's urban vs. rural population, 2001-2036



World Bank (2017) data

1.2 Regional context

Thailand together with Indonesia, Malaysia, the Philippines and Singapore founded the Association of Southeast Asian Nations (ASEAN) in 1967, which was subsequently joined by the other five countries in Southeast Asia (ACE, 2017a). ASEAN economic performance has been significant over the past five decades since its founding, with the exception of the financial crises. ASEAN has become the sixth-largest economy in the world with a doubling of its share of global GDP over the same period (ASEANstats, 2017). The momentum of its growth is projected to continue at an annual rate of 5.1% of real GDP for the immediate term, i.e. over 2017-21, according to estimates by the Organisation for Economic Co-operation and Development (OECD, 2017),[3] and at around 4.6% for the longer term to 2035-40 according to estimates in the Southeast Asia Energy Outlook (IEA, 2013) and the 5th ASEAN Energy Outlook (ACE, 2017b). This would lead to a substantial growth in energy demand over the next two decades or more, even though average regional energy elasticity is expected to decline thanks to improved energy efficiency and energy conservation. By 2040, the total energy demand of ASEAN member states is expected to increase by 110-130% compared to the levels of 2014 or 2015,[4] as estimated by the Institute of Energy Economics of Japan (IEEJ) in 2016 (IEEJ, 2016) and by the ACE in 2017 in its 5th ASEAN Energy Outlook, respectively.

Today more than three-quarters of regional energy production is from three primary resources in ASEAN, namely coal, oil and natural gas, which are unevenly distributed in just a few countries. Indonesia possesses 80% of the steam coal reserve while Viet Nam has most of the rest (18%). About 87% of the total natural gas reserves and 90% of the crude oil are in Indonesia, Viet Nam and Malaysia. For lignite, 92% of the total reserves in the region are in Indonesia and Thailand (ACE, 2015a).

[3] GDP growth for Thailand is projected at a rate of 3.5% by the Thai authorities compared to the 3.6% estimated by the OECD.

[4] The difference between these two years (624 vs. 630 million tonnes of oil equivalent [Mtoe]) is nominal compared to the aggregated amount of the projected period of time. So, the total primary energy consumption for 2014 and 2015 are treated as the same amount.

ASEAN renewable energy resources also hold great potential,[5] dominated by hydro resources in the Greater Mekong Sub-region, but also with abundant solar, wind, geothermal and biomass energy across the region (IRENA and ACE, 2016). With drastic cost reductions in certain renewable energy technologies and the multiple benefits associated with modern renewable energy applications, renewable energy has been given a lot of attention in most ASEAN member states. The benefits it offers include enhanced energy security, improved environmental quality (particularly reduced air pollution) and the creation of new job opportunities, as well as provision of cost-effective electrification options to the remote areas or islands.

In this context, ASEAN has set a region-wide renewable energy target in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-25, aimed at achieving 23% renewables in total primary energy consumption by 2025 (ACE, 2015b), and ASEAN Energy Ministers have made a commitment to support the scaling up of renewable energy sources at the regional level (ASEAN, 2016).

1.3 Methodologies

This Renewable Energy Outlook for Thailand was conducted jointly by the International Renewable Energy Agency (IRENA) team and the Department of Alternative Energy Development and Efficiency (DEDE) of the Ministry of Energy (MoE) of Thailand, applying two methodologies that were developed by IRENA, namely the Renewable Readiness Assessment (RRA) and REmap analysis.

Renewable Readiness Assessment

IRENA developed the RRA as a tool for carrying out a comprehensive evaluation of the conditions for renewable energy deployment in a particular country. The RRA is a country-led and consultative process. It provides a venue for multi-stakeholder dialogue to identify challenges to renewable energy deployment and to come up with solutions to existing barriers. For Thailand, the RRA methodology was applied to assess the key challenges the country faces in achieving its 2036 target of 30% of total final energy consumption (TFEC) to be provided by renewable resources by 2036, as established in its Alternative Energy Development Plan (AEDP) 2015 (DEDE, 2015).

IRENA and DEDE worked alongside a local consultant to conduct research, set the process in motion and co-ordinate with relevant stakeholders. The first step in the RRA process was to prepare the basic background information, which presents an overview of the geographical, economic and social environment of Thailand. It describes the present status of the energy sector, available renewable energy resources, and the energy policies, programmes and strategies adopted thus far to advance renewables use.

IRENA, supported by DEDE and the local consultant, interviewed key stakeholders (government agencies, grid operators, industrial associations, project developers, financial institutions and academia) to validate these issues and to gather first-hand information and data on what is already happening on the ground. The interview results fed into the analysis of AEDP 2015 with the aim of assessing how feasible it would be to achieve its targets. The qualitative analysis provides a baseline or reference case for the quantitative analysis that was conducted by applying REmap methodology to chart out the alternative pathways of achieving a high share of renewables by 2036.

REmap – Renewable Energy Roadmap analysis

The REmap programme[6] – IRENA's Renewable Energy Roadmaps – paves the way to promoting accelerated renewable energy development through a series of activities, including global, regional and country studies. The global REmap programme includes analysis of 70 countries accounting for 90% of world energy use, while a REmap regional analysis for ASEAN identified the path for the region to achieve its renewable energy target of 23% in the energy mix by 2025.[7]

[5] Renewable energy sources in the report cover all forms of renewables, including large-scale hydropower generation facilities, while in Thailand, alternative energy includes renewables and some forms of non-renewable-derived alternative, albeit renewables are the predominant component.

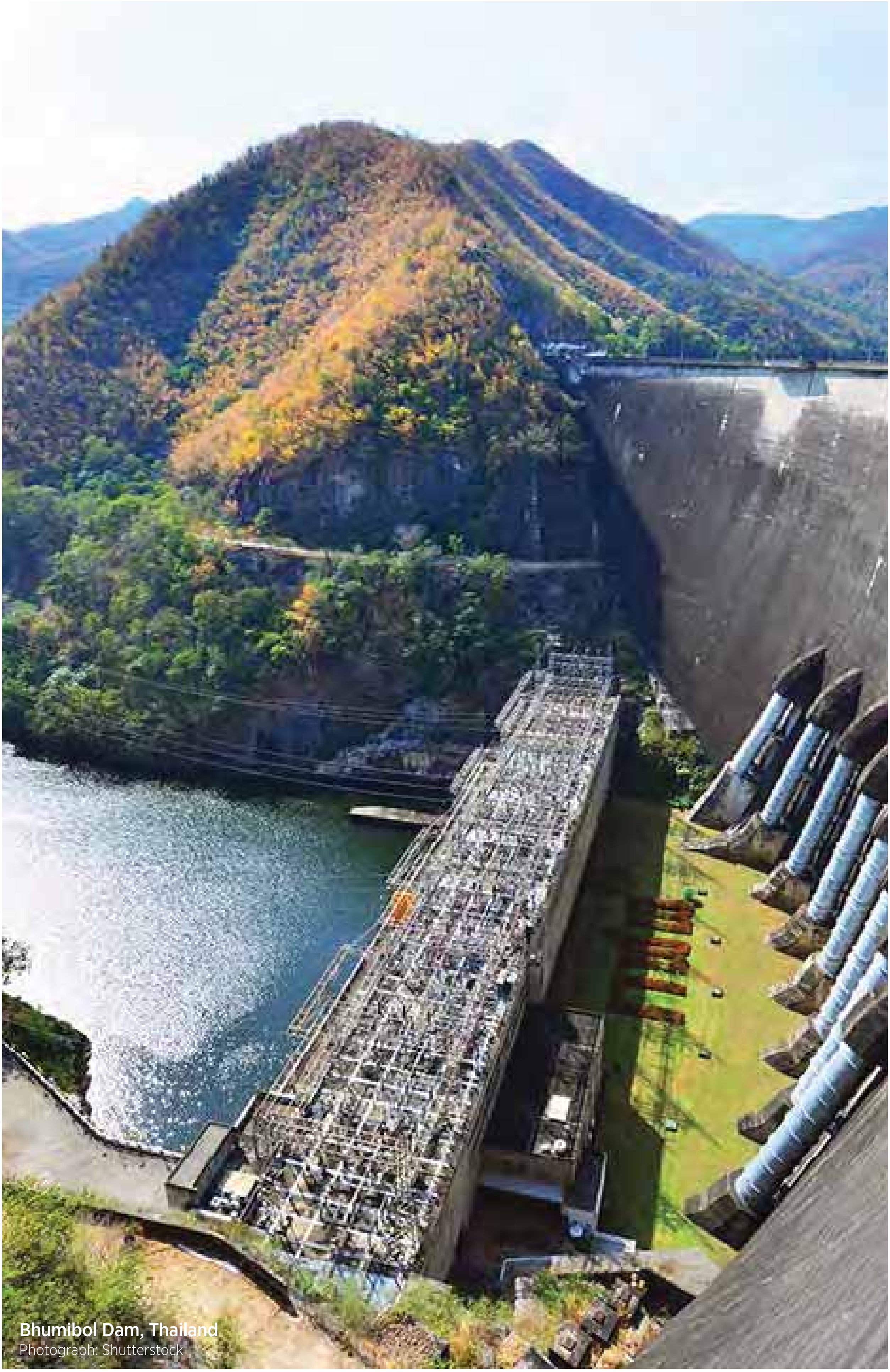
[6] REmap analysis and activity also informs IRENA publications on specific renewable technologies or energy sectors and topics. More related reports can be found at www.irena.org/REmap.

[7] It was published in 2016 under the title of Renewable Energy Outlook for ASEAN. More can be seen at www.irena.org/DocumentDownloads/Publications/IRENA_REmap_ASEAN_2016_report.pdf.

REmap takes a bottom-up approach. The analysis utilises an internally developed REmap tool that incorporates detailed energy demand and supply data by sector, a substitution analysis on technology options for renewables, and an assessment of associated costs, investments and benefits. The analytical process is carried out by IRENA teams in close collaboration with the energy experts in countries through a series of multi-stakeholder consultative workshops and expert meetings.

For the case of Thailand, the analysis presented in this report builds on the initial REmap analysis conducted for the country as part of the regional report for ASEAN. The IRENA team has expanded and deepened the scope of the analysis. The baseline and projection years were also adjusted to the Thailand context, i.e. 2015 and 2036 in relation to Thailand's AEDP 2015. IRENA has engaged Thailand through DEDE over the course of 2016 and 2017 through two multi-stakeholder consultative workshops, several expert group meetings, in-depth interviews and field studies to deepen an understanding of the potential of renewables in the country.

For more information about the methodology and approach for the REmap analysis, please see Annex: REmap Methodology, Assessment Approach and Data Sources.



Bhumibol Dam, Thailand
Photograph: Shutterstock

ENERGY CONTEXT

Wind turbines at Khao Kho, Phetchabun, Thailand
Photograph: Shutterstock

02

Thailand has explicitly set energy security as the top policy objective, followed by economic affordability and environmental sustainability, in the Thailand Integrated Energy Blueprint (TIEB) underpinned by five individual but interrelated energy plans covering natural gas, oil, energy efficiency, the power sector and alternative energy sources, respectively. Such prioritisation was in response to the continuous growth in energy demand while depleting domestic reserves of energy resources in Thailand.

However, with the Paris Agreement entering into force in November 2016, options to enhance energy security require re-evaluation from a climate perspective in order for the Government of Thailand to fulfil its commitment, known as Nationally Determined Contributions (NDC), to reduce carbon emissions from its energy, industrial,[8] agricultural and waste sectors by 20-25% from the business-as-usual scenario by 2030.

This chapter first provides an overview of Thailand's energy system and a brief evolution of the energy balance over the past decade, with a special focus on expenditure on energy importation, and a snapshot of emissions from the energy sector. This is followed by the key legislation shaping the current energy sector, and a map-out of the main institutions in the energy sector with their core mandates. The key energy policies and plans, especially the TIEB, are also discussed in this chapter.

This chapter is intended to present the key elements used to contextualise the discussions and analysis in the other chapters, rather than to provide a comprehensive description of Thailand's energy sector status and evolution, which would deserve a separate study of their own.

8 It is also known as the industrial processes and product use (IPPU) sector.

2.1 Overall energy system

Energy consumption and production

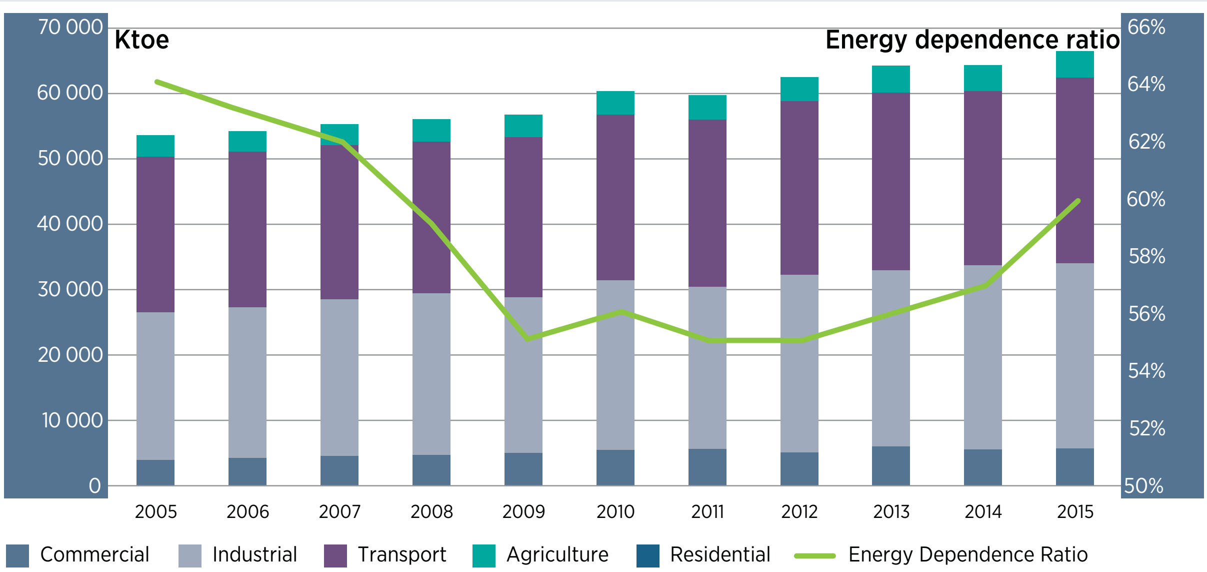
For the past decade, Thailand's total TFEC has been steadily increasing, as illustrated in Figure 2. The industrial and transport sectors consumed largely three-quarters of the total. The secondary axis in the figure shows the energy dependence ratio,[9] with more than one-half of TFEC met by imported energy sources.

Expenditure on energy imports reached a peak of 12% of Thailand's GDP in 2008, attributable to the oil price surge. While it had nearly halved from the peak in 2015, the country's energy dependence ratio,on the other hand, went up in response to the lower oil prices (EPPO, 2016a). This might not be regarded as an alarming signal if it were put into historical perspective. Over the past four decades, Thailand has been relying on imported fuels to meet more than half of its energy demand, having reached a record high of 90% dependence in the 1970s before the discovery and extraction of indigenous oil and natural gas resources.

However, the combination of high dependence ratios and today's intensified energy-commodity price volatility could pose a greater energy security challenge in the future, unless substantial efforts are made to improve energy efficiency and diversify the energy mix while maximising the use of domestic energy resources, especially renewables given the limited oil and natural gas reserves.

9 Defined as imported energy as a percentage of total primary energy consumption.

Figure 2. Thailand's energy consumption by sector, 2005-2015

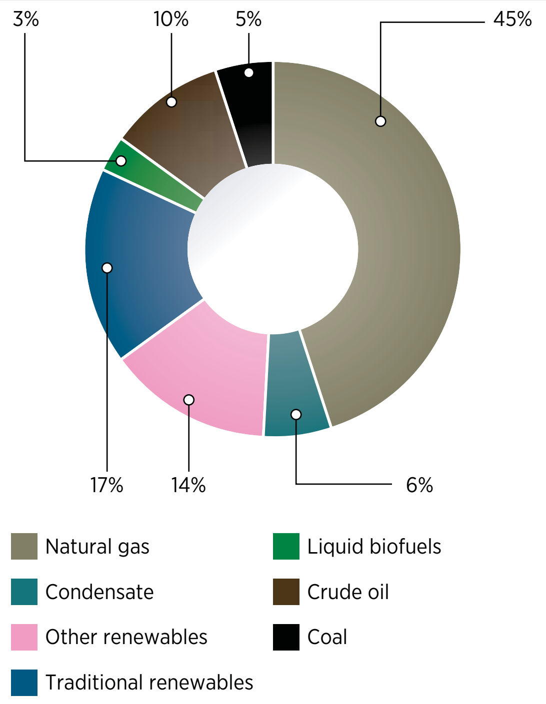


Note: ktoe = thousand tonnes of oil equivalent
Based on data from EPPO and DEDE, Ministry of Energy of Thailand

Thailand has its own fossil energy resources such as crude oil, natural gas and coal, but the oil and gas are not adequate for domestic consumption and are expected to deplete in a decade if current production rates were to remain same as they are.[10] If only the proven reserves are counted, Thailand would have about 4-5 years left for either oil or natural gas, according to data from the MoE, while merely 2.3 years for oil and 5.5 years for gas according to BP. Put it into perspective, the world average for oil or natural gas is about 50 years or so (EPPO, 2016a; BP, 2016).

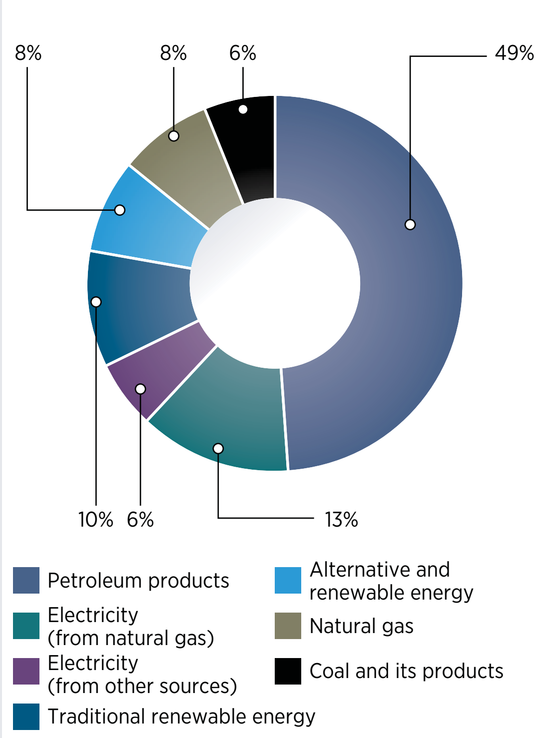
10 This includes proven, probable and possible reserves in Thailand as well as in the Malaysia-Thailand joint development areas.

Figure 3. Thailand's total primary energy production (from indigenous resources), 2015



Source: EPPO, 2016b

Figure 4. Thailand's energy consumption by fuel type, 2015



Source: EPPO, 2016b

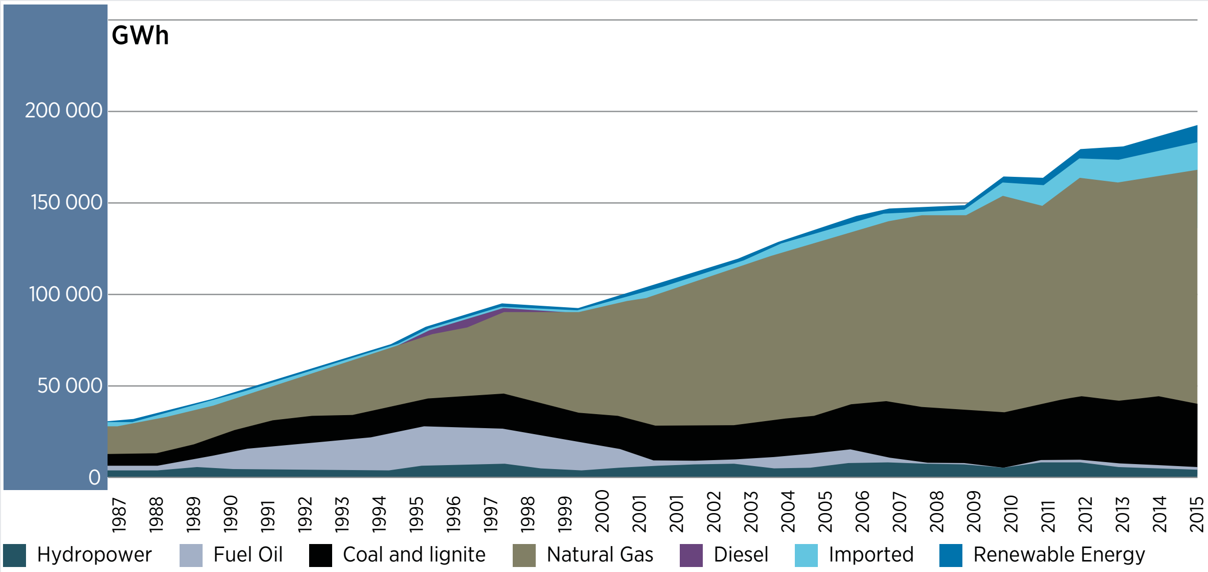
Figure 3 shows that natural gas, condensate and crude oil accounted for 61% of total energy production from indigenous energy resources in 2015. On the consumption side, oil-derived energy products and natural gas accounted for around 70%[11] of Thailand's TFEC, as presented in Figure 4. This means that imported energy or domestic lignite coal consumption would increase if the other forms of energy were scaled up to fill the gap from the depletion of indigenous oil and gas resources. If so, this might lock Thailand into a carbon-intensive energy system in future, unless carbon capture and storage can present a viable technological option, which does not appear as if it will be the case.

[11] Two-thirds of electricity were generated from natural gas.

Electric power system

Thailand has a well-established electric power grid infrastructure providing nearly universal access to electricity, thanks to the two-decade long Thailand Accelerated Rural Electrification programme. Power production has been steadily increasing to meet growing demand, as illustrated in Figure 5. This was, in part, attributable to the abundant supply of domestic natural gas following its exploration and discovery in the 1970s. With the depletion of natural gas reserves, Thailand has stepped up its effort in diversifying the power mix by increasing the share of renewable energy sources, in particular solar photovoltaic (PV) and wind power generation capacity, as discussed in greater detail in Chapter 3.

Figure 5. Thailand's Power Supply, 1987-2015

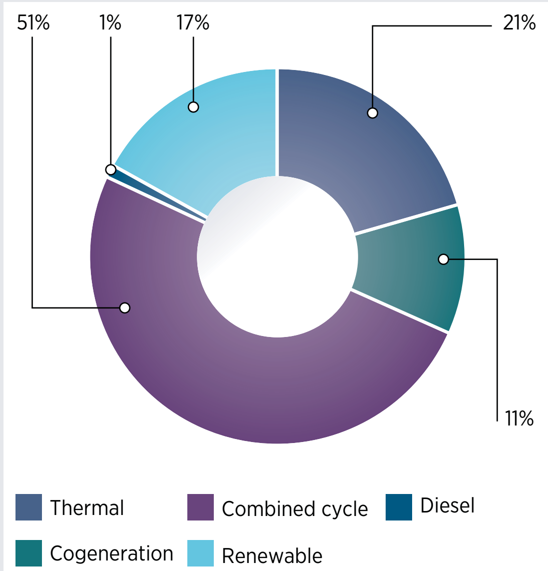


Note: GWh = gigawatt-hour
Based on data from the Electricity Generating Authority of Thailand (EGAT), Provincial Electricity Authority (PEA) and Metropolitan Electricity Authority (MEA), compiled by Energy Policy and Planning Office (EPPO)

Thailand's electrical infrastructure consists of three systems, which are a) the generating system, including EGAT, independent power producers (IPPs), small power producers (SPPs)[12] and very small power producers (VSPPs),[13] b) the transmission system (EGAT), and c) the distribution system (PEA and MEA). In addition, the annual power exchange with and purchase from neighbouring countries through interconnected grids contribute about 7% of the total electricity consumption (IEA, 2016).

As of September 2016, the electricity generating capacity of Thailand's system reached nearly 42 gigawatts (GW),[14] of which, by technology, combined-cycle and condensation thermal power plants counted for about 70% of the total, while renewables accounted for 17%, as illustrated in Figure 6. As regards the ownership of generation assets, EGAT owns and controls the largest share of the nation's total, while the other half is owned by IPPs, SPPs and VSPPs.

Figure 6. Thailand's power generation capacity by technology, 2017



Based on data from EGAT

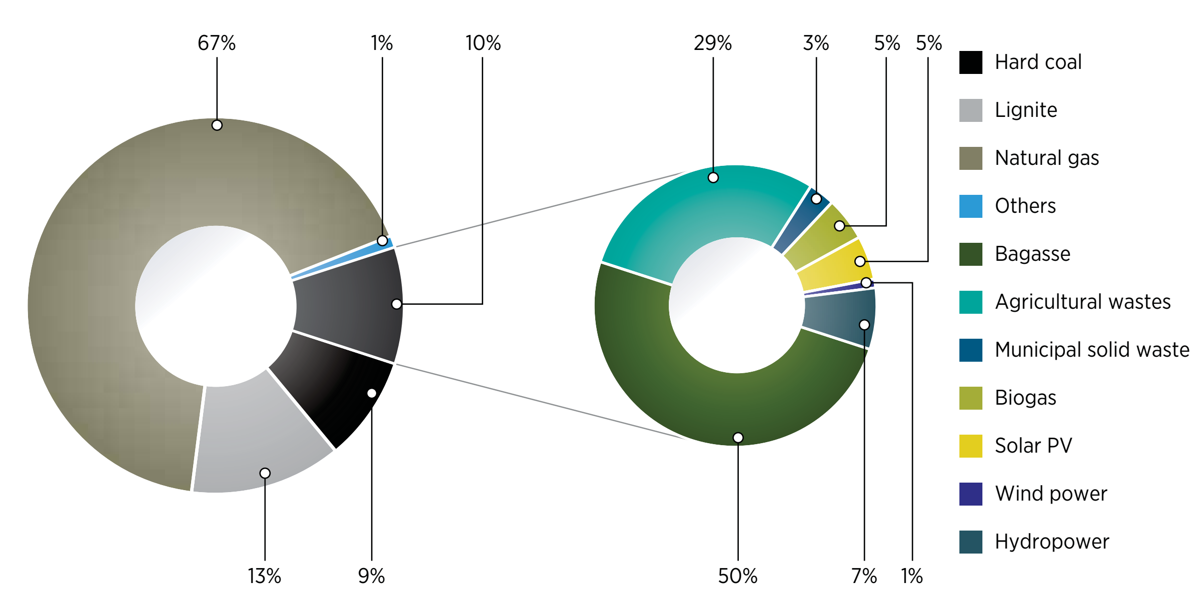
As to the electricity generated, Figure 7 below shows that natural gas and hard coal and lignite accounted for nearly 90%, while renewable electricity contributed only 10% of the total. It is evident that fossil fuels, particularly natural gas, followed by hard coal and lignite, still remain the dominant fuel for power generation, while biomass-based energy sources account for the major share within the renewable energy generation portfolio.

[12] Generation capacity of 10-90 megawatts (MW).

[13] Generation capacity no greater than 10 MW.

[14] Including the installed generation capacity of Thailand and those that are accessible through power purchase contracts with neighbouring countries.

Figure 7. Thailand's electricity generation by fuel, 2016



Based on data from EGAT

Aside from domestic generation, Thailand signed a memorandum of understanding (MoU) on the purchase of electricity from Lao PDR in September 2016. The agreement allows for the purchase of up to 9 000 MW, including 1 878 MW from lignite and the rest from hydropower. Hydropower from the Lao PDR is insignificantly affected by seasonal variations in hydrological circulation due mainly to the large capacity of its reservoirs and high surface water run-off. In addition, Thailand has also been increasing its electricity imports from other countries, such as Myanmar and Malaysia. Electricity imports from neighbouring countries would be expected to increase over the next two decades, but will be capped at 15% due to security concerns.

With regard to power transmission and distribution, EGAT owns and manages the transmission system, thus acting as the transmission grid operator, while PEA and MEA are responsible for the operation of distribution networks, taking the role of distribution grid operator, although they also own certain transmission lines with a voltage level of 69 kilovolts (kV) and 115 kV.

For the transmission networks managed by EGAT, the standard voltage levels are 500 kV, 300 kV, 230 kV, 132 kV, 115 kV and 69 kV at the operating frequency of 50 hertz. The total length of transmission lines as of March 2017 was 33 430 circuit-kilometres connected by more than 200 substations with the total transformer capacity of 100 829 mega-volt amperes (MVA).

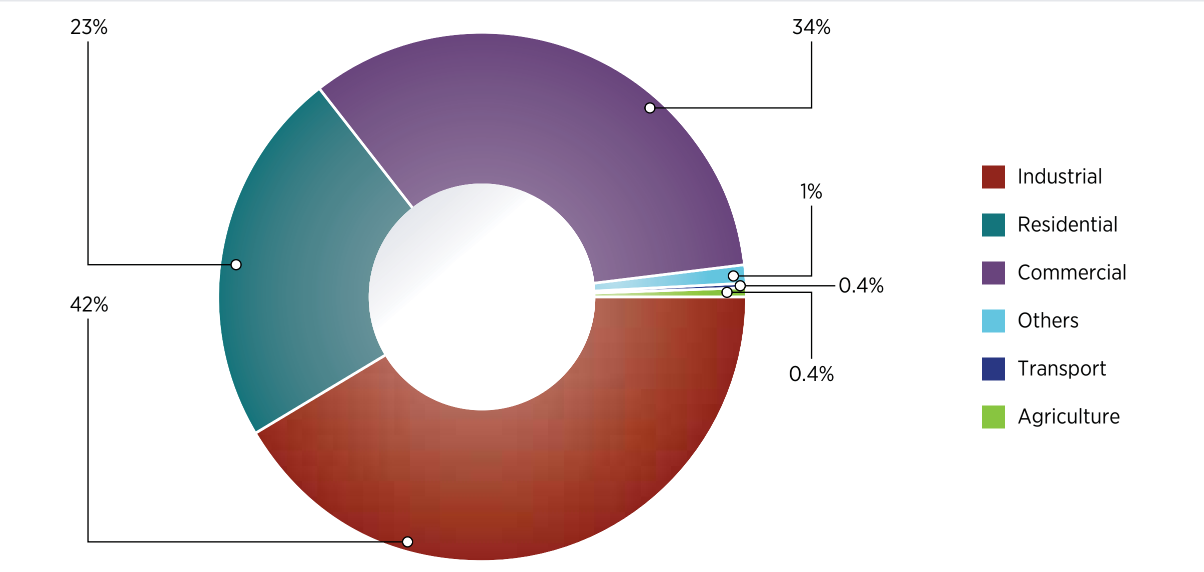
For the distribution networks within MEA, the standard voltage levels are 230 kV, 115 kV and 69 kV transmission lines. The total length of transmission lines as of December 2015 was 1 742 circuit-kilometres. The distribution system also contains 24 kV and 12 kV feeders of 18 434 circuit-kilometres, and 220/380 volt secondary lines of 28 307 circuit-kilometres. There were 132 substations with the transformers totalling 17 905 MVA of installed capacity (MEA, 2015).

PEA, responsible for electricity supply covering 99.4% of the country's area, has standard voltage levels of 115 kV, 69 kV, 22-33 kV and less than 22-33 kV distribution lines. It owned 11 776 circuit-kilometres of the total transmission line in 2015 (PEA, 2015).

In addition to its role as grid operator, EGAT also operates its own electricity generation facilities, and purchases electricity from domestic IPPs, SPPs and neighbouring countries, while only VSPPs can sell electricity directly to PEA and MEA. In VSPPs' case, MEA has already connected 54 projects with a purchasing capacity of 67 MW while PEA has connected 839 projects with 3,498 MW (ERC, 2016).

For electricity consumption by economic sector, the industrial sector (76 914 GWh or 42.4%), the commercial sector (61 446 GWh or 33.9%) and the residential sector (41 443 GWh or 22.8%) are the key consumers, as shown in Figure 8.

Figure 8. Electricity consumption by economic sector, 2015



Source: EPPO, 2016b

2.2 Key energy legislation and institutions

Key energy legislation

In 1992, three important pieces of energy legislation were enacted, namely, the National Energy Policy Council Act, B.E. 2535 (1992), amended by the National Energy Policy Council Act (No. 2), B.E. 2550 (2007) and the National Energy Policy Council Act (No. 3), B.E. 2551 (2008), the Energy Development and Promotion Act, B.E. 2535 (1992), and the Energy Conservation Promotion Act, B.E. 2535 (1992), amended by the Energy Conservation Promotion Act (No. 2), B.E. 2550 (2007). These acts, as amended and alongside the Energy Industry Act, B.E. 2550 (2007), have largely defined today's legislative framework for Thailand's energy sector, providing the legal foundation for national energy sector management, development of energy production, transport and distribution, and also energy efficiency improvements.

The key elements of the above-mentioned legislation are described in Table 1.

Table 1. Key elements of important energy legislation

Legislation	Key elements
National Energy Policy Council Act, B.E. 2535 (1992), amended by the National Energy Policy Council Act (No. 2), B.E. 2550 (2007) and the National Energy Policy Council Act (No. 3), B.E. 2551 (2008)	• Determined the mandates, powers, duties and operational mechanism, and institutional structure of, and under, the National Energy Policy Council – the highest governmental entity in oversight of energy sector management reporting to the Cabinet in Thailand. • Defined the scope of energy, renewable energy, non-renewable energy, and fuel, to be used as reference in, for instance, the Energy Industry Act, B.E. 2550 (2007).
Energy Development and Promotion Act, B.E. 2535 (1992)	• Replaced the National Energy Act B.E. 2496 (1953), as amended, while specified the implications for the enforcement of other decrees, regulators or orders issued under the previous act. • Changed the title of "National Energy Administration" to the "Department of Energy Development and Promotion" of the then Ministry of Science, Technology and Energy (the present Ministry of Science and Technology). • Defined in detail the department's authorities, duties and operational mechanism and principles that should be followed.
Energy Conservation Promotion Act, B.E. 2535 (1992), amended by the Energy Conservation Promotion Act (No. 2), B.E. 2550 (2007)	• Focused on key energy end-use sectors, including industrial and buildings sectors, with respect to energy conservation and efficiency improvement. • Referred to as guidance for policy, strategy and programme development as far as energy conservation is concerned, with the aim of promoting application of high-efficiency measures in end-use sectors. • Defined the authorities and duties of relevant governmental entities, and determined (institutionally and financially) the supportive schemes and programmes for promoting and supporting energy efficiency improvements in end-use sectors. • Defined the penalties for non- and under-compliance with the act, or fraudulent behaviours.
Energy Industry Act, B.E. 2550 (2007)	• Established a new regulatory framework, with independent performance of energy policy making, regulation, formulation and implementation, for the electric power and natural gas sectors. • The key objectives were to encourage engagement of the private sector and the general public through active participation and increased competition, promote the efficient and environmentally responsible use of energy resources, and also promote the use of renewable energy sources. • Established the Energy Regulatory Commission and defined its authorities and duties and the specifics of certain operations, such as setting tariffs, energy network system supervision and power development funding. • Provided comprehensive guidance for energy industry policy making and defined the powers of the Minister.

Based on:
EPPO (1997), Energy Management,
www.eppo.go.th/images/policy/PDF/docs/p01_EnergySectorManagement.pdf;
Thailand Law Forum (2016), National Energy Policy Council Act, B.E.2535 (1992),
www.thailawforum.com/database1/national-energy-act.html;
and the Energy Development and Promotion Act, B.E. 2535 (1992),
www.thailawforum.com/laws/The%20Energy%20Development%20and%20Promotion%20Act.pdf.

As presented in Table 1, the acts provide the legal foundation for establishing the main energy institutions administering the energy sector in Thailand, including the National Energy Policy Council, the MoE, the Energy Regulatory Commission, EPPO, and DEDE (the former Department of Energy Development and Promotion). In addition, they also provide the legislative basis for energy policies, regulations and development plans.

Main institutions in the energy sector

The **National Energy Policy Council (NEPC)**, chaired by the Prime Minister with the support of the Deputy Prime Minister designated by the Prime Minister as Vice-Chairman, is the ultimate authoritative body for the review and approval of proposals pertaining to national energy policy and regulation, energy sector management and development plans and strategies, with the objective of enhancing energy security and reducing dependency on imported energy while ensuring the affordability and sustainability of energy commodities.

In addition to the Chairs, the council also has among its membership: 11 cabinet ministers who are highly relevant to energy sector policy and management;[15] one minister attached to the Office of the Prime Minister; the Secretary-General of the Council of State, indicating strong engagement from the top management of the administration;[16] the Secretary-General of the National Economic and Social Development Board; the Director of the Bureau of the Budget due to the close ties between energy and the country's economic and budgetary activities; the Permanent Secretary of Energy; and the Director-General of the Energy Policy and Planning Office. Each member has one vote in the decision-making process and a decision is made by a majority of votes.

Benefiting from the high-level involvement of important cabinet ministries, the NEPC serves de facto as an inter-ministerial co-ordination mechanism for policy making as well as implementation. In the face of rising interaction of energy with other sectors on a range of issues – energy security, climate challenges, regional and local environments, rural development, job creation and the adoption of information and communication technologies for future grid infrastructure development – having a high-level effective co-ordination mechanism has become increasingly important for making important decisions on energy policy. These include determining the price of energy products and ensuring effective policy implementation, such as the TIEB, which contains five individual but interrelated plans.

At the operational level, EPPO as part of the MoE provides technical support to the NEPC, in addition to any other committees or sub-committees that may be established if requested in addition to the NEPC.

The **Ministry of Energy (MoE)** is the governmental authority responsible for oversight of the overall operation of the energy sector, including fossil fuels, electric power and rural energy supply, and also including managing the Thailand Oil Fund. It was also given a mandate to propose energy policies and regulations, formulate energy plans and strategies and supervise their implementation. The MoE is supported by its four operational departments covering energy policy and planning, managing mineral fuels, supervising energy business operations, and promoting alternative and energy efficiency, respectively.

The **Energy Policy and Planning Office (EPPO)** acts as an operational body of the NEPC and is responsible for formulating proposals on national energy policy and strategies addressing the existing and emerging challenges in energy management, energy conservation, promotion of alternative energy sources and oil supply. It oversees the implementation of various policies and plans upon entry into force.

It was behind the consolidation of the five individual energy plans into one master plan with the same timeframe, i.e. the TIEB 2015-36. The harmonisation was indeed a positive move towards the common goals that Thailand has been striving to achieve.[17] Yet, how to implement the plan in an orchestrated manner remains a challenge.

15 The Minister of Defence, the Minister of Finance, the Minister of Foreign Affairs, the Minister of Agriculture and Cooperatives, the Minister of Transport, the Minister of Natural Resources and Environment, the Minister of Energy, the Minister of Commerce, the Minister of Interior, the Minister of Science and Technology, the Minister of Industry.

16 A high-level advisory body for the Prime Minister on legal and administrative matters.

17 Energy security, economic affordability and ecological sustainability.

The **Department of Alternative Energy Development and Efficiency (DEDE)** has an increasingly significant role to play in the context of the growing concerns over security of energy supply and the climate targets set in the Paris Agreement, and the falling costs of some renewable energy technologies over the past five years, such as solar PV modules and inverters, and on-shore wind power systems. In addition to renewables, DEDE also promotes energy efficiency measures as an instrument to reduce or minimise the growth in energy demand. The Permanent Energy Secretary oversees the operation of this department, while the Director-General is the commanding officer for, and thus responsible for the performance of, the department.

It is worth pointing out that DEDE covers the domain of all alternatives to conventional energy sources in view of seeking optimal or plausible solutions for the long-term energy security for Thailand. Therefore it covers more than just renewables in the notion defined as "alternative". Having that said, while the meaning of "renewable energy" is clearly defined in both the National Energy Policy Council Act (1992)[18] and the Energy Development and Promotion Act (1992), there is no such definition for "alternative" energy in any of the legislation.

The Electricity Generating Authority of Thailand (EGAT) is a state-owned enterprise managed by the Ministry of Energy that is responsible for electricity generation, including those from IPPs and SPPs, as well as the transmission network and bulk electricity sales in Thailand. Being the largest power producer in Thailand with its own operating power plants at 45 sites across the country, EGAT could generate electricity at the total installed capacity of 16 GW by June 2017, or 42% of Thailand's total generation capacity. With regard to electricity system implementation, the Energy Regulatory Commission regulates power purchases and sets policy on power sector procurement.

EGAT, as the sole owner of the transmission system, manages 500 kV, 230kV and 115 kV lines, including the 300 kV high-voltage direct current (HVDC) link in the south with Malaysia.

The **Metropolitan Electricity Authority (MEA)** engages in the distribution of electricity in Thailand. Being a state-owned enterprise under Ministry of Interior, MEA is responsible for the high-voltage distribution network within its service territory of Bangkok, Nonthaburi and Samut Prakarn Provinces, supplying two-thirds of Thailand's electricity demand to its customers. MEA is also involved in the design, installation and maintenance of high-voltage and low-voltage electrical systems. MEA owns no power plants, purchasing electricity from EGAT or directly from VSPPs.

MEA also works in other sectors, including, for example, centralised air-conditioning systems, the manufacture and distribution of electrical products and operating fibre-optic telecommunication network and data centres.

The **Provincial Electricity Authority (PEA)** is a state-owned enterprise under the Ministry of Interior and is responsible for providing 74 provinces with the generation, procurement, distribution and sale of electricity. The 510 000 kilometre square area, or 99.4% of the country, excludes Bangkok, Nonthaburi and Samut Prakarn Provinces, which are managed by EGAT. PEA does not own or control any voltage lines greater than 115 kV within its service territory.

The **Energy Regulatory Commission (ERC)**, established on the foundation of the Energy Industry Act (2007), was designed to function as an independent regulatory agency overseeing energy sector operations in both the power and natural gas sectors. One of its main tasks is to make sure tariffs are calculated in an appropriate and transparent manner and the procurement process is followed, ensure fair competition in the energy marketplaces and thus ultimately protect the interests of energy consumers. Through its 13 regional offices covering the entire country, ERC works directly with energy consumers, licensees and various stakeholders. ERC's budget and work plan are reviewed by the MoE, which also nominates the chairmanship of ERC. This interaction could in some way risk jeopardising ERC's independence.

[18] "Renewable energy" defined in the act includes "energy obtained from wood, firewood, paddy husk, bagasse, biomass, hydropower, solar power, geothermal power, wind power, and waves and tides". This is as opposed to "non-renewable energy" defined in the same acts as "energy obtained from coal, oil shale, tar sands, crude oil, oil, natural gas and nuclear power".

The **Petroleum Authority of Thailand (PTT)**, as the largest energy company in Thailand, is responsible for the supply of petroleum and natural gas. PTT seeks to secure the long-term supply of natural gas on the global markets. Pipelines and liquefied natural gas terminals are part of PTT's infrastructural development in this regard.

2.3 Energy policy and plan

With greater volatility of energy commodity prices, the rising concern over energy security and the increasingly compelling cases made for renewables, the dynamics shaping the energy policy landscape have rapidly evolved in Thailand. The primary objectives of national energy policies are centred on enhancing the country's energy security by diversifying the energy mix and strengthening the supply of depleting fossil fuels, while keeping energy prices at affordable rates and minimising the adverse impacts of energy production and consumption on the environment and society.

Overall, Thailand's policy objectives for energy sector development have remained consistent, with a central focus on enhancing the security of energy supply in recognition of its critical importance to national economic and social development.

National Energy Policy 2008

National Energy Policy 2008 was released in the context of the world being in the middle of oil price volatility. It therefore placed even greater stress on the importance of energy security and put forth a series of targets and actions to reduce the country's dependence on imported fuels by increasing the domestic supply of energy sources, and secure long-term supply from international energy commodity markets, as well as improve energy efficiency. The energy policy, along with the Renewable Energy Development Plan (REDP) (2008-22),[19] aimed to increase energy security and the use of alternative energy sources, encourage high-efficiency energy technologies, and scale up green alternatives among communities.

Thailand Integrated Energy Blueprint

In 2015, the five major energy plans were harmonised into one integrated energy document known as the Thailand Integrated Energy Blueprint (TIEB) 2015-36. At present, the TIEB serves de facto as the national energy policy and energy sector development plan combined. This is because the official National Energy Policy 2008 has yet to be updated or replaced by a new policy document that may be developed in future.[20] The long-term perspective and system approach taken in the TIEB could potentially change the way that energy policy is implemented in Thailand. It could yield the desired results, provided that an effective mechanism for inter-ministerial co-ordination and an implementation monitoring system are put in place.

The TIEB consists of the Power Development Plan (PDP), the Energy Efficiency Plan (EEP), the Alternative Energy Development Plan (AEDP), the Oil Plan, and the Gas Plan. The assumption on the annual average GDP growth rate over 2015-36 was 3.94%, as estimated in the National Economic and Social Development Plan, being slightly adjusted downward from the previously estimated 4.41% in the 2010-30 Power Development Plan.

Table 2 below highlights the key targets set under each plan, with a breakdown for the power sector, heating, and transport.

[19] It was updated twice before the present version, which is known as AEDP 2015 (2015-36).

[20] According to the interview with EPPO, a new version of the National Energy Policy will be established in the short term – two to three years as a roughly estimated timeframe.

Table 2. Key targets in energy plans, 2015-2036

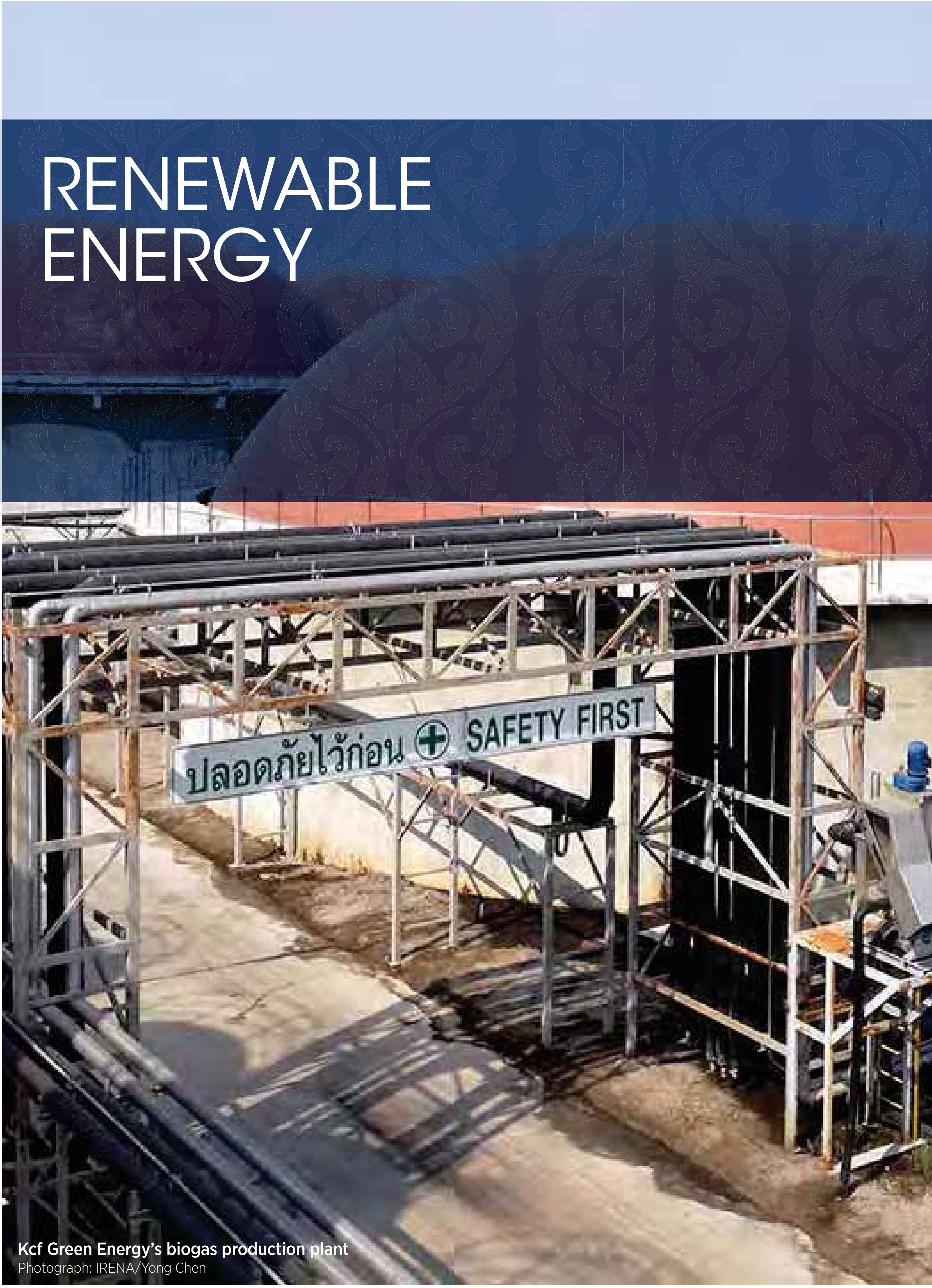
Energy plans	Overall target	Sector breakdown		
		Power sector	Heating	Transport
EEP	Energy intensity reduction of 30% by 2036 from the 2010 level	Expected saving of 90 865 GWh/7 813 ktoe accounting for 15% of the total savings	Expected saving of 13 673 ktoe, accounting for 26% of the total savings	Expected saving of 30 213 ktoe, accounting for 58% of the total savings
PDP	Fuel/generation capacity mix (2015-36): • Gas: 64% - 37% • Coal: 20% - 23% • Nuclear: 0% - 5% (2035) • Imported hydropower: 7% - 15% • Renewable energy: 8% - 20%		• Heat from co-generation with efficiency not lower than 45% should account for 10%	
AEDP	• Renewables (final energy consumption): 39 389 ktoe, or 30% of TFEC in 2036, i.e. 131 000 ktoe	• 19 684 MW (installed capacity): • Solar PV: 6 000 MW • Wind: 3 002 MW • Large hydro: 2 906 MW • Small hydro: 376 MW • Biomass: 5 570 MW • Biogas: 600 MW • WTE: 550 MW • Energy crops: 680 MW	• 25 088 ktoe (final energy consumption): • MSW: 495 ktoe • Biomass: 22 100 ktoe • Biogas: 1 283 ktoe • Solar heating: 1 200 ktoe • Others*: 10 ktoe	• Bioethanol: 11.3 million litres/day • Biodiesel: 14 million litres/day • Pyrolysis: 0.53 million litres/day • Compressed biogas: 4 800 tonnes/day • Others**: 10 ktoe

Notes: MSW = municipal solid waste; WTE = waste to energy.

* = such as geothermal, used tyres.
** = such as bio-oil, hydrogen.

Sources:
DEDE (2015), Alternative Energy Development Plan 2015; EPPO (2015), Thailand Power Development Plan 2015-2036; Pichalai (2015), "Thailand Energy Efficiency Development Plan (2015-2036)", presentation made at the Renewable Energy Asia Seminar held on 4 June 2015, www.renewableenergy-asia.com/Portals/0/seminar/Presentation/03-Overview%20of%20Energy%20Efficiency%20Development%20Plan%20(EEDP%202015).pdf.

RENEWABLE ENERGY



Kcf Green Energy's biogas production plant
Photograph: IRENA/Yong Chen

03

This chapter describes Thailand's key achievements on renewable energy development over the past decades, with the success factors and the important lessons learnt, and the status of development of the renewable energy sector with a breakdown into the power sector, renewable energy for heating, and biofuels.

3.1 Overview of renewable energy development in Thailand

Thailand has long been promoting and supporting energy development, especially in the field of alternative energy[21] and energy conservation, driven primarily by the pursuit of enhanced energy security, stabilised economic prosperity and improved well-being. With the steadily increased use of alternative energy sources and improved energy efficiency, imports of fossil fuels would be expected to decline, and so would the long-term risks of energy expenditure on energy importation. In addition, indigenous clean energy development could bring multiple co-benefits such as environmental, social and economic advantages, including job creation, in comparison to imported fossil fuels.

Toward this end, indigenous renewable energy resources, including solar, wind, various biomass-based energy sources and hydropower, have been given priority with clear and ambitious targets and supportive policy schemes in place.

By 2015 Thailand had developed a decent share of renewables in primary energy production and more so when traditional biomass for cooking is included, as shown in Figure 3. In 2015 alone, modern renewable energy increased by 11.7% on a year-on-year basis – as much as four times the annual growth rate of the total primary energy supply. Of the total amount of renewable energy consumption in 2015 (10 306 ktoe), about 64% was used for heating, 16% for electricity generation, and nearly 20% for biofuel production.

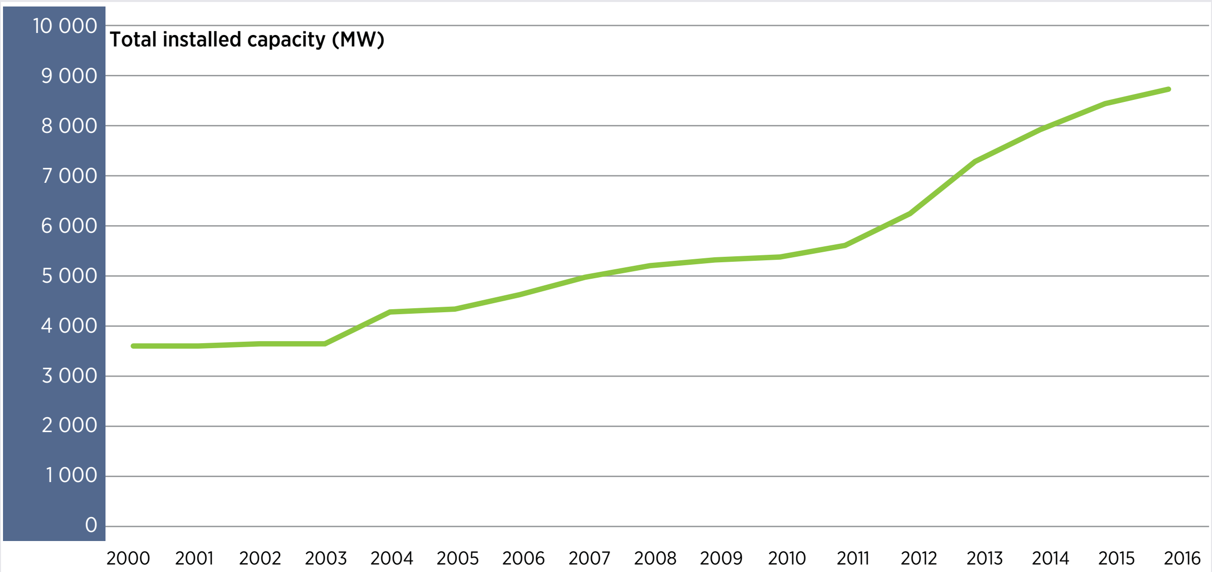
[21] The scope covers renewable energy sources and industrial waste under the category of WTE.

As far as the power sector is concerned, installed renewable energy generating capacity has doubled over the past decade and seen a steeper ramp-up since 2012, as illustrated in Figure 9. Among the power mix, hydropower and bioenergy account for the lion's share, while the share of solar PV and wind power has quickly caught up, attributed largely to the generous adder rates and favourable feed-in-tariffs (FITs) for these two technologies (details in section 3.2).

However, large-scale hydropower in Thailand reached almost 3 GW in 2000, which leaves little room for further development in view of its potential environmental impacts, while small hydropower has been on the rise but at a modest rate. Bioenergy has scaled up by a factor five over the same period.

As regards solar PV, although the first solar PV farm, with a capacity of 504 kilowatts (kW), was installed by EGAT in 1996, the real take-off began in 2007 when favourable policy and regulatory schemes were put in place. Thailand started to exploit its wind energy as early as 1983 with several small wind turbines ranging from 1 kW to 150 kW in Phuket Island in southern Thailand, but the country has scaled up deployment at a modest growth rate due to the relatively low wind speed, especially in the areas close to load centres or transmission grids. Thailand has very modest geothermal potential in northern Thailand. In 1989, the first geothermal power generation facility with a capacity of only 300 kW was built in the Fang District. However, the development of geothermal has since then been stagnant due to very little resource availability.

Figure 9. Thailand's total renewable electricity generating capacity, 2000-2016



Note: MW = megawatt.
Source: Based on IRENA's statistics database, at http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=16.

For non-power sectors, applications of renewable energy are concentrated in heating and transport. Heating applications of renewable energy are mostly adopted in industry and the buildings sector. In the buildings sector, the use of solid biomass for cooking (referred to as traditional biomass) represents a significant share of renewable energy use in Thailand. Since Thailand is abundant in agricultural products, biomass has been the traditional energy source in Thai rural areas, using agricultural residues as a major source of domestic fuel. Households in rural areas use biomass for cooking and heating purposes. An estimated 30% of the population (or 4 million households) still rely primarily on traditional bioenergy for cooking and heating. This practice is often associated with negative impacts on the quality of life of dwellers due to indoor air pollution and the time wasted gathering fuel.

In the industrial sector, many small- and large-scale industries rely on biomass as their primary energy resource. Many small-scale plants focusing on agro-processing and food processing use biomass fuel for their process heat. Larger-scale plants producing sugarcane, cassava and palm oil use biomass (both solid biofuels as well as biogas) in co-generation plants to produce heat and electricity mostly for their own consumption. Future expansion of heat applications using biomass in industry will come mainly from on-site co-generation plants. In 2015, biomass was used to provide 5 990 ktoe of heat for industry – an increase of 15.5% over the previous year – accounting for almost 60% of the renewable energy used in the country.

On transport fuels, Thailand has a strong motivation to replace petroleum-derived fuels with alternatives, given its high dependency on road transport as well as on the importation of gasoline and diesel for transport. Although the share of energy used for transport in TFEC remained in the region of 36% over 2005-15, the absolute amount of energy increased by 20% over the same period, reaching 28 501 ktoe in 2015, due to the growth in the number of vehicles and motorcycles. This increase in consumption also corresponded to the rising energy dependency ratio, as illustrated in Figure 2, indicating the dominance of petroleum-derived transport fuels, accounting for more than two-thirds of the total energy consumption in the transport sector. Taking all liquid fuels into account, about 92% are consumed by the entire transport sector, 69% by road transport alone. Biofuel blending, namely gasohol and blended biodiesel, is now a common practice in Thailand after a decade of development. In 2015, the volumetric share of liquid transport fuel consumption that was met with biofuels stood at around 11% in the case of gasoline and 6% in the case of diesel. The overall volumetric share was close to 8%.

Gasohol covers E10 RON 91, E10 RON 95, E20 RON 95, and E85, among which E10 accounts for 80% while E85 for only 3.5%.[22] For biodiesel blending, the maximum ratio was frozen at B7 in 2016, due largely to the supply constraints experienced in 2016, and to some extent the automobile industry was somewhat concerned about the risk that a continued increase in the blending ratio to B10 might challenge compliance with exhaust gas emission standards if set at any level above Euro 4 level.

3.2 Support programmes for renewable energy development

The Government of Thailand has long recognised the importance of alternative, especially renewable, energy sources, but also realised that there was a need to introduce programmes in support of renewable energy development and deployment.

With that, a variety of support programmes have been put in place to promote renewable energy development, ranging from tax exemptions, a feed-in premium (FIP)/adder programme and FITs to competitive bidding, to address the various challenges that renewable energy projects face in the early stage of development.

The Thailand Board of Investment (BoI) is an institution established half a century ago with a mandate to promote investment, and was known as the Board of Industrial Investment until 1972. Since 2004 it has provided alternative energy projects with support, mostly in the form of tax exemptions. Examples include the following:

- Projects using waste, including refuse-derived fuel, to produce electricity or steam are eligible for eight-year corporate income tax exemption without an exemption cap, as well as exemption from import duty on machinery, and other non-tax incentives.
- Other renewable energy projects that have an eight-year corporate income tax holiday, import duty exemption on machinery and non-tax incentives, include the manufacture of solar cells and/or raw materials for solar cells, as well as power produced from renewable energy sources, *e.g.* solar energy, wind energy, biomass or biogas.
- Projects that target biofuel production from agricultural products and by-products, for example biomass to liquid (BTL) or biogas from wastewater, are given an eight-year corporate income tax holiday, import duty exemption on machinery and raw or essential materials used in manufacturing export products, as well as other non-tax incentives.
- Projects aimed at biomass briquettes and pellets are exempt for five years from corporate income tax and import duty on machinery and other non-tax incentives.

[22] As per the statistical data for 2015 from DEDE.

By June 2015, the BoI had approved 845 renewable energy projects, while an additional 93 projects were approved in 2016, as shown in Table 3. The privileges granted to renewables investment demonstrate the degree of the government's support for the sector.

Table 3. Renewable energy projects supported by the BoI

Energy plans	Approved by 2015		Approved in 2016	
	No. of power plants	Capacity (MW)	No. of power plants	Capacity (MW)
Waste (MSW and non-hazardous industrial waste)	18	228	4	165
Biomass	196	2 793	8	125
Biogas	196	585	8	18
Solar farm	239	1 422	62	256
Solar rooftop	153	83	9	76
Wind	36	1 916	1	10
Waste heat	7	172	1	12
Total	**845**	**7 199**	**93**	**661**

Source: Thailand Board of Investment, 2016

The FIP, known as the Adder Programme in Thailand, was approved by Cabinet in 2006 and put into effect in 2007. Under the Adder Programme, the premium rates added on top of wholesale electricity prices vary according to the technology and scale of installed capacity that SPPs or VSPPs adopt in their projects.

The programme was designed for 10 years for solar PV and wind, and 7 years for biomass, biogas, MSW and mini/micro hydropower, starting from the COD with provision of an internal rate of return of 10-12% for the project developers/investors. It jump-started the deployment of solar PV and wind power systems in Thailand from the outset.

However, after three years of operation several disadvantages of the Adder Programme were identified, as listed below, which effectively triggered the policy change from the adder to FITs in Thailand. One of the key issues was the uncertainty associated with the computation of tariffs paid to the SPPs/VSPPs. Given that basic power tariffs and automatic tariff adjustment[23] vary with global energy commodity prices, the Adder Programme, building on such variables, causes some level of uncertainty in the long-term tariffs paid to investors/developers as well as the end users; in addition, it does not accurately reflect the levelised cost of energy (LCOE). Supported by this argument, the policy was shifted from the adder to the fixed FIT in 2013 to enhance investors' confidence. However, because of the interruption in implementing the adder over 2010-13, concerns over policy consistency arose among the investors.

Following the FIT scheme, and with drastic cost reductions for solar PV and onshore wind installations, the government has introduced a competitive bidding scheme with the FIT set as the ceiling price. This is aimed at allowing the market to determine the real prices at which renewable electricity should be paid. This would help the government minimise the risks of over-subsidising renewable energy projects. Thailand started testing the scheme with several pilot bioenergy projects in the southern regions in 2016-17, as a stepping stone towards nationwide adoption. The COD is expected to be reached in 2018, following postponement from the original estimate of 2017.

[23] Known as Ft in the calculation formula used in Thailand.

3.3 AEDP 2015: Observations and discussions[24]

Over the eight-year period from 2007 to 2015, Thailand revised its renewable energy targets four times. The most recent revision, which was made in 2015, has set a target of 39 388 ktoe, representing 30% of TFEC in 2036,[25] with a breakdown shown in Table 4 below. It has raised the level of ambition compared with the previous targets, driven by the government's strategic decision to replace imported primary and secondary energy sources, i.e. natural gas and electricity respectively, with indigenous energy sources – to a large degree from renewables.[26]

More profoundly, the extension of the planning timeframe from 10 to 20 years was an important revision as it provides investors and developers with a stable and consistent policy framework, allowing them to have a longer-term business plan.

As shown in Table 4, the 2036 renewable energy target (30%) is distributed among: a) renewable electricity, which is expected to contribute 4.2% (5 588 ktoe), meeting approximately 20% of total electricity demand in 2036; b) renewables for thermal use, which are expected to account for 19% (25 088 ktoe); and c) biofuels representing the remaining 6.7% (8 712.43 ktoe). In terms of installed power generating capacity, solar PV is expected to meet 31% of the total with 15% from wind, and the remainder from biomass-based sources and hydropower stations.

Figure 10 below shows the changes in the share of renewables respectively for power generation, thermal use/heating and transport in TFEC in 2015, 2021 and 2036,[27] based on the current data and estimations of DEDE. It indicates that renewables for thermal use would largely remain the same and consistently account for the lion's share over the timeframe of AEDP 2015. Currently, electric vehicles play a very minor role in Thailand while transport biofuels are regarded as the prominent alternative to fossil-derived transport fuels. However, this might alter in future if the use of electric vehicles could gradually scale up.

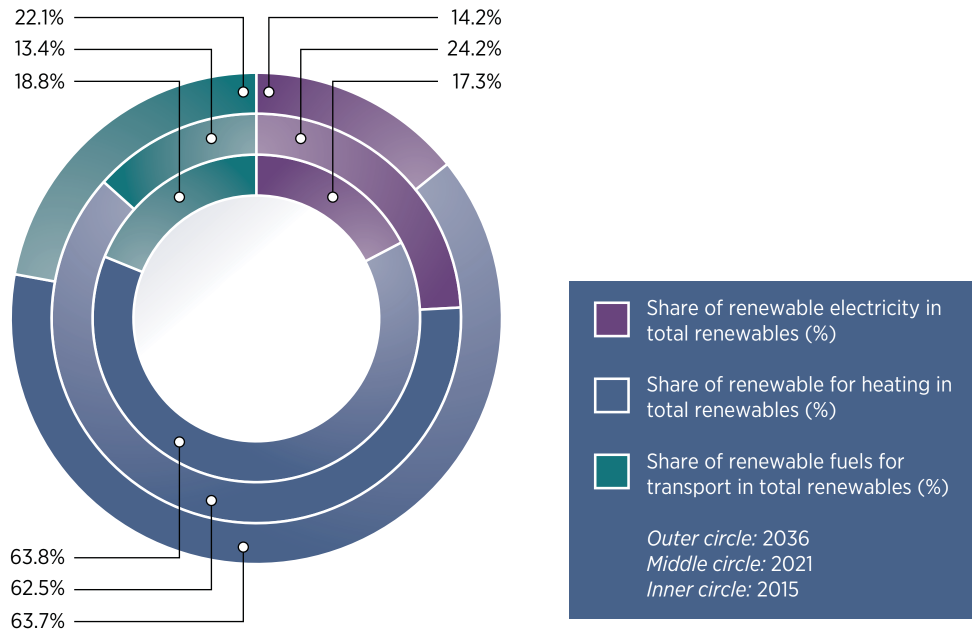
[24] Due to data limitations, this section does not assess the renewable energy zoning development that is connected with the transmission grid expansion and grid stability study.

[25] Under the assumption of TFEC of 131 000 ktoe by 2036.

[26] In Thailand, the target should be met only by indigenous renewable energy sources (excluding traditional renewables), indicating that imported renewable energy sources will not contribute to meeting the target.

[27] For the purpose of consistency in dataset, the estimates for 2021 made by DEDE were used.

Figure 10. The shares of renewable energy production under the AEDP by sector in 2015, 2021 and 2036



Based on data in the DEDE (2015) Alternative Energy Development Plan

Table 4. Renewable energy use and AEDP targets

Energy type	Reference (2015)*	Target in 2021	Target in 2036	Reference (2015)	Target in 2021	Target in 2036
Power	Final energy consumption (ktoe)	Capacity (MW)	No. of power plants	Capacity (MW)	Capacity (MW)	Capacity (MW)
Municipal waste	44	214	261	131	410	500
Industrial waste	-	26	26	-	50	50
Solid biomass	1 104	2 059	2 910	2 726	3 940	5 570
Biogas	92	234	313	372	448	600
Biogas (energy crop)	-	225	395	-	387	680
Small hydropower	24	79	115	172	259	376
Wind	28	64	403	233	475	3 002
Solar	202	358	716	1 419	2 993	6 000
Large hydropower	290****	446	446	2 906	2 906	2 906
Sub-total	**1 786**	**3 706**	**5 588**	**7 962**	**11 871**	**19 684**
Thermal	**ktoe**	**ktoe**	**ktoe**			
MSW	88	178	495	-	-	-
Biomass	5 990	8 649	22 100	-	-	-
Biogas	495	716	1 283	-	-	-
Solar	5	43	1 200	-	-	-
Other alternative energy**	-	0.35	10	-	-	-
Sub-total	**6 578**	**9 586**	**25 088**	**-**	**-**	**-**
Biofuel	**ktoe**	**ktoe**	**ktoe**	**Million litres/day**	**Million litres/day**	**Million litres/day**
Ethanol	879	892	2104	3.5	4.79	11
Biodiesel	1 063	1 126	4 405	3.4	3.58	14
Pyrolysis Oil	-	4	171	-	0.011	0.53
Compressed biogas (tonne/day)	-	33	2 023	-	78	4 800
Other alternative energy***	-	-	10	-	0.001	10
Sub-total	**1 942**	**2 055**	**8 713**	**6.9**	**-**	**-**

* Please note that the 2015 data in the table are closer to year-end 2014 data than 2015 year-end data; for example, the cumulative solar PV installed capacity for 2015 was 1 419.58 MW compared to 2 021 MW at the end of 2015.
** Such as geothermal, used tyres.
*** Such as bio-oil, hydrogen.
**** Updated in March 2017 from the previous 59.7 ktoe.

Renewable electricity generation

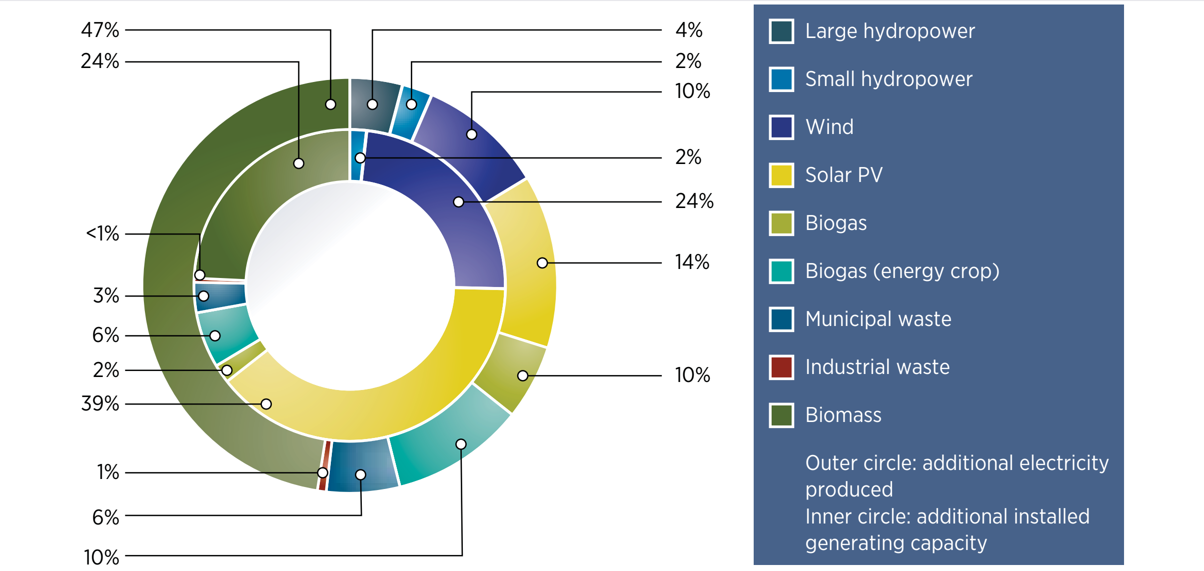
Overall observations

Total installed renewable electricity capacity (excluding large-scale hydropower) would triple over the next two decades, if AEDP 2015 were implemented as planned. To meet the target, total additional capacity of 11 721 MW would be required[28] and be expected to deliver 46 902 GWh annually, assuming an overall capacity factor of 45.7%. As illustrated in Figure 11, bioenergy including solid biomass combustion, municipal waste and industrial waste, as well as biogas for electricity generation, account for the lion's share of electricity output under this scenario, while their corresponding aggregated generating capacity would represent less than one-third of the total additional capacity.

Provided feedstock sourcing is not an issue, biomass-based electricity generating facilities could generally provide a baseload with a relatively high capacity factor. By contrast, combined solar PV and wind capacity represent 63% of the total additional capacity to be installed over the same period, while the electricity output from these two sources accounts for only one-quarter of the total, due to the lower capacity factors that these generating systems generally have.

Therefore, it would be important to develop a portfolio of different renewable energy sources in the mix that can complement each other in terms of resource availability. This would help achieve a higher overall capacity factor, reduce the requirements placed on the reserve capacity, and thus minimise overall system costs.

Figure 11. Capacity additions and electricity generated by technology in 2036



Note: The inner circle represents installed generating capacity that would be added from 2015 to 2036, while the outer circle represents the electricity to be produced by the additional electricity generating facilities in question.

Several other observations merit further discussion and investigation:

1. Large-scale hydropower (excluding pumped storage[29]): the political decision was made in the process of developing AEDP 2015 that installed large hydro generating capacity should remain at 2 906 MW with no further capacity to be added due to environmental concerns. The statistical data on electricity produced by large hydropower was adjusted upwards from 694 GWh to 3 409 GWh (equivalent to an increase from 59.7 ktoe to 290 ktoe) in March 2017. Even so, the capacity factor was extremely low for 2015 compared to common practice. This can to some extent be explained by the data in Figure 12, which show how hydroelectric production has been trending downwards since 2012.

[29] The pumped storage station, Lam Ta Kong, with the capacity of 500 MW, will double its capacity by 2018.

Based on the data in AEDP 2015, hydropower is forecast to generate an additional 1816 GWh in 2036 compared to the 2015 reference year. On that basis, only 20% of the total capacity would be utilised in 2036. Taking into account the 1 000 MW of pumped storage capacity available by then, plenty of hydropower generating capacity should be available in 2036 to use as regulating power when needed, especially in the scenario where the share of the variable energy sources such as solar PV and onshore wind power increase substantially in the power system.

Figure 12. Electricity production from hydropower in Thailand (excl. pumped storage)

Source: based on data provided to IRENA by DEDE

2. Solar PV: the mid-term target (2021), set at 2 993 MW, appears to be met sooner, if not already at the time of writing. The 2036 target appears to require updating if this momentum continues. By 2016 the majority of installations had been utility-scale. However, rooftop solar PV installations could scale up in future in response to the constraints on land availability for utility-scale installations, which is already the case for the Bangkok metropolitan area.

3. Geothermal: This energy source is missing from AEDP 2015, which is understandable as Thailand has quite modest geothermal resources with a temperature range of 40-60°C, with some spots reaching about 80°C. Even though the current installation of 300 kW can be upgraded or expanded to the magnitude of MW in the future, it would nonetheless remain insignificant.

Electricity generation from biomass-based fuels

Thailand has traditionally been an agricultural economy. Even with the rising industrial and tourism sectors, agriculture remains important due to the large number of registered farmers that generally live in poor conditions. Therefore, the government has strong incentives to create opportunities for farmers to diversify their incomes with the aim of generating new streams of revenue, but also as a hedge against global food price volatility. Electricity generation from biomass, i.e. residue or energy crops, is a priority in Thailand.

The biomass-fuelled electricity generation target in AEDP 2015 is the doubling of installed generating capacity, as shown in Table 4, and the increase in electricity production from biomass combustion by a factor of 2.6 from 1 104 ktoe to 2 911 ktoe.

This represents nearly half of the total addition to renewable electricity by 2036, as illustrated in Figure 11. The targets for electricity generation from biomass in AEDP 2015 are divided into five components:

- solid biomass – 5 570 MW
- biogas – 600 MW
- biogas from energy crops – 680 MW
- MSW – 500 MW
- industrial waste – 50 MW

The solid biomass component is by far the most significant of all biomass-based electricity targets. It refers to the production of electricity in conventional steam power plants using solid biomass residues from biomass harvesting and processing, such as sugarcane bagasse, rice husks, empty fruit bunches and others. In most cases, these plants operate in co-generation mode for the production of both electricity and heat, and are associated with some other industrial operation that produces the biomass residues or has direct access to harvesting residues, such as a sugarcane mill or a palm oil plant. Independent power plants also obtain their biomass residues from third parties.

A comprehensive list of biomass residues has been compiled by the Ministry of Agriculture and Cooperatives (MoAC) and DEDE, and is presented in Table 5. The figures presented in the table are the net amount made available for energy purposes only. The compilation indicates a potential of 6 040 MW for electricity generation in 2036. The government is also considering additional sources, such as dedicated energy plantations.

Table 5. Biomass residue potential in Thailand

Biomass type	Available residues for energy purposes (2014)			Available residues in MoAC's development plan for energy purposes		
	tonne/ year	ktoe	Power potential (MW)	tonne/ year	ktoe	Power potential (MW)
Rice husk	432	0.14	0.05	432	0.14	0.05
Rice straw	4 124 630	1 204	461	4 124 630	1 204	461
Sugar cane and leaf	2 928 140	1 073	411	5 265 619	1 929	738
Bagasse	-	-	-	21 280 000	3 712	1 421
Corn cob	80 889	18	7	80 889	18	7
Corn trunk	3 369 690	784	300	3 369 690	784	300
Cassava rhizome	2 838 125	369	141	3 372 560	439	168
Cassava trunk	1 052 636	388	149	2 084 755	769	294
Palm frond	14 606 671	2 265	867	33 586 191	5 208	1 993
Palm empty fruit bunch	606 541	104	40	1 402 455	240	92
Palm fibre	-	-	-	2 944 803	795	304
Palm shell	-	-	-	619 959	248	95
Para wood root	1 411 834	287	110	1 411 834	287	110
Coconut shell	79 678	31	12	79 678	31	12
Coconut coir	71 875	27	10	71 875	27	10
Coconut bunch and frond	249 026	91	35	249 026	91	35
Total	**31 420 166**	**6 642**	**2 542**	**79 944 394**	**15,783**	**6 040**

Based on data from MoAC and DEDE

Geographically, agricultural residues such as rice husk, cassava and bagasse are mostly distributed in the central, northern and northeastern regions, while oil palm residues exist largely in the southern provinces, according to the Office of Agricultural Economics of Thailand.

Given the importance of solid biomass residues in AEDP 2015, the MoE has launched a nationwide survey of biomass potential for energy purposes, involving seven universities.[30] The objective of the survey is to improve knowledge about the types and quantities of residues available, as many studies that were previously undertaken arrived at substantially different resource potentials depending on the methodology, approach/tool, assumptions and survey skills.

Regardless of what the results may be, three key challenges need to be addressed to sustain the supply of feedstocks for electricity generation. They are:

1. To establish a fair and reasonable pricing mechanism for residue collection, handling and storage.
2. To develop the biomass supply chains needed to ensure the collection and storage of a large amount of biomass residues from dispersed areas.
3. To co ordinate planning practices with MoAC and the Ministry of Natural Resources and Environment (MoNRE), in respect of land use and the certainty of demand for biomass for energy purposes.

These challenges are real for grid-connected large-scale power plants, as a significant part of the existing agricultural and forestry residues are treated as a commodity and their accessibility is subject to market conditions. The conflicting interest in the use of biomass feedstock between different sectors may cause concerns.

In principle, MoAC welcomes any opportunity to diversify farmers' income streams to hedge against price volatility in the food market by developing a stronger value chain for agricultural products and residues. This requires innovative pricing mechanisms for feedstocks to be put in place where a conflict of interest exists between food and energy. For biomass feedstocks for energy, an adequate pricing mechanism is one that considers the production costs, logistics, quality and opportunity costs. First and foremost, the pricing mechanism should be able to provide enough economic incentive to the biomass producer at levels that promote long-term engagement from the producer in the supply of biomass to the intended energy application, so that the costs of biomass production, collection and availability at the farm gate are covered. The pricing mechanism must also take into account the costs of transporting the biomass from the farm gate to the biomass user, if those costs are borne by the biomass producer. Certainly, the pricing mechanism must also beware of the opportunity costs of the biomass feedstock when alternative markets exist that might divert biomass to uses other than energy. Nonetheless, the bottom line is that food security for both human and animal/livestock must remain the top priority.

MoAC is also responsible for safeguarding farmers' overall economic interests. If designed and enforced well, multiple benefits can be achieved. For instance, much agricultural residue is burned on farmland, contributing to the air pollution problem. With regard to logistics and feedstock supply management, a good collection and handling infrastructure needs to be established in consideration of the ageing labour force in the agricultural sector.[31]

A fair and sound regulatory framework should be put in place to ensure a fair distribution of the benefits between the farmers and the energy producers, particularly when deals go through processing collection companies (including agricultural co operatives that operate as a collector in some places), processing mills and other businesses involved.

[30] Including Chiang Mai University, Khon Kaen University, Suranaree University of Technology, Kasetsart University, King Mongkut's University of Technology Thonburi, Prince of Songkla University, and Chulalongkorn University.

[31] It has been increasingly difficult to sustain the farming labour force as the would-be next generations of farmers prefer to work in cities. Most farmers are over 55 years old. These farmers would not be able to work hard enough to collect the residues even if the given price for residues were as high as THB 10 000 per tonne. The land reform programme aims to address the ageing issue by providing new generations of farmers with farmland incentives (after three years of agricultural practice, the farmers can own the land) and technical training enabling them to continue farming practices.

The production of electricity from dedicated energy crops (such as fuelwood) is still at an early phase. Whether it is necessary for the government to pursue this option remains uncertain until the ongoing survey of biomass potential is finished. The development of dedicated energy crops requires a careful assessment of the potential risks involved in the competition for scarce resources, such as land and water, which put pressure on other uses like food crops, livestock farming and forestry.

Electricity generation from biogas is another important component of AEDP 2015. The plan explicitly considers two areas: the production of biogas from biomass wastes and the use of energy crops for biogas production. In the first case, AEDP 2015 plans to increase the installed capacity of biogas-to-electricity from the existing 400 MW to 600 MW. And in the second, no plants are currently installed and the plan is to have 680 MW of installed capacity by 2036.

Traditionally, biogas production in Thailand has been promoted as a win-win solution to treat the wastes from livestock production (poultry, pigs and cattle), wastewaters from food processing industries, sewage, and a proportion of agricultural residues by applying anaerobic digestion technology (DEDE, 2012a).

Improvements to the existing biogas generation systems are likely to be an option, for instance by increasing biogas generation and reducing methane losses in anaerobic digesters. According to existing data, the use of biogas for electricity generation is currently operating at a capacity factor of 32%. Considering only the capacity additions in AEDP 2015 and the electricity generation associated with them, the capacity factor of the new additions would be close to 130%, which is clearly not possible. This indicates that either the planned capacity additions are not sufficient to meet the electricity generation goals, or that the current biogas facilities would have to be upgraded or operate for longer hours than they are now, to achieve the overall average capacity factor of 69% in 2036.

With the growth in industrialised livestock production, especially the increasing demand for chicken meat in response to the recent lifting of the importation ban by many countries and regions, the amount of poultry wastes is duly expected to increase. This will in turn provide more feedstock for biogas production. In existing industries such as bioethanol, vinasse (a residue from wine distillation) represents very significant potential for use in biogas production. Co-digestion of vinasse and filter cake (another residue from sugarcane processing) is a further promising option.

In parallel, a sub-target of 680 MW electricity generation from biogas produced from energy crops was also set in AEDP 2015. The aim was to scale up biogas production from alternative resources. This was based on the research results under DEDE's supervision on biogas production from Napier grass, also known as "elephant grass" – a fodder with a high level of protein, fat and carbon, making it suitable for anaerobic digestion (DEDE, 2012b).[32]

The use of energy crops for biogas production is no different from other applications of dedicated energy crops. Energy cropping is a legitimate way to secure biomass feedstocks that can be used not only for biogas production, but also in biomass boilers to generate electricity and/or heat, and can also be converted into liquid and gaseous biofuels through thermochemical process such as gasification or pyrolysis. However, it must be considered carefully in a broader context of land use development because it introduces further pressure on land and water resources, especially given the emphasis on energy crops for bioethanol and biodiesel production.

A further priority under bioelectricity is MSW. MSW is a national priority while bioenergy is often viewed as a by-product. The volume of MSW has been increasing, along with the growing population, improved living standards and the expanding tourism industry in Thailand, according to the Pollution Control Department of Thailand. In 2015, about 73 560 tonnes of MSW were generated per day (PCD, 2016), representing nearly a 9% increase on 2012, stretching the country's waste disposal capabilities (Suthapanich, 2014).

[32] According to the DEDE research programme, 70-120 cubic metres of biogas can be generated from a tonne of Napier grass.

In this context, the target for WTE from MSW was raised to 500 MW in AEDP 2015 from 160 MW in the previous AEDP 2012-21. It should be noted that with the support of the Adder Programme,[33] 83% of the previous 2021 target was met by 2015. It can then be extrapolated that the 2036 target for MSW would be exceeded by 15%. This could be a very reasonable scenario when factoring in the mounting pressure on municipal waste management – the key driver for MSW-based WTE. Nevertheless, MSW WTE would account only for a small proportion of the future energy mix.

Solar PV

Thailand is endowed with abundant solar energy resource across the country, with high irradiance in the northeast and central parts of the country covering one-quarter of the total land area, as illustrated in Figure 13. The peak density of solar radiation in those areas is in the range of 1 200-1 400 kilowatt hours (kWh) per square metre per year, with seasonal peak in April and low point in December. (DEDE, 2012c).

To develop this potential into electricity generating capacity would require the alignment of other variables, including transmission capacity, availability of suitable land, load profile, grid flexibility and a suitable regulatory framework. In view of the variability and potential complementarity of different forms of renewables such as solar, wind, biomass and hydropower, the sector has evolved from a single-source renewable energy development model into a region/zone-based model, also known as the "renewable energy zoning" approach. In Thailand, EGAT has been working in collaboration with the MoE on this in connection with the development of the transmission networks.

33 At the rate of 2.50 THB/kWh for seven years.

Figure 13. Thailand solar energy resource potential

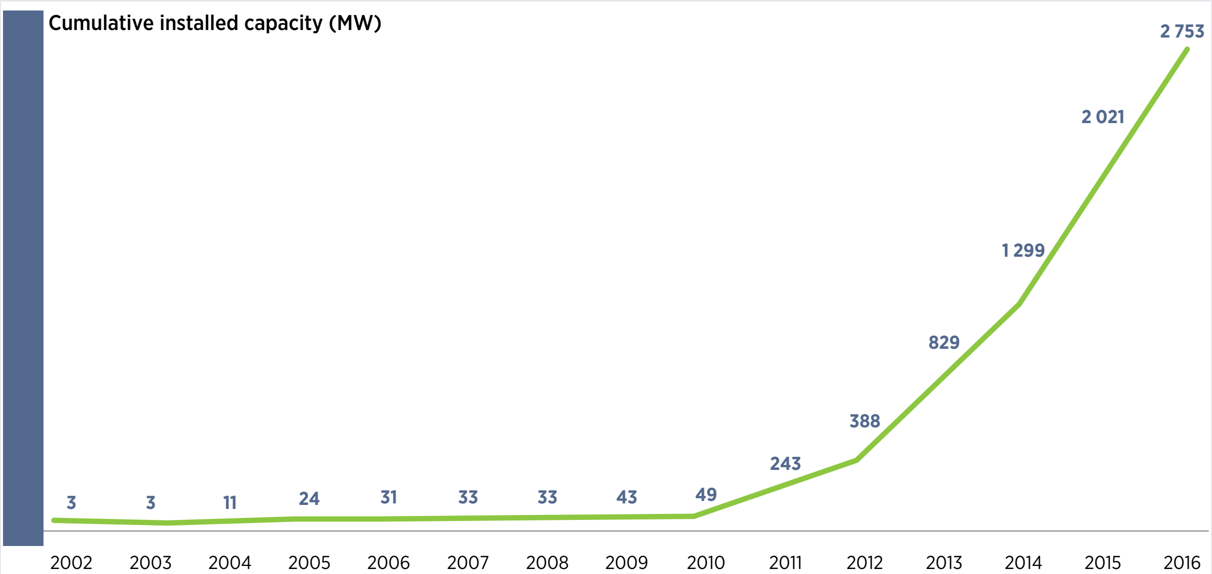
Global Horizontal Irradiation kWh/m² World 1km 1994/1999/2007-2015 WBG

- 1.6 - 1.85 kWh/m²
- 1.85 - 2.09 kWh/m²
- 2.09 - 2.34 kWh/m²
- 2.34 - 2.58 kWh/m²
- 2.58 - 2.83 kWh/m²
- 2.83 - 3.08 kWh/m²
- 3.08 - 3.32 kWh/m²
- 3.32 - 3.57 kWh/m²
- 3.57 - 3.81 kWh/m²
- 3.81 - 4.06 kWh/m²
- 4.06 - 4.3 kWh/m²
- 4.3 - 4.55 kWh/m²
- 4.55 - 4.8 kWh/m²
- 4.8 - 5.04 kWh/m²
- 5.04 - 5.29 kWh/m²
- 5.29 - 5.53 kWh/m²
- 5.53 - 5.78 kWh/m²
- 5.78 - 6.03 kWh/m²
- 6.03 - 6.27 kWh/m²
- 6.27 - 6.52 kWh/m²
- 6.52 - 6.76 kWh/m²
- 6.76 - 7.01 kWh/m²
- 7.01 - 7.25 kWh/m²
- 7.25 - 7.5 kWh/m²

Global Atlas for Renewable Energy (IRENA, 2017)

Over the past five years, Thailand's total installed solar PV generating capacity has increased tenfold, as shown in Figure 14. This remarkable achievement can be attributed to the attractive premiums offered under the country's Adder Programme, the dramatic global decline in the cost of PV modules and utility-scale PV projects, and growing acceptance of solar PV projects especially in the financial sector, and most importantly the consistent political support for renewable energy development.

Figure 14. Thailand's cumulative solar PV installed generating capacity, 2002-2016



Based on data from DEDE and ERC
Note: 2016 data as of September

As of December 2016, Thailand has nearly doubled the 2015 reference point used for AEDP 2015 by reaching solar PV installations of 2 446 MW (already in operation as defined by the COD record), of which 95% are from ground-mounted utility-scale installations. Another 307 MW are in the process of reaching COD. The industry expects to see another surge in solar PV installations in 2017, based on the pipeline of projects and the potential new rounds of tendering for SPPs and VSPPs, activity in the rooftop solar PV market and the continued reduction in costs, including savings from simplified administrative procedures.

The indications and implications of such rapid growth and continued momentum on the AEDP 2015 solar target are briefly discussed below:

- Total installations are already half way to reaching the 2036 solar PV target of 6 000 MW, suggesting there is room for increasing the target. The estimated addition is presented in the REmap findings in Chapter 4.
- Grid stability has not become a major issue with the share of variable renewable energy (VRE) sources[34] in the power mix estimated at about 1.5%. However, MoE has taken precautionary actions in this regard by demanding that new project developers provide semi-firm or firm capacity – essentially a hybrid system based primarily on biomass-derived power, hybridised with solar PV or wind – as seen in the Box below.

  In addition, NEPC has approved establishing a merit of order in AEDP 2015 – a priority list for grid integration of renewable electricity generating capacity ranked against the impact on grid stability from least to highest, i.e. MSW, solid biomass, biogas from wastes and waste water, small-scale hydropower, biogas from energy crops, wind, solar PV, and geothermal.

[34] Including wind power, which is currently at a much smaller scale compared with solar PV.

- SPPs and VSPPs dominate the solar PV market and will most likely continue to dominate for the next two decades; by contrast, EGAT's ultimate contribution to solar PV would be expected to be below 3% in 2036. This is partly because under the enhanced single buyer power market, EGAT as the transmission system operator is obligated to completely purchase any electricity generated using renewable energy. By not being heavily involved in VRE generation, EGAT keeps a neutral position in respect of grid constraint issues such as the necessary curtailment. However, given that the share of natural gas in the power mix would nearly halve from the current level of 67% in the PDP 2015, EGAT has planned to scale up biomass electricity generation,[35] coal-fired thermal power, imported hydropower and other sources to fill the gap such a reduction may create.
- The rooftop solar PV market remains largely untapped. New business models using PV as part of an energy efficiency programme for buildings to lower electricity bills could speed up the adoption of rooftop solar PV. However, unlocking its potential, especially in the Bangkok metropolitan area which has about one-third of the total national power demand but little land available for ground-mounted solar PV deployment, would still require stronger engagement from MEA and PEA in addressing the challenges this sub-sector faces. This is discussed in the following paragraphs.

35 At present, EGAT plans to deploy 2 082 MW of biomass power generating capacity. However, this internal target is likely to be updated once EGAT completes its survey of biomass feedstock and the need for additional transmission capacity.

Non-firm, semi-firm and firm electricity generating capacity in Thailand

In the current power purchasing agreements for SPPs and VSPPs, two types of contract are applicable for power plants with firm and non-firm capacity, respectively. VRE sources often fit into the latter, as the electricity production from solar or wind varies with the availability of the resources.

Firm capacity refers to those who can provide power for a whole year, while semi-firm capacity is defined as 100% availability of dispatchable power generation capacity during 08:00-22:00, with 65% of the total capacity during 23:00-07:00 for every day over the four peak months (March-June) in a year. Non-firm capacity refers to those who can provide power for the rest of the year.

There is a policy change for FIT bidding requirements. Only those SPPs and VSPPs who can provide firm and semi-firm generating capacity from renewable energy sources will be eligible. Hybrid systems are encouraged.

Source: Department of Energy, 2017

Presently, rooftop solar PV in Thailand plays a very small role due largely to the following key challenges.

Overall, Thailand lacks a dedicated target for rooftop solar PV development. In addition, for residential households the incentives are less attractive as rooftop solar PV can only be used for self-consumption, due partly to the lack of net-metering schemes. This basically eliminates the potential use by residential households as they are mostly not at home to use the electricity during the daytime. For commercial and industrial users the story is different, as rooftop solar PV can match their load profile. In general, more economic incentives should be provided for rooftop solar PVs.

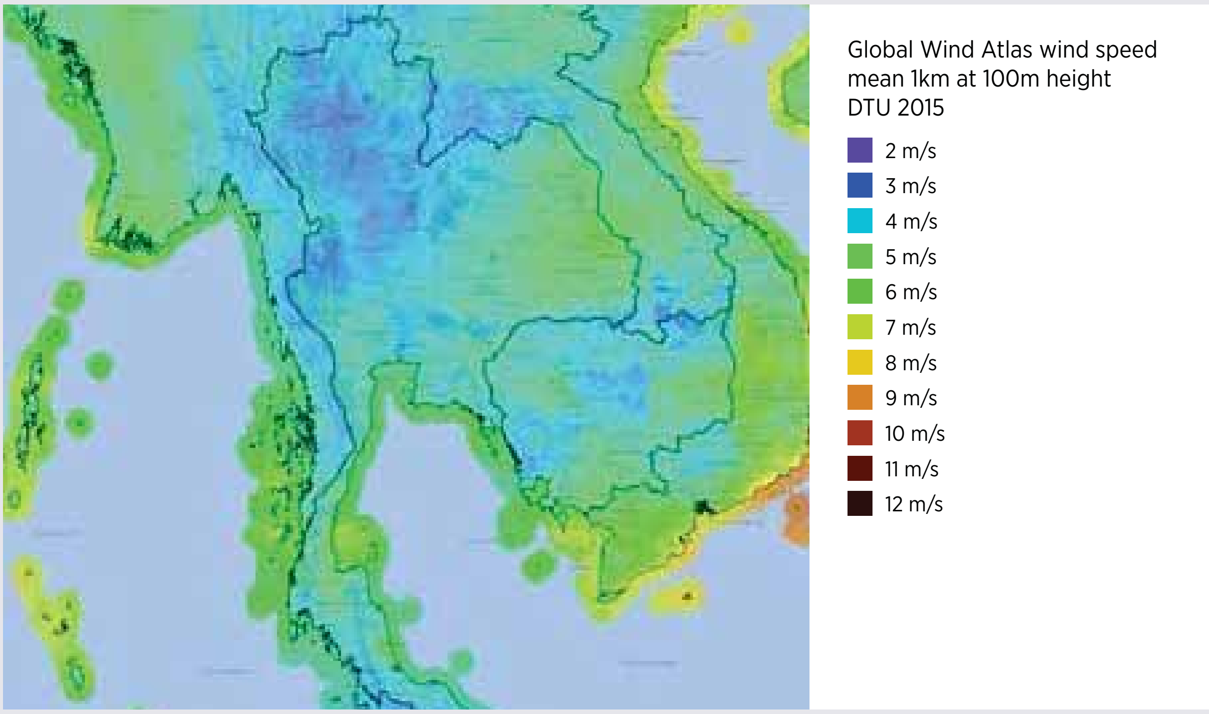
For connection to the distribution networks, PEA and MEA have set a ceiling of 15% of the transformer's capacity with the intention to minimise the risk of interfering with power quality for other customers. Yet this limits the potential for VSPPs to develop rooftop PV for commercial and industrial users unless effective energy management can be put in place, including battery energy storage systems.[36] Following the appropriate grid stability analysis, PEA and MEA may opt to raise the threshold.

Wind power

Thailand has wind potential according to an average wind speed of 6 metres per second (m/s) measured at a height of 90 metres, as shown in Figure 15. Based on recent wind potential assessment results that were endorsed by DEDE, technical potential can reach 13 GW in 21 areas across the country. The greatest wind potential is geographically located in the northeast, western and southern regions of Thailand, which are generally far away from the loads. A study by Manomaiphiboon et al. (2017) has shown that Thailand has technical wind energy potential up to 17 GW if modern low-speed wind turbines are used, and yet only one-third of this can be realised if conventional wind turbines are adopted instead. This partly explains the huge gap between the 13 GW wind potential and the wind power target of 3 GW set in AEDP 2015, and also suggests that how soon the 2036 target for wind can be achieved would to a large extent depend upon the selected wind turbine technology, the installation location and the hub height.

[36] The application of battery energy storage systems in Thailand is in its infancy, despite EPPO since October 2016 providing grants as high as about USD 23 million to support research and development (R&D) projects on battery technology through its ENCON Fund. As of July 2017, 32 projects had been approved with the total planned disbursement of USD 8.95 million.

Figure 15. Wind potential map for Thailand at 90 metres



Global Atlas for Renewable Energy (IRENA, 2017)

In respect of offshore wind potential along the coast of the Gulf of Thailand, Waewsak et al. (2015) highlighted that the total offshore wind potential stands in the magnitude of 7 GW, nearly half of which is in the Bay of Bangkok – the northernmost part of the Gulf of Thailand. Under the assumption of a capacity factor at 24%, total electricity production from this estimated capacity would reach 15 terawatt hours (TWh) per year.

Thailand utilised wind energy to generate electricity as early as 1983 when the first three turbines with a capacity of 1 kW, 10 kW, and 150 kW, respectively, were installed at the Phromthep Alternative Energy Station on Phuket Island. By 2015, Thailand had reached a total capacity of 234 MW, most of which was in the northeast as shown in Table 6. This doubled the 2012 level, representing an annual average growth rate of 30%, and the rapid growth continued throughout 2016.

According to the implementation plan for AEDP 2015, the annual growth rate would expect to slow to an average of 12-13% over the next two decades, as illustrated in Figure 16. Like solar PV projects, most of the wind projects will be developed by the private sector – IPPs, SPPs and VSPPs – while EGAT plans to limit its contribution to less than 6% of total wind power generating capacity by 2036.

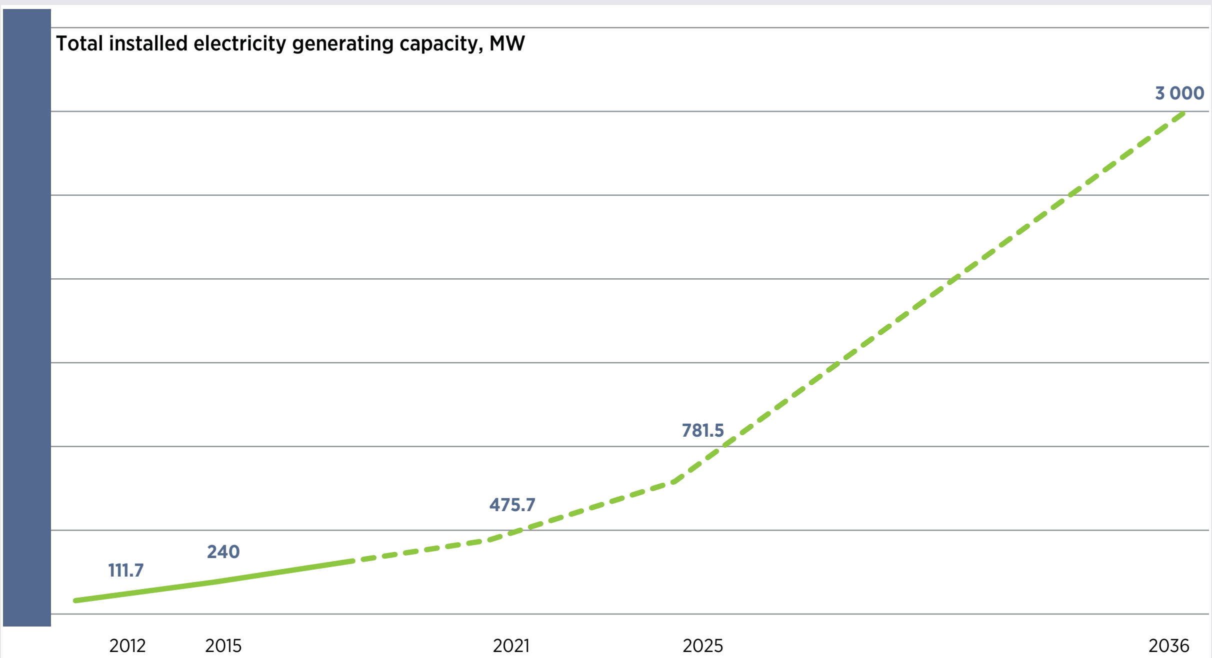
However, whether wind power development in Thailand evolves as planned will largely depend on how the current land use or acquisition challenges facing wind project developers can be satisfactorily resolved.

Table 6. Thailand's total installed wind electricity generating capacity by 2015

Location	Capacity (MW)
Wind power Northern	1.86
Wind power plant in Northeastern	215.41
Wind power plant in Central	2.70
Wind power plant in Southern	13.93
Total capacity	233.9

Based on data from DEDE

Figure 16. Thailand's total installed wind electricity generating capacity, 2012-2036 (estimate)



Based on data from DEDE

Discussion

Several cross-cutting issues could have a significant impact on whether and how the renewable energy target for power generation could be achieved by 2036. The following paragraphs discuss some of the key points identified through the consultative process.

Key factors in PDP 2015 affecting AEDP 2015

As briefly discussed in the previous section, TIEB took a unique approach to interconnect all five energy-related development plans in a synchronised timeframe. Under the framework of PDP 2015, AEDP 2015 has been closely linked with the EEP target, i.e. an energy intensity reduction of 30% in 2036 from the 2010 level. In absolute terms, it means a total amount of 51 700 ktoe should be saved through energy conservation and efficiency improvement measures in all sectors over the course of the next two decades, 85% of which would be expected to occur in the thermal sector. This interlinked target could bring some uncertainty in respect of meeting the renewable target set, as TFEC in 2036 could change.

Another important factor is how the development of other sources of power generation, notably natural gas and coal-fired power generation, could affect renewables. In PDP 2015, the target was set to reduce the share of natural gas from the current 64% to 37% in 2036, while the share of coal power would rise from the current 20% to 23%. Whether these two sub-targets can be achieved would greatly depend on the long-term security of supply of natural gas at affordable prices and the public acceptance of coal power that is now under fire.

Proactive power grid development planning

EGAT has realised the importance of integrating future renewable electricity generators into the power grid development plan. As stipulated in PDP 2015, EGAT has the obligation to purchase all the electricity generated from renewable energy sources. This requires EGAT to upgrade and expand its transmission networks to be capable of accommodating a growing share of VRE from, for instance, solar and wind. For example, the interconnection between central and southern Thailand (600-700 kilometres) will be significantly enhanced by upgrading the transmission capacity to 1 000 MVA with a 500 kV voltage level. By 2023, EGAT will be able to provide an additional 5 180 MW of transmission capacity in the northeastern, northern, central and southern regions to accommodate renewable electricity generation of up to 12 GW. It is planned to add another 19 GW after that. But the PDP is supposed to be reviewed every four years or so, and the planned target after 2023 might be updated in the next review.

The plan developed by EGAT was based on the two studies it conducted in collaboration with the MoE, i.e. the grid stability assessment using the PowerFactory model, and the development of renewable energy development zones in connection with the plan for power grid expansion and enhancement. Despite the fact that the results are presently not available to the public, some general observations can be drawn from the discussion of the procedures. They include the following:

- As regards zoning practice, it appears that EGAT gave priority to biomass while other renewable energy sources were built into the plan based on the biomass-centric modelling results. This would miss the optimisation of different types of renewable energy sources, notably wind and solar due to their potential complementarity, and matching with load profiles (although total power demand is considered).

- The grid stability study was conducted in two steps, i.e. running the simulation on the existing and planned conventional generators and transmission grid data without variable renewables, and then with the variable renewables examining how much the grid can accommodate and where the weak points would be at various disruption events to devise the enhancement plan and the operational procedures. However, without the inputs from the distribution networks, the final simulation results can only be sub-optimal.

Regional power grid interconnections

In addition to the existing interconnections with neighbouring countries, Thailand has approximately 22-25 GW of cross-border transmission capacity planned to be built by 2025, as shown in Table 7. However, these transmission interconnection projects were identified under the ASEAN Power

Grid Initiative, which is facing significant challenges in respect of attractiveness of investment. Therefore, how feasible it is for these projects to be developed by 2025 remains unclear.

Nevertheless, Thailand is making efforts and investments in its neighbouring countries, mostly Lao PDR and Myanmar for importing hydropower and possibly coal power. In accordance with the eligibility of renewable energy sources for compliance with the renewable energy target in AEDP 2015, the imported renewable electricity is not accounted.

Table 7. Thailand's cross-border transmission projects in the ASEAN power grid plan

Transmission grid interconnection	Capacity (MW)
Thailand – Lao PDR	7 328
Thailand – Myanmar	11 709 - 14 859
Thailand – Cambodia	2 300
Thailand – Peninsular Malaysia	780
Total capacity	22 117 - 25 267

Source: Heads of ASEAN Power Utilities/Authorities

Regulatory framework and potential power market reform

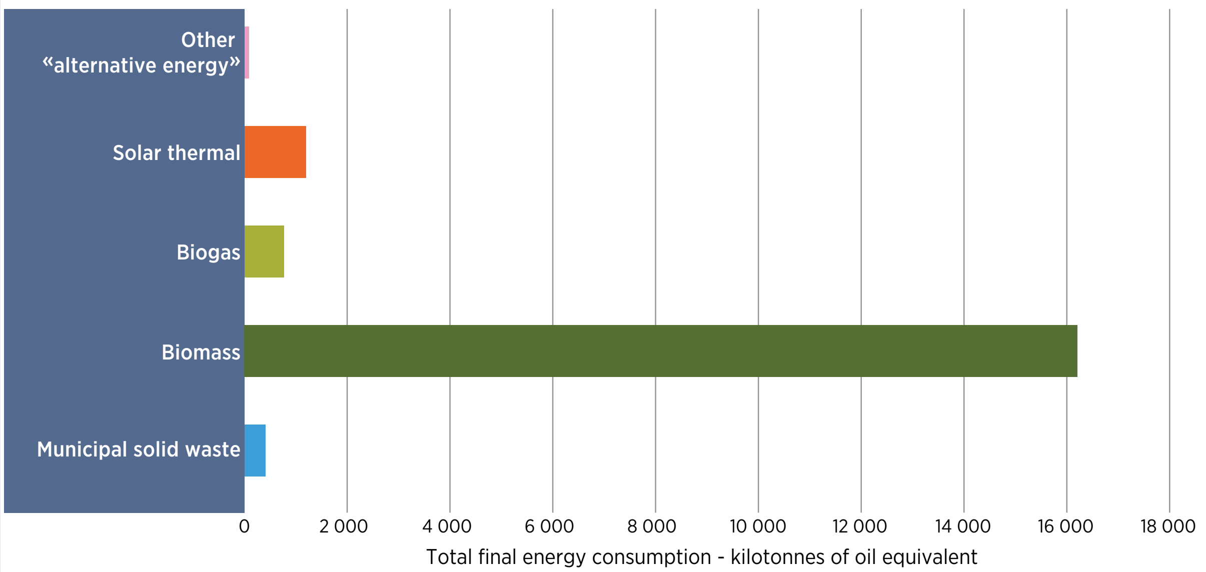
The recently proposed renewable energy promotion plan by EPPO, requiring all SPPs and VSPPs to provide firm or semi-firm capacity in their renewable energy projects, aims to reduce the requirement for grid flexibility and thus ultimately support the implementation of AEDP 2015. It would also increase the challenge that developers are facing, although some of the big players seem to be prepared for this change by making strategic acquisitions. In general, this new plan will push costs upwards on the developer side. The plan is now under discussion and is expected to be launched in 2017.

Worldwide, the high penetration rates of VRE could pose greater challenges for grid operators, and thus incentivise them to place technical requirements on developers. However, other options can be explored, for instance, matching VRE outputs with load as much as possible using intelligent control systems, including adopting more advanced demand-side management schemes. Increasingly, market-oriented tools are gaining popularity in addressing the frequent regulation of frequency and voltages in a system with a high share of VRE, as presented in the report Adapting Market Design to High Shares of Variable Renewable Energy (IRENA, 2017a). For Thailand, another option that deserves attention is to develop a market for regulating power, given the system has a large number of gas turbines and hydropower stations.

Renewable energy for heating: industrial, commercial and residential

In 2036, renewables for heating are expected to account for 37% of the total heating demand, representing a more than doubling of their share from the 2015 level, according to AEDP 2015. As illustrated in Figure 10, their share of the renewable portfolio remains unchanged at approximately 64%. However, given that the share of renewables in TFEC is expected to increase from the current 10% or so to 30% in 2036, the contribution of renewables in the heating sector would grow substantially in absolute terms, estimated at 18 509 ktoe as shown in the Table 4 – fivefold the amount of renewable electricity generation. As much as 85% of the increment would be expected to come from biomass, followed by biogas and solar thermal, yet to a significantly lesser extent, as shown in Figure 17. The category of biomass covers both biomass residues and dedicated energy crops. A significant part of that biomass is expected to be used in co-generation plants, contributing to both heat and electricity generation. Solar thermal covers the applications of solar water heaters and solar drying systems, as well as solar cooling applications.

Figure 17. Increment of renewables for heating in 2036 from 2015 in Thailand



Based on data in the DEDE (2015) Alternative Energy Development Plan

Unlike power generation and transport fuels from renewable energy sources, renewables for heating lack a clear roadmap. This issue can be attributable to the following causes:

- Biomass, in the form of residues and wastes, has traditionally been used for process heat in the agricultural and forestry sectors. For instance, more than 80% of the process heat in the sugar, pulp and paper, rice milling, timber, and palm oil industries is provided by biomass residues and wastes. Unless their production capacity increases, the use of biomass in those industries can hardly increase. However, the unused biomass residues from those industries could be utilised by other industries should the technological challenges be addressed and incentives be provided. In fact, biomass currently offers the only real renewable technology alternative to fossil-fuel-based high-temperature process heat generation (IRENA, 2014b). Few other renewable sources can provide the high-temperature process heat that many industries need.

- A related issue is that there is no programme to evaluate how much biomass residue could be used by other industrial users for energy purposes. The technological, technical and logistical challenges need to be identified and addressed with the appropriate level of policy and regulatory interventions. This includes a pricing mechanism to be devised for biomass feedstocks, as discussed in the previous chapter.

- Most of the industrial facilities that can potentially use biomass for process heat are large-scale, centralised plants operating at economies of scale, which will require large energy flows to be brought from within and across national borders. The key factors defining the economic viability of biomass are: its energy density, production costs, the distance it needs to be transported, and the type of transport mode. Cost-competitiveness of biomass can be maintained through an effective logistics infrastructure as consumption increases. Therefore, it is essential to support the development of biomass supply chains that ensure the delivery of reliable, high-quality and affordable biomass fuels to those industries that are willing to use biomass. The development of such supply chains would benefit not only heat applications, but also electricity production and more importantly combined heat and power. Focus on those supply chains should be another priority in the development of the AEDP.

- The competition for biomass from power applications must also be considered. The AEDP should look at power and heat in an integrated manner to ensure that enough resources are available and that no competition develops that could hinder the development of bioenergy in those sectors. The use of the scarce solid biomass resources, especially agricultural residues, that will be available in the AEDP time frame should be prioritised. Mechanisms should be put in place that ensure the development of a healthy and sustainable biomass market that serves those end users that will maximise the production of both electricity and heat, as well as those that have few other renewable energy options, such as for high-temperature heat applications.

- Coal use by industrial users has more than doubled during 2000-2014, reaching 12 million tonnes and accounting for 47% of total coal consumption in 2014. The year 2014 alone saw a 23% increase. The remaining 53% was consumed by the power sector, in which SPP consumption remained stable over the same period, while IPPs tripled their consumption since 2006 (EPPO, 2015).[37] In this context, how much coal can be substituted by renewables may be a worthwhile question to study. This could be even more appealing and sensible in view of the current strong public objection to coal combustion, notably the case of the 850 MW coal power plant in Krabi province in the south of the country. Yet, should biomass replace coal, there could also be an institutional challenge as the lignite mines and import of coal are managed by EGAT, while biomass feedstocks are under the oversight of MoAC and MoNRE.

- Renewables for heating lack a proven business case due mostly to the fact that the technology has been largely overlooked worldwide. It has just recently been realised that renewable energy use in the heating sector could provide huge potential for meeting the growing demand.

A wider range of applications exist for renewable heating in the industrial sector, such as water heating for laundries, cooking, food drying and sterilisation, process heating and preheating of effluents in combustion systems. Solar heating, geothermal (low to medium temperatures) or ground-level resources, and biomass can potentially provide renewable energy for these heating purposes.

In Thailand, solar water heating does not appear to be widely used in the residential sector, but it may be an appealing option for hotels given that Thailand's tourism industry is well developed and continues to grow. Solar drying systems can be used in the agricultural sector for food drying. However, this would require studies to look further into the feasibility of the two potential applications, followed by a promotional scheme/ strategy.

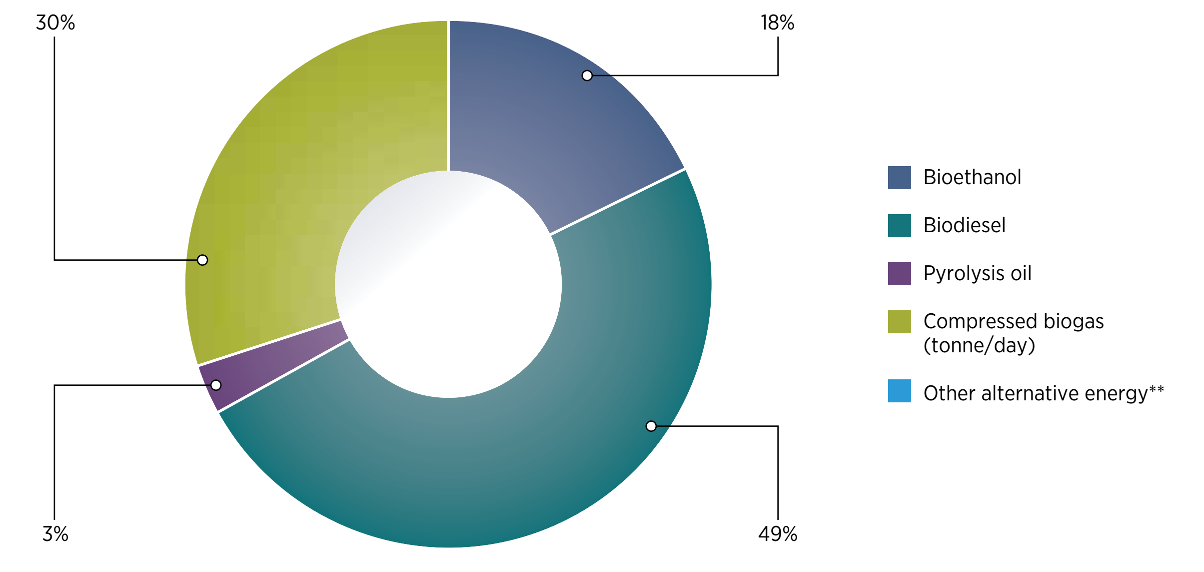
More importantly is the urgent need to establish a statistical system for non-power renewable energy sources, on which basis the right set of policies and incentive schemes for the use of renewables in sectors other than just electricity could be developed.

Renewables for transport

As indicated in Figure 10, the share of renewables for transport in Thailand's total renewable energy use is expected to increase by 2036. Biofuels, i.e. biodiesel and bioethanol, account for two-thirds of the total renewables anticipated to be used in the transport sector in 2036, as shown in Figure 18. Compressed biogas could fill much of the remaining one-third, greatly depending upon the roll-out of technology and the infrastructure (refilling stations). AEDP 2015 also introduces pyrolysis oil as a new option in transport fuels Although it contributes a much smaller share of transport energy demand, this initiative moves in the right direction of diversification of transport fuels using new and promising conversion technologies.

[37] www.eppo.go.th/info/cd-2015/pdf/cha4.pdf.

Figure 18. Share of increment of renewables for transport in 2036 from 2015 in Thailand



Based on data in the DEDE (2015) Alternative Energy Development Plan
Note: Data measured in ktoe; graph presented in percentages

To meet the corresponding target through the current commercially viable technologies, feedstock does not generally appear to be a major roadblock, but must be considered with caution. The volatile yield of palm oil, subject to the climate and weather conditions, could potentially pose a challenge. For bioethanol, the potential of cassava as feedstock is under discussion in the context that sugarcane might at some point reach its limit. Another option is to convert some low-yield rice fields into sugarcane farms.

Concerns over the guaranteed long-term demand for feedstock must be addressed to sustain the supply. Therefore, some level of guarantee on long-term demand and purchase price may be needed. This would help minimise the negative impact of oil price volatility on the farming economy, and in return enhance farmers' confidence in investing in energy crops. Additionally, prices should, in principle, be stable or predictable over the long term, and should not be set too high or too low in relation to food prices. Biomass feedstocks (cassava, molasses) represent over 70% of ethanol costs and a similar situation holds for biodiesel. This is sufficient reason to pay close attention to stable and reliable biomass supply.

Looking forward, the future generation of biofuels could greatly increase potential supply without creating further pressure on land and water use. The inclusion of pyrolysis oil, although as a small share of the transport fuel demand, is an encouraging move in that direction. Advanced liquid biofuels can be refined from a range of sources. These include agricultural residues associated with food crops, as well as forest residues like sawdust from lumber production. Other sources include non-food energy crops, such as the rapidly growing grasses switchgrass and miscanthus, and short-rotation tree species like poplar and eucalyptus. These emerging options provide a wider range of feedstock for production of biofuels for transport, while mitigating sustainability risks associated with changing land use and competition over food production. Residues do not compete with food or lumber production but grow alongside it. High-yielding grasses and trees can grow more energy per unit of land area than conventional biofuel crops, potentially mitigating the impact of any land use change. As IRENA's innovation outlook indicates, the production costs of advanced biofuels are declining. And innovation may further reduce the cost of advanced biofuel production by up to a third over the next three decades.

Thailand has considered bio-compressed natural gas (CNG), i.e. purified biogas, as one option for alternative transport fuel in AEDP 2015 and has set a target of producing 4 800 tonnes per day by 2036. However, it is important to provide clear signals that the infrastructure and supply chains will be in place, in order to develop a wider compressed biogas market. The conversion of vehicles to use gaseous fuels, such as compressed biogas, is only widely adopted if there is confidence that the fuel will be available in a sustained manner over large areas of the country. It is often preferred that compressed biogas is adopted in captive fleets, such as taxis, buses and transport companies, such that fuel demand and refuelling locations can be planned under the control of the fleet operator. The development of compressed biogas will also require significant expansion of the existing capacity of biogas production and upgrading. In addition to anaerobic digesters, the production of compressed biogas requires upgrading plants that turn biogas into compressed biogas, which entails the development of adequate technology suppliers and technologies for long-term operation. A distribution network to ensure that the fuel will reach its end-use markets is also essential, taking into consideration the geographic distribution of compressed biogas production and existing gas pipelines. Quality standards for blending compressed biogas with natural gas should also be developed from the early stages of the programme.

Discussion on biofuel and electric vehicles

The topic of alternatives to petroleum-derived fuels for vehicles has been hotly debated in Thailand, largely because the automobile industry contributes 10-11% of Thailand's GDP, and provides 800 000 jobs for the country. Around 60% of production is for the global market while 40% of the vehicles made in Thailand are for the domestic market. It is therefore a very important industrial sector for Thailand's economy and deserves continued attention and discussion regarding the direction of its future development.

At present, the consensus tends to recognise that Thailand needs more than just one type of transport fuel, while diversification should also be limited in view of the costs associated with the infrastructure transition needed. Biofuels, even at times of high oil prices, can hardly meet the demand for the whole transport sector, due to supply constraints on the feedstock.

While it is likely that electricity will be common for two- and three-wheeled forms of road transport, four-wheel vehicles can be powered by biofuels and electric drivetrains. Liquid fuels are likely to continue being used in large quantities for freight transport.

However, local industry needs to be considered. Roughly half of the domestic market for automobiles – 800,000 units per year – are diesel vehicles, with the other half gasoline. The country has been blending E10, E20 and E85 for gasoline cars, while for biodiesel, B7 blending is currently applied. While the automobile industry in Thailand has yet to start to produce electric vehicles (EVs) in quantity, it is open to the development of EV manufacturing capacity in future as it has witnessed the revolutionary technological breakthroughs that have occurred over recent years. At present, potential policy uncertainty and lack of long-term clarity in terms of technological pathway for the transport sector are recognised as the greatest challenges. Therefore, the industry is requesting that policy makers provide a perspective on where the market could develop.

In this context, the National Innovation System Development Committee, chaired by the Prime Minister, has approved the Roadmap for EV development in Thailand. It includes three strategic development stages: a) making the infrastructure ready, particularly in public transport; 2) using EVs for public transport while at the same time making the infrastructure ready for personal vehicles; 3) scaling up the use of the EVs for personal use. In parallel, EVs are also incorporated in the National Energy Efficiency Action Plan as a means to reduce the consumption of petroleum-based transport fuels.

For public transport, Thailand is focusing on replacing the conventional two- and three-wheelers (tuk-tuks[38]) with e-motorcycles not only to address the environmental issues in cities, but also to avoid challenging the market share of four-wheelers.

In 2016, EPPO set up a subsidised scheme to establish 100 charging stations nationwide for infrastructure readiness and to increase public awareness of EVs. EPPO plans to replace 22 000 conventional tuk-tuks with electric tuk-tuks within 5 years. The first 100 electric tuk-tuks will be piloted in 2017-18 with the support of the ENCON Fund. Details of the subsidy are still under consideration as are the standards for electric tuk-tuks for safety purposes.

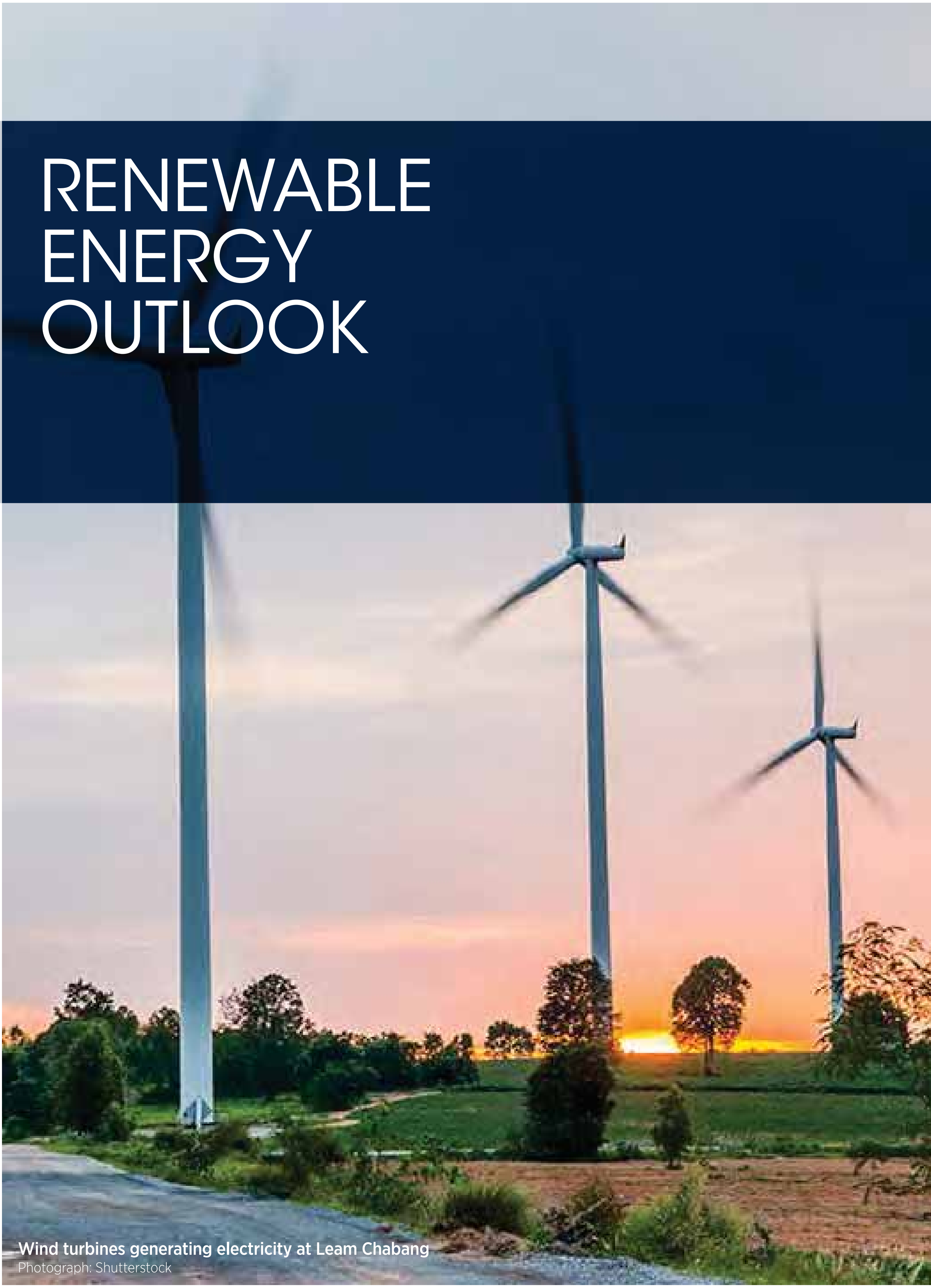
[38] It is named after the sound that the two-stroke engine makes and is an important urban transport tool in Thailand, but also causes noise and air pollution in cities.

Apart from the intended effort in promoting EVs in Thailand, MEA, PEA, EGAT and Bangkok Mass Transit Authority (BMTA) have set up plans for promoting electric public buses as part of their support to address urban transport issues as well as to implement Thailand's Industry 4.0 strategy. MEA will install charging stations for BMTA's pilot electric buses. PEA will install charging stations with both normal and fast charging capabilities at Suvarnabhumi Airport as well as public buses for Pattaya Airport. Nation-wide, PEA plans to install 11 public charging stations for EVs in 2017 and then scale up the number to 74 by 2019 to cover more service areas. EGAT will provide electric buses and a charging station for visitors to its Smart Grid for EV Demand Management Learning Center. PTT also provides electric bus from its headquarters to the nearest Skytrain station.[39]

[39] A public transport system in Bangkok

Wind turbines at Khao Kho mountain
Photograph: Shutterstock

RENEWABLE ENERGY OUTLOOK



Wind turbines generating electricity at Leam Chabang
Photograph: Shutterstock

04

The previous chapters have outlined the energy context of Thailand, and provided a view on how the country's energy landscape will change over the next two decades based on government plans and targets in the TIEM, and specifically the AEDP. However, Thailand's energy system is highly dynamic as evidenced by how the AEDP has been revised and updated four times in the last couple of decades due to changing market dynamics and priorities for the country and its longer-term energy goals. Whereas the RRA approach detailed in the previous chapter is focused on analysing policy and institutional frameworks to assist countries in the deployment of renewables, based on current or planned policies and targets, IRENA's REmap analysis presented in this chapter provides a view on the longer-term potential of renewables in a country's energy mix and identifies where renewable energy could be scaled up beyond what countries are planning.

This chapter evaluates the additional potential for renewable energy technologies ("REmap Options") in Thailand's end-use sectors of industry, buildings and transport, as well as for power generation. The REmap Options assess renewable potential on top of the Reference Case, which is aligned with the AEDP 2015 targets. This section therefore provides a view on where Thailand can expand renewables even further, and what the associated cost and benefit of such an expansion would be. For more information about the REmap approach, methodology and sources please see Annex: REmap methodology, assessment approach and data sources.

The process for deriving the REmap Options, simplified, is as follows:

- A Reference Case to the year 2036 was developed based on forecasts submitted by Thailand and developed in co-ordination with experts during consultations and workshops. This case represents a current or expected policies scenario, is broadly in line with targets set forth in AEDP 2015, and is considered the baseline case of the analysis.

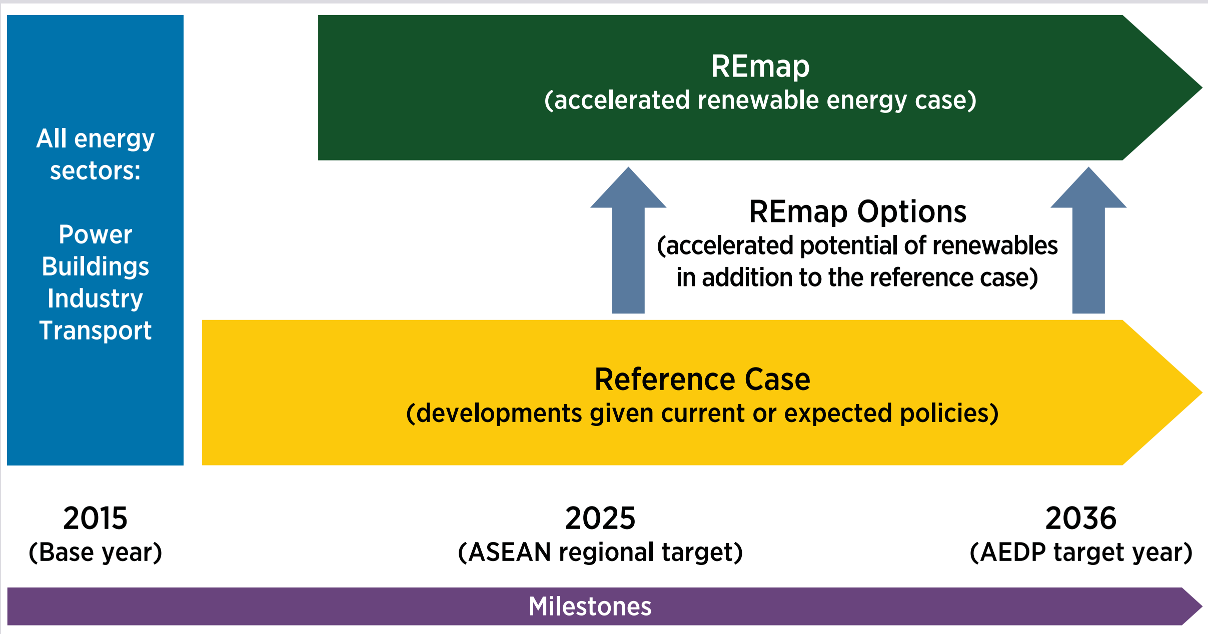
- The additional renewable energy options for the end-use sectors and the power sector were analysed based on various studies and assessments, consultation with experts from Thailand during the numerous workshops and meetings, and IRENA analysis.

- Fuel prices were forecast based on existing literature and IRENA estimates; and technology cost and performance criteria (*e.g.* capacity factors) were estimated to reflect conditions particular to Thailand.

- The REmap case is created to reflect how the REmap Options change the Reference Case in order to accelerate renewable energy deployment. The results of these Options are then quantified in terms of their costs, investment needs, and benefits resulting from lower levels of air pollution, carbon dioxide (CO_2) emissions and other impacts.

Figure 19 provides an overview of the key cases discussed in this chapter, and the years that will be highlighted. This chapter will focus first on presenting developments that are likely to occur in the Reference Case based on current or expected policies contained in AEDP 2015. Next the chapter will go into depth on the accelerated potential of renewable energy beyond what is expect to occur in the Reference Case. These accelerated possibilities are called the REmap Options, and the resulting high-renewables case is called the REmap case. Two future years will be highlighted: 2025 to provide a perspective relevant to the ASEAN regional target for renewable energy; and 2036 to provide a perspective relevant to Thailand's national policy making and AEDP 2015.

Figure 19. Overview of key year milestones for REmap and case description



4.1 Reference Case

The Reference Case represents a view on energy supply and demand based on current or planned policies. For the analysis, the Reference Case is based on energy demand and supply forecasts submitted by Thailand in a data questionnaire and then refined through a series of consultations and workshops. The result is a Reference Case that is broadly in line with expected developments as detailed by Thailand's AEDP.

The development of this case as the most likely development pathway for Thailand's energy system to 2036 is based on an understanding that Thailand is firmly committed to reaching energy targets and goals as set out in AEDP 2015 and TIEB. The government has a long history of comprehensive and planned energy blueprints and strategies, and institutional processes and mechanisms that work towards achieving the aims set out in these comprehensive plans.

Also, by aligning the Reference case with AEDP 2015, the REmap analysis can focus on identifying additional and accelerated renewable potential that goes beyond the targets that are currently part of this plan. As the AEDP has been revised numerous times over the past decade, this REmap analysis can provide a view on where the additional potential of renewables lies, with the aim of informing the Government of Thailand as to where new efforts and focus are needed.

This chapter does not go into detail on specific developments of the Reference Case or AEDP, as these developments and goals are detailed in depth in the TIEB and AEDP discussions in Chapters 2 and 3. However, some key changes in energy and economic indicators are discussed, and key energy shares and developments for the Reference Case are overviewed in the following sections.

Economic and energy demand developments

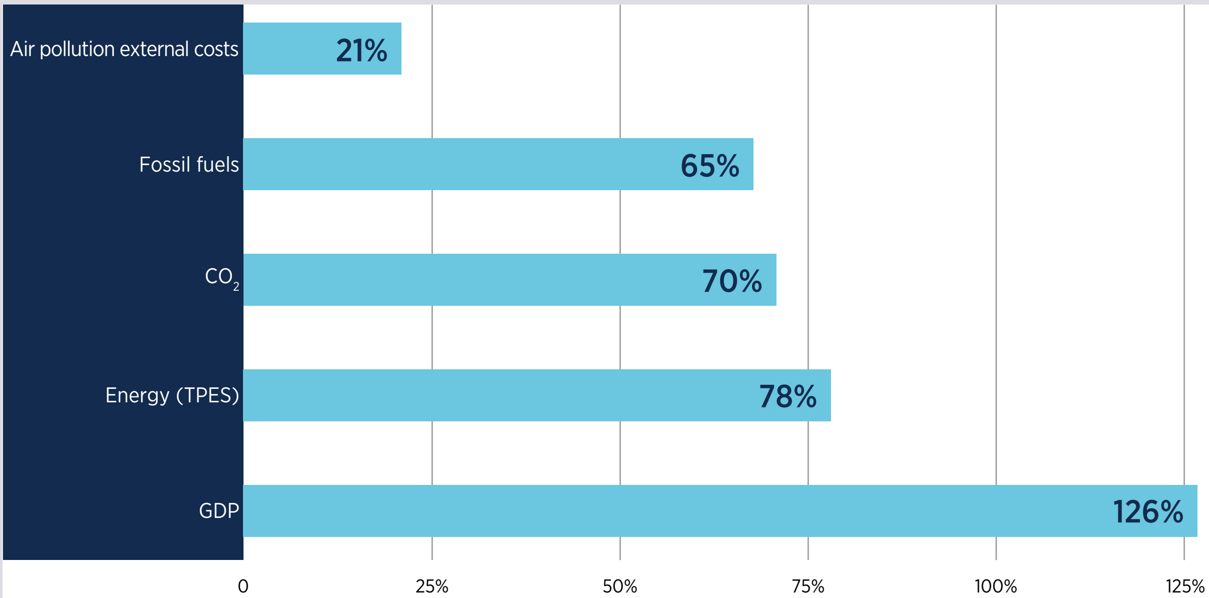
- *Over the period from 2015 to 2036 demand for energy will increase by 78%. Fossil fuel consumption will increase by almost 65%. However, demand for energy is lower than overall GDP growth, which increases by 126% over the period, indicating some decoupling of energy demand growth and economic growth.*

- *However, the resulting growth in energy demand, in particular fossil fuels, will result in increased imports of coal, natural gas and oil. With corresponding increases in energy-related CO_2 rising by over 70%, external costs relating to air pollution from fossil fuels increase by 21% to an average of USD 68 billion in 2036.*

Thailand is projected to have robust economic growth over the coming two decades, averaging around 3.9% per year over the period. The result is an increase in GDP of 126% by 2036. Over the period, demand for energy will increase by 78%, from 142 Mtoe in 2014 to 253 Mtoe by 2036 (see Figure 20). Demand for fossil fuels will grow by 65%, with coal increasing 160%, natural gas 60%, and oil products over 30%.

As Thailand's economy grows, it will see GDP increases that are higher than increases in energy demand, indicating significant improvements in energy intensity of the country's economy. Energy intensity will decrease by more than 20% from 134 tonnes of oil equivalent (toe) per USD 1 million at purchasing power parity (PPP) in 2015 to 106 toe per USD 1 million PPP by 2036. This is shy of the AEDP 2015 goal of a 30% decrease over the period, but it is encouraging to see this improvement already occurring in the Reference Case, and is an indication that steps are being made to meet the goals for energy efficiency efforts in the TIEB.

Figure 20. Increase in key economic and energy indicators, 2015-2036 (Reference Case)



Note: TPES = total primary energy supply.

However, despite this, there are negatives. For instance, energy-related CO_2 emissions will increase from 246 Mt in 2014 to 418 Mt in 2036. This will be driven largely by increases in emissions from the power generation and industrial sectors, with around half of the increase coming from increased use of coal, which brings with it not just higher CO_2 emissions, but also increased levels of air pollution. Additionally, the use of oil will increase by over 30%, much of it in urban areas, where its effects on local air pollution are particularly acute.

Therefore, external costs relating to air pollution from fossil fuels, such costs largely resulting from adverse effects on human health, will increase by on average 21% by 2036. Annual costs will increase from a range of USD 23-92 billion in 2015, to between USD 28 billion and USD 108 billion by 2036 (with an average of USD 68 billion). Most of the increases will come from greater use of fossil fuels, in particular coal, in the industrial and power sectors. However, the largest source of external costs related to air pollution, representing around half of the costs, will remain the use of oil products in the transport sector due to high associated damage to human health in urban areas.

The overall picture of development in the Reference Case to 2036 is consequently mixed. It is encouraging to see the improvements in energy intensity, driven by a variety of factors that include shifts to modern energy, more efficient energy conversion, deployment of renewable energy, and improvements in energy efficiency in end uses. But at the same time, the increased use and dependence on fossil fuels drives increases in imports, higher levels of CO_2 and more air pollution.

Key source and technology developments

- *The share of renewables increases in all sectors in the Reference Case by 2036 except in the buildings sector. Despite sustained growth in renewable power, the renewable share of power generation only increases marginally due to similar increases in overall power demand. In the end-use sectors, the use of fuels and other direct uses of renewable energy for thermal and transport applications increase largely based on the use of bioenergy. Meanwhile, in the buildings sector the decrease is led by the replacement of both traditional bioenergy and modern bioenergy with fossil fuels, largely LPG.*

- *Total system power capacity will increase by over 60%, with growth in coal, natural gas, bioenergy, solar PV and wind. Natural gas is still expected to be the main source of electricity generation, accounting for around 60% of domestic generation.*

In the Reference Case the share of renewables increases in all sectors except in the buildings sector (see Table 8). Overall the renewable share of TFEC increases by around two-thirds to 28%, but remains short of the 30% target for 2036. The renewable power share of domestically produced electricity (which excludes imports of large hydropower) increases only marginally to 18%, and despite significant growth in renewable power, its relative share does not increase much due to significant overall growth in power demand of just under 80%. However, if imported electricity is considered, and it is assumed to be mostly hydroelectric, then the share of renewable power increases to around 25%.

In the end-use sectors of buildings, industry and transport, increases in the renewable share of fuels and direct uses of energy for thermal applications and transport are largely driven by increased use of bioenergy. In the transport sector, significant increases in biodiesel and compressed biogas, and more modest increases in bioethanol, drive a surge in the share of renewable energy in transport fuel demand from 6% to 26%. This is the most pronounced increase in the renewable share of any sector, and driven entirely by the highly aggressive supply of bioliquids envisioned by AEDP 2015.

Industry sees more than a tripling of bioenergy use largely in the form of solid biomass residues, which are likely to be the product of increases in residue supply from the production of liquid biofuels for the transport sector. The result is that the industrial sector has the higher renewable share of fuels and direct use of energy, with over 40% by 2036. The buildings sector sees a decline in its renewable share despite some increases in solar thermal for water heating in buildings. The significant decline in bioenergy use in buildings, and a shift to both LPG for cooking and electrification, result in a renewable energy share of just 4% in 2036.

Table 8. Key renewable energy shares by sector in the Reference Case

	2015	2025	2036
Electricity generation (domestic)	13%	17%	18%
Industry (fuels, direct uses)	33%	38%	43%
Transport (fuels)	6%	9%	26%
Buildings (modern) (fuels, direct uses)	26%	7%	4%
TFEC – (modern)	17%	20%	28%
TPES – (modern)	13%	15%	22%

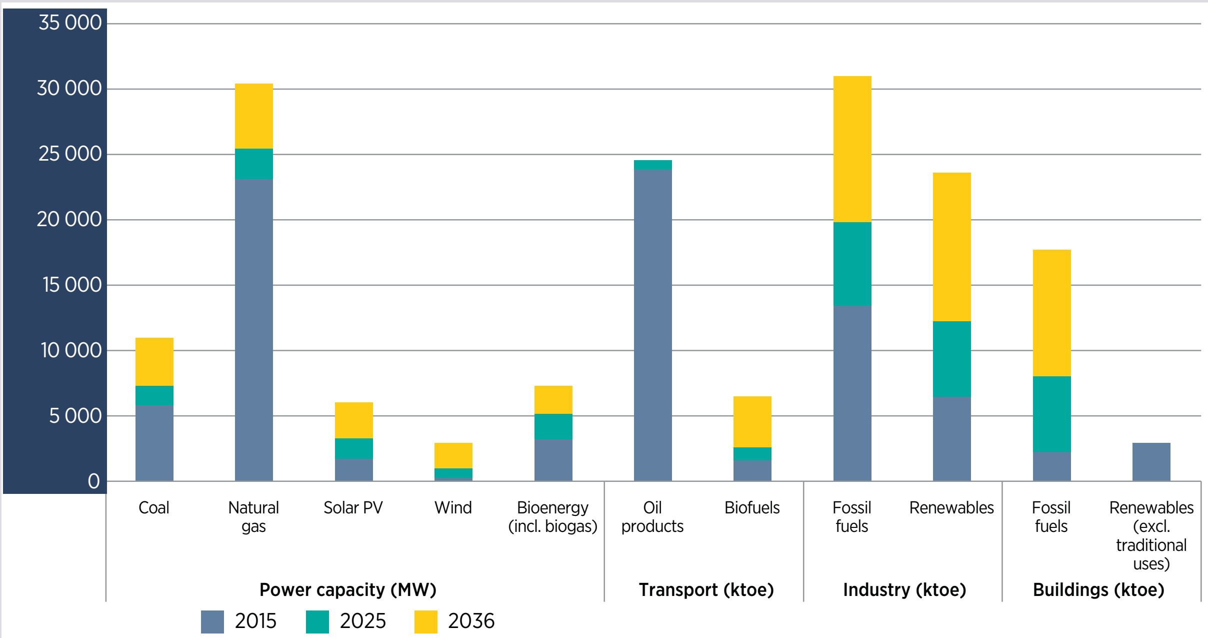
Note: End-use sector shares (industry, transport and buildings) show the share of renewable energy in the each sector's energy demand excluding electricity, i.e. fuels and other direct uses of energy.

Total system power capacity will increase by 60% from 38 GW in 2015 to 62 GW in 2036. Capacity additions take place for coal, natural gas, solar PV, bioenergy and wind power (see Figure 21). Natural gas will remain the dominant source of electricity generation, accounting for around 60% of domestic supply according to the Reference Case in 2036.

In the transport sector, fuel demand growth is limited over the period, only increasing by 14%. Oil products remain the dominant fuel source, supplying around 70% of the sector's energy needs by 2036. However, significant increases in the supply of liquid biofuels occur, increasing their share of the sector's energy from 6% in 2015 to 20% by 2036. Biodiesel from oil palm, and bioethanol from cassava and sugarcane molasses are expected to be the main sources of bioliquids, with around two-thirds being in the form of biodiesel. In addition, there is significant growth in compressed biogas from wastes and energy crops that supplies 6% of transport sector energy by 2036. The remainder is met largely with CNG and some electricity.

The industrial sector sees the highest share of renewable energy due to the significant use of biomass residues, mostly driven by the growing output of biomass processing industries, such as sugarcane, cassava and oil palm, and by surplus biomass residues that are currently not used. Biogas from biomass processing wastes also contributes to the increase in renewable energy share. The share of sector energy demand met by renewables, almost entirely bioenergy, will increase from a quarter to over 40%. This growth is tied in part to the increased supply of residues resulting from the increases in liquid biofuel production. The buildings sector sees the only decline in renewable share, the result of a decrease in the use of bioenergy and the significant growth in the use of oil products, largely LPG, for cooking.

Figure 21. Selected physical unit changes in the Reference Case: Fossil and renewable energy, 2015-2036



4.2 REmap results

This section outlines the REmap Case, which is an assessment of the accelerated potential of renewable energy in Thailand. The key findings that are detailed relate to the REmap Options, which are technologies and sources of renewable energy that have additional potential to be utilised or deployed on top of development expected in the Reference Case, which is broadly in line with AEDP 2015. Therefore, this section's main aim is to outline where the additional potential of renewable energy lies in Thailand beyond AEDP 2015, deployable by 2036.

This section also describes what is needed at the sector and technology levels to achieve this level of higher renewable energy deployment. The REmap Options explore the potential to increase renewables across all sectors of Thailand's energy system – it is a mixed approach aimed at maximising renewable energy deployment – and address options in power, thermal uses, transport and cooking needs. For further information on the approach used to determine the REmap Options and sources, please see Annex: REmap methodology, assessment approach and data sources.

Drivers for renewable energy

The REmap Options identify areas across the entire energy system of Thailand where additional renewable energy potential lies. The criteria to select these options are not solely based on cost, but also on additional motivating factors that incline governments to support increased deployment of renewable energy technologies. These factors can include efforts to improve energy security, promotion of domestic industry, and efforts to improve local health and reduce environmental damage.

However, the REmap Options do show that renewables are in many cases the least-cost option for energy supply in Thailand. The cost case is even more appealing when considering benefits that arise from reduced air pollution and CO_2 emissions. As the costing section shows, the grouping of technologies identified in REmap not only reduces energy system costs as a whole – meaning lower overall energy costs for consumers – but also results in a similar decrease in external costs due to reduced air pollution and environmental damage.

Additionally, the value of investment certainty with renewables is appealing. Fossil fuels have price volatility risk, particularly when an increasing share of those fossil fuels are imported, as is the case in Thailand. Valuing this risk is difficult, but should be considered when evaluating energy system investments. The renewables identified in this section either have no fuel price volatility (such as for solar, wind or hydro resources), or in the case of bioenergy are based largely on the local agro-economy, which generally affords government more control over the market.

Subsequently energy security and diversification are a key driver in Thailand's energy policies. The country currently imports around 60% of its energy. With declining domestic production of natural gas, and limited recoverable coal and oil, the country will see an increase in this share over the coming decades unless other indigenous energy resources can be scaled up to fill the gap (ACE, 2015a). Renewables provide a means to decrease dependency on imported fossil fuels, particularly because local renewable resources are underutilised and significant additional potential exists as detailed in Chapter 3.

The following sections go into greater depth on what exploiting this additional potential entails, in which technologies and sectors. It will also quantify those technologies and sources in terms of their costs, benefits and investment needs. In all, the findings show that domestic industry can thrive if more renewable energy is deployed – from the local bio-economy utilising the entire value chain of locally produced bioenergy, to local expertise in solar thermal technologies, and the development of low-cost electricity from solar PV and wind.

Summary of REmap findings

- *In REmap, the share of renewables increases across all sectors. The two largest sectors that see increases are power and buildings, but increases are also seen in transport and industry. Overall renewable energy can provide 37% of Thailand's TFEC in 2036, surpassing by a wide margin the government's current target of 30%.*

- *The renewable power mix moves from one dominated by hydropower and bioenergy, to a much more diverse mix of technologies that includes sizable generation from solar PV and wind. In REmap in 2036, 25% of domestic generation is supplied from renewable sources, and if imported hydropower is included, then almost 30% of electricity is from renewable sources.*

- *Renewable use in the end-uses sectors is also evident in the REmap findings, with high shares in both industry and buildings. The use of all renewables in TFEC increases from 19 Mtoe in 2015, to 38 Mtoe in the Reference Case and 49 Mtoe in REmap by 2036 – an increase of 150% over the period.*

REmap identifies additional renewable energy potential across all sectors of Thailand. However, due to significant renewables growth already occurring in the industrial and transport sectors in the Reference Case – largely from the bioenergy-based targets set forth in AEDP 2015 – most of the additional potential is identified in the power and buildings sectors. The power sector sees significant growth due to untapped potential particularly in solar PV, but also in wind, whereas the buildings sector sees growth from the utilisation of modern bioenergy and slowing the uptake of LPG.

Overall renewable energy can provide 37% of Thailand's TFEC, surpassing the government's current target of 30%. Across the sectors, the share of renewable energy will vary from a low of 27% in transport to as high as 50% in industry. While the share of renewable energy in domestic power generation will be 25%, when including imported hydropower the share increases to almost 30%. The high share of renewables in industry and buildings are due, in part, to the table showing the share of renewable energy just for fuels and direct uses, therefore excluding electricity, which if included, would lower the renewable share in the sectors' total final energy.

Table 9. Renewable energy shares in 2036: different cases compared

	2015	Reference Case 2036 *	REmap 2036 **
Electricity generation (domestic)	13%	18%	25%
Industry (fuels, direct uses)	33%	43%	50%
Transport (fuels)	6%	26%	27%
Buildings (modern) (fuels, direct uses)	26%	4%	38%
Total final energy consumption (modern)	17%	28%	37%
Total primary energy supply (modern)	13%	22%	28%

* Reference Case = Expected outcome of today's plans and policies
** REmap = Achievable outcome with accelerated uptake of renewables

Several key findings are evident when looking at how these shares translate into energy supply as viewed in final energy terms (Figure 22). One is that renewable power generation sees its relative importance grow as a share of renewable energy consumed in the country. However, the renewable power mix moves from one dominated by hydropower and bioenergy to a much more diverse mix of technologies that includes strong growth in solar PV and moderate growth in wind power capacity. Renewable power consumed in the country quadruples over the period to 2036.

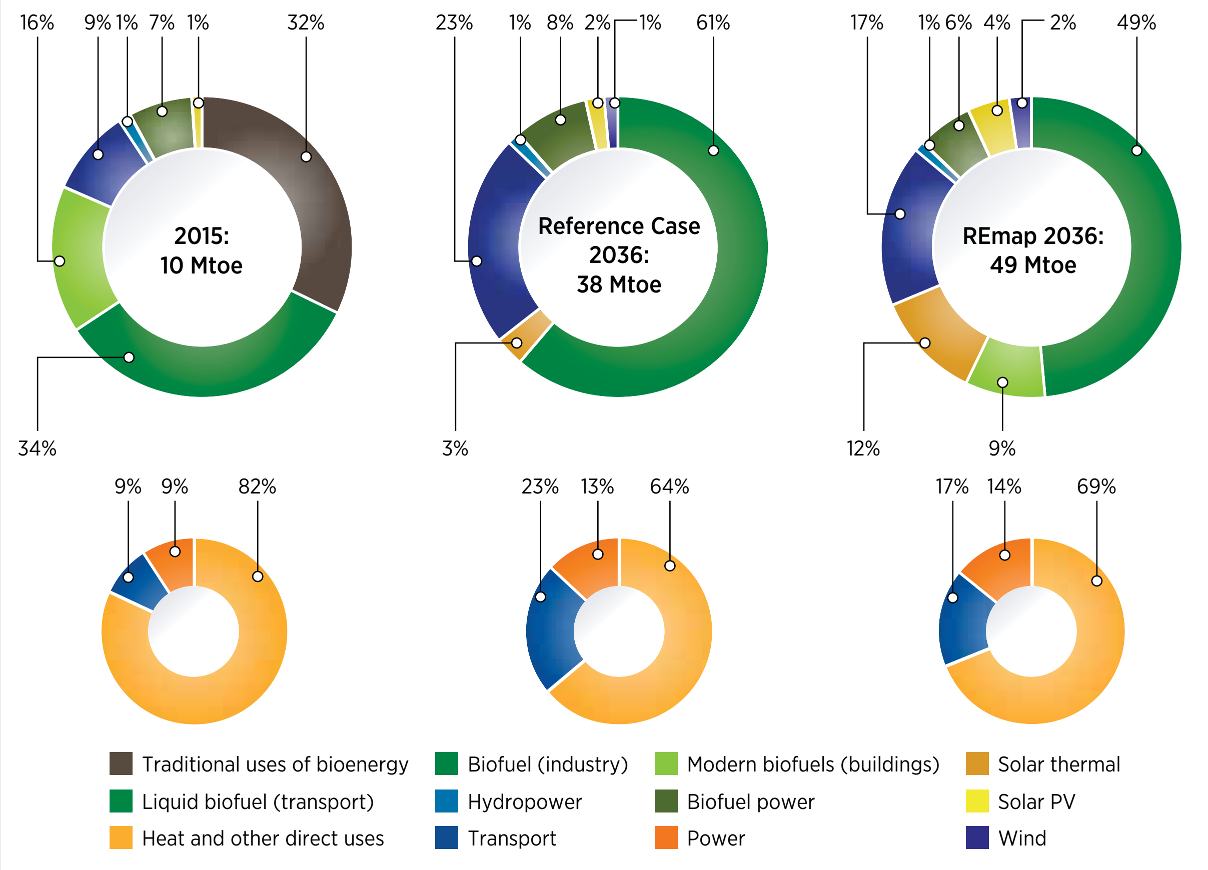
Another finding is the continued importance of renewable energy use in the end-uses sectors of buildings, industry and transport. In these sectors energy is needed in the form of fuels and direct use for thermal, cooking and transport applications. In final energy terms these applications are dominant, and generally make up 85-90% of renewable energy use over the period. Bioenergy remains the dominant source in the end-use applications due to its ability to be used as a source of heat and transport fuel. However, the REmap Options demonstrate limited additional bioenergy consumption due to the aggressive targets and growth already occurring in AEDP 2015, as reflected in the Reference Case.

For instance, in transport, REmap assumes no additional use of biodiesel, bioethanol or compressed biogas for CNG vehicles. In industry, the use of biomass residues and biogas increases slightly, but only by around 3%, boosted by the growth in the biomass processing industry and by using a larger and more diverse pool of biomass residues from agriculture due largely to better collection methods. Traditional uses of bioenergy in the residential sub-sector are phased out between 2025 and 2030 in the Reference Case. However, REmap assumes that a share of this traditional use of bioenergy can be combusted efficiently and sustainably, with the use of modern cookstoves and biogas digesters, resulting in an increase in modern bioenergy in the residential sector by reversing the uptake of LPG instead.

Solar thermal is also an important source of renewable energy in the end-use sectors. The technology can provide domestic hot water in the residential sector, but also in sub-sectors such as tourism. In industry, Thailand has a history of solar thermal systems providing low-temperature heat and pre-heating services. The Reference Case does see an increase in both solar thermal systems in the buildings and industrial sectors, providing around 2% of heating demand by 2036 (excluding electricity). In REmap significant additional potential has been identified, raising the share of heating demand met by solar thermal across the two sectors to just over 10%.

In total, the amount of renewable energy used in Thailand will increase from 19 Mtoe in 2015 to 38 Mtoe in the Reference Case, and increase further to 49 Mtoe in REmap – a 150% increase over the 2015 level. This would lead to an increase in the share of modern renewables in TFEC from 13% in 2015 to 37% in REmap.

Figure 22. Renewable energy in total final energy consumption: Reference Case and REmap, 2015-2036



Solar power station in Thailand
Photograph: Shutterstock

Table 10. Roadmap table, 2015-2036

Thailand			Unit	2015	Reference Case 2025	Reference Case 2036	REmap 2025	REmap 2036
Energy production and capacity	Power Sector	Total installed power generation capacity	GW	38.5	45.9	61.6	49.7	74.2
		Renewable capacity	GW	9.0	12.6	19.7	17.8	34.0
		Hydropower (excl. pumped hydro, domestic)	GW	3.5	3.1	3.3	3.2	3.4
		Wind	GW	0.2	0.9	3.0	2.3	6.0
		Biofuels (solid, liquid, gaseous)	GW	3.2	5.1	7.4	5.1	7.4
		Solar PV	GW	2.0	3.4	6.0	7.2	17.2
		CSP	GW	0.0	0.0	0.0	0.0	0.0
		Geothermal	GW	0.0	0.0	0.0	0.0	0.0
		Marine, other	GW	0.0	0.0	0.0	0.0	0.0
		Non-renewable capacity	GW	29.5	33.3	41.9	31.9	40.2
		Total electricity generation	TWh	178.9	237.5	319.3	239.4	336.8
		Renewable generation	TWh	22.7	40.2	58.3	50.0	84.2
		Hydropower	TWh	3.1	5.4	5.7	5.8	6.3
		Wind	TWh	0.4	1.8	6.3	5.3	13.9
		Biofuels (solid, liquid, gaseous)	TWh	17.1	28.3	37.9	28.3	37.9
		Solar PV	TWh	2.2	4.6	8.4	10.5	26.2
		CSP	TWh	0.0	0.0	0.0	0.0	0.0
		Geothermal	TWh	0.0	0.0	0.0	0.0	0.0
		Marine, other	TWh	0.0	0.0	0.0	0.0	0.0
		Non-renewable generation	TWh	156.2	197.3	261.0	189.4	252.6
Final energy use - Direct use	Building and industry	Total direct uses of energy	Mtoe	31.7	44.1	72.9	43.9	72.0
		Direct uses of renewable energy	Mtoe	15.8	16.1	24.2	19.8	33.7
		Solar thermal – Buildings	Mtoe	<0.1	0.2	0.6	1.0	2.6
		Solar thermal – Industry	Mtoe	<0.1	0.1	0.5	1.1	3.1
		Geothermal – Buildings and Industry	Mtoe	0.0	0.0	0.0	0.0	0.0
		Bioenergy (traditional) – Buildings	Mtoe	6.2	3.1	0.0	3.1	0.0
		Bioenergy (modern) – Buildings	Mtoe	3.1	0.6	0.0	2.2	4.2
		Bioenergy – Industry	Mtoe	6.5	12.1	23.0	12.4	23.8
		Non-renewable – Buildings	Mtoe	2.4	8.1	17.7	5.7	11.1
		Non-renewable – Industry	Mtoe	13.5	19.9	31.1	18.4	27.2
	Transport	Total fuel consumption	Mtoe	28.5	30.0	32.4	29.6	31.3
		Liquid biofuels	Mtoe	1.8	2.6	6.5	2.6	6.5
		Compressed biogas	Mtoe	0.0	0.0	2.0	0.0	2.0
		Non-renewable fuels	Mtoe	26.7	27.4	23.9	27.0	22.7
TFEC			Mtoe	79.5	95.8	134.7	95.4	133.1
TPES			Mtoe	142.2	177.7	253.6	178.4	257.9
RE Share	RE share in electricity generation			13%	17%	18%	21%	25%
	RE share – Buildings – final energy use, direct uses (modern)			26%	7%	4%	26%	38%
	RE share – Industry – final energy use, direct uses			33%	38%	43%	42%	50%
	RE share – Transport fuels			6%	9%	26%	9%	27%
	Share of modern RE in TFEC			17%	20%	28%	25%	37%
	Share of modern RE in TPES			13%	15%	22%	19%	28%
Financial indicators**	Incremental system costs (USD bln/yr in column yr)			N/A	N/A	N/A	-0.6	-1.2
	RE investment needs (USD bln/yr annually [period average])			N/A	N/A	1.3	N/A	2.6
	Investment support for renewables (USD bln/yr in column yr)			N/A	N/A	N/A	0.2	0.6
	Reduced externalities – air pollution (avg.) (USD bln/yr in column yr)			N/A	N/A	N/A	0.5	1.2
	Reduced externalities – CO_2 (USD 50/tonne) (USD bln/yr in column yr)			N/A	N/A	N/A	1.0	2.4
	CO_2 emissions from energy (Mt/yr)			246	313	418	293	369

*Lower heating value is used.
**USD2010.
Notes: bln = billion; BF = blast furnace; CO = coke oven; CSP = concentrated solar power; DH = district heat; EJ = exajoules; Mt = megatonne; N/A = not applicable; PJ = petajoule; RE = renewable energy; TFEC = total final energy consumption; yr = year

Power sector

- *Electricity demand will grow by almost 90% between 2015 and 2036 to over 325 TWh annually. Renewable power generation grows significantly in both the Reference Case and REmap; however, due to significant overall growth in electricity demand, the increase in renewable energy share is modest. The overall renewable energy share in generation from domestic power producers will reach 25% in REmap in 2036, up from 18% in the Reference Case, and 13% in 2015. If imported hydro is also considered, the share would be 4-5 percentage points higher.*

- *Power system capacity will increase from 39 GW in 2015 to 62 GW in the Reference Case, and beyond that to 74 GW in REmap. Natural gas will remain the largest power capacity source; however, in REmap the second-largest is solar PV, followed by coal and then wind.*

The power sector in Thailand will see important and substantive shifts over the next two decades. In an attempt to diversify supply in view of declining natural gas production, the power system sees the need to install more coal- and renewables-based power generation. However, the future of coal is uncertain, and while additions are expected, REmap shows that their additions could be slowed and instead increased power demand met with higher deployment of renewable power technologies such as solar PV and wind.

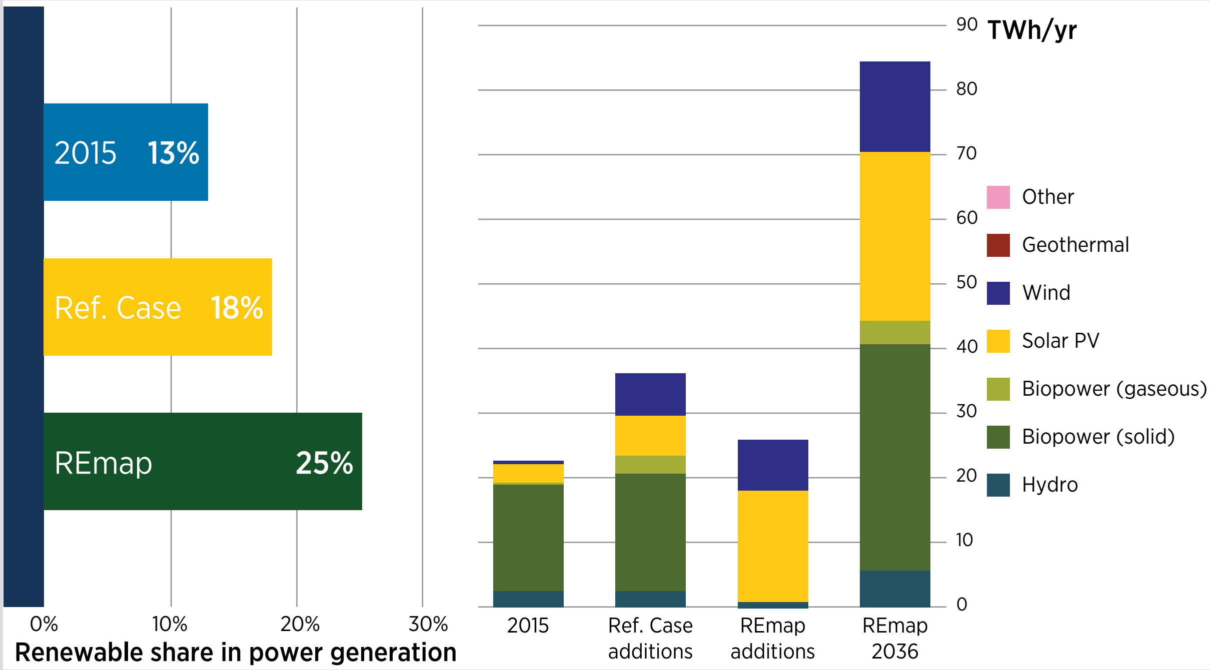
Electricity demand will grow between 2015 and 2036 by almost 90% to over 325 TWh per year. Renewable power generation grows significantly in both the Reference Case and REmap; however, due to significant overall growth in electricity demand, the increase in the renewable energy share is modest. As can be seen in Figure 23, the overall renewable energy share in power generation from domestic generation will reach 25% in REmap in 2036, up from 18% in the Reference Case and 13% in 2015. Domestic power system capacity will increase from 39 GW in 2015 to 62 GW in the Reference Case, and beyond that to 74 GW in REmap. The increase in REmap is due to both increased electrification in end-uses, such as from EVs, but also the lower capacity factor of solar and wind necessitating more installed capacity.

Imported electricity will also grow, mainly from hydropower sources from regions north of Thailand. This is already reflected in the Reference Case as AEDP 2015 targets an increase in imported hydropower from 7% to over 10% of electricity demand.

The renewable power additions occurring between 2015 and 2036 differ between the Reference Case and the REmap Options (see Figure 23). Roughly half of renewable power generation additions in the Reference Case are from bioenergy sources, largely industrial co-generation linked to high planned utilisation of biofuel residues, with the remainder split between wind and solar PV. Total renewable power generation will increase by 36 TWh over the period – an increase of around 150%.

Solar panels in the mountains, Krabi
Photograph: Shutterstock

Figure 23. Renewable share in the power sector and generation additions, 2015-2036

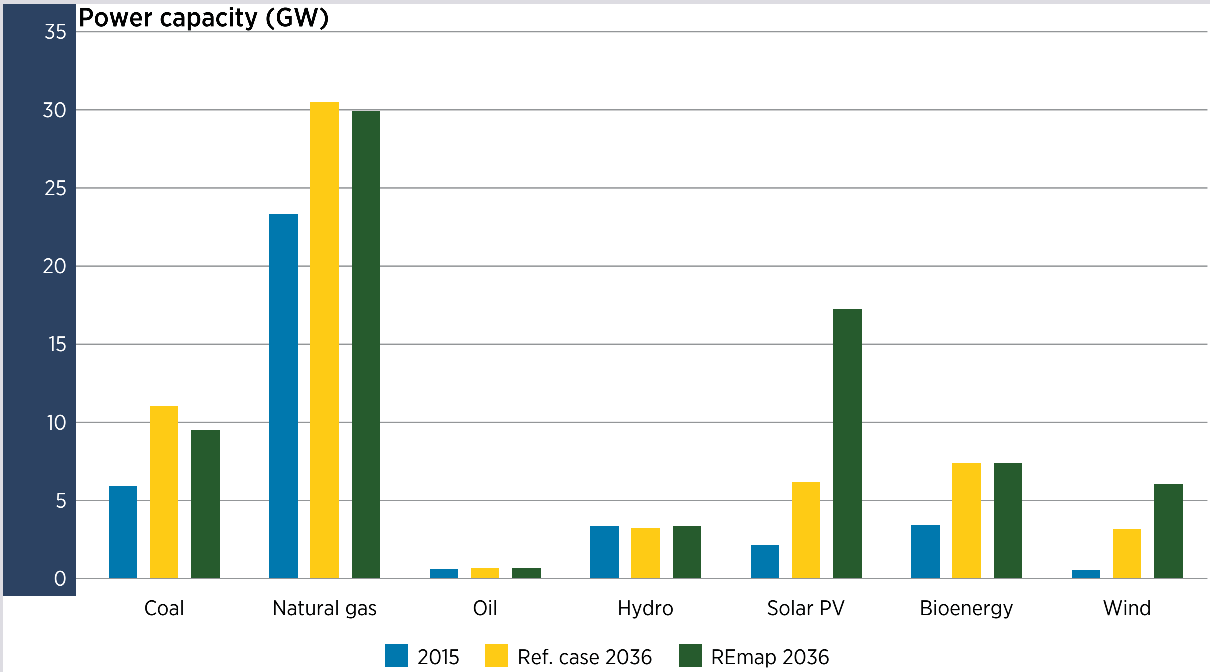


The REmap Options see power generation additions that differ from the Reference Case. The largest new source is solar PV, followed by wind. Even so, in REmap natural gas remains the largest generation source, with half of the power system capacity and around two-thirds of generation. However, because of the REmap Options, by 2036 solar PV becomes the second-largest renewable power source (behind bioenergy) and fourth overall. This significant growth in solar PV is largely the result of rapidly improving market conditions for solar PV, and the ability for new plants to be built quickly and in a more distributed manner than traditional central station power plants.

It is also important to note the growing importance of wind power, which sees an increase from around 3 GW in the Reference Case to 6 GW in REmap in 2036. Declining wind turbine costs are a driver, and even though 6 GW is significant growth over the 0.4 GW in operation as of 2015, recent studies show wind potential as high as 14 GW in areas with favourable wind speeds (6 m/s). Wind generation will increase in REmap to provide just over 4% of gross electricity generation – roughly half of the 8% supplied by solar PV. In total, these two variable sources of electricity will provide 12% of Thailand's gross inland supply.

Thermal power generation from coal and bioenergy have roughly similar capacities in REmap in 2036 (see Figure 24). Coal-fired capacity declines in REmap from the Reference Case; however this is modest, and its decline could be greater if the government decides to replace new coal plants with either natural gas-fired or renewables capacity. Some in the country have emphasised the need for coal as a means of energy diversification and to avoid overreliance of natural gas, which is seeing declining domestic supply. However, as REmap shows, the better option would be to consider expanding renewables further to offset increases in coal (which will largely need to be imported).

Figure 24. Power sector capacity developments, 2015-2036



Bioenergy-based generation will remain the largest domestic source of renewable electricity generation. This is due entirely to developments occurring in the Reference Case according to AEDP 2015. The use of bioenergy-based electricity generation is widely developed in Thailand and is consolidated in many industries. Most of the power capacity is installed in biomass-based industries that have easy access to reliable sources of residual biomass produced as part of their operations. The main industries are the sugarcane industry, where bagasse is widely used in co-generation systems, the palm oil industry, which uses oil palm residues in power and heat generation, and the cassava industry, where both solid and liquid wastes are used for biogas production and power generation. A significant part of the electricity generated in those plants is, in fact, used by the industry itself, in self-generation arrangements, and a smaller share is exported to the electricity grid. Also, significant amounts of rice straw and husks are used in independent power plants, as well as biomass residues from rubber trees and maize (straw and cobs). In addition to solid biomass residues, biogas produced from biomass wastes and wastewater is widely used for electricity generation in Thailand too. The country has an impressive amount of biogas power plants in different sectors of the economy, including the sugarcane, palm oil and cassava sectors, slaughterhouses, food processing industry and others.

VRE integration in Thailand's power system

If all the REmap Options were deployed, the share of VRE (solar PV and wind) in Thailand's power system would stand at 31% of system capacity, and 12% of annual generation in 2036. REmap does not analyse what types of flexibility measures might be needed to accommodate this amount of variable production capacity. However, IRENA has significant project data and analysis on the topic from other countries, regions and for general power system contexts. This section details some of the key findings from those studies and other literature relevant to Thailand. It provides a qualitative view and applies them to the Thai energy context. However, further study and analysis needs to take place to provide a better understanding of how electricity end users, local grid and transmission operators, and government regulators can start to plan for a power system with increasing shares of VRE power technologies.

Renewable energy resources such as solar and wind are typically operated differently from conventional power generation plants due to their variability. Depending on the share of VRE and the power system features, these differences may prompt changes in the way the systems are planned and operated to guarantee an efficient and reliable supply of electricity. The variability of VRE and limitations in forecasting its production with high accuracy can pose new challenges for the planning and operation of the power system. If high shares of VRE are to be integrated, the system must be able to deal with additional uncertainty and variability in its operation.

In the case of Thailand, the REmap Options result in a VRE share of only 12% of annual domestic electricity production. While this is not a high share, and many power systems around the world today integrate a similar share without issue, it is important to understand how power systems move to increasing proportions of VRE and what efforts may be needed. While it is likely that Thailand will not require additional flexibility measures to integrate the VRE detailed in this study, as the country moves beyond the envisaged share of VRE in the post-2036 timeframe, a view on the longer-term planning for the country's power system is needed and that planning should begin today.

A recently published IRENA report, *Planning for the Renewable Future: Long-Term Modelling and Tools to Expand Variable Renewable Power in Emerging Economies*, part of AVRIL ("Addressing Variable Renewable Energy in Long-Term Energy Planning"), explains the best practices in long-term planning and modelling for the management of high shares of VRE (IRENA, 2017c). Requirements for VRE generators to support the stable operation of the system must be identified and established. One way is through updates to the existing grid codes. IRENA's recent report *Scaling Up Variable Renewable Power: The Role of Grid Codes* (IRENA, 2016b) explains various aspects of grid connection code development with country illustrations that might serve as a reference for Thailand's future grid code development in the context of increasing shares of VRE.

Additional efforts include strengthening and expanding transmission infrastructure. As part of EGAT's network development plan, a 500 kV transmission line equivalent to 13% of total grid capacity will be further extended by 2019 to facilitate the country's growing renewables potential and to ensure electricity security with adequate flexibility of generating fleet (IEA, 2016).

Another method of increasing grid flexibility is the use of so called "smart grids". The IRENA report, *Smart Grids and Renewables: A Guide for Effective Deployment* (IRENA, 2013), details how effective deployment of smart grids can play a crucial role in enabling higher shares of renewable power, facilitating its smooth integration. They also support the decentralised production of power and enable the creation of new business models through enhanced information flows. Additionally, consumer engagement and improved system control provide flexibility on the demand side. Another IRENA report, *Smart Grids and Renewables: A Cost-Benefit Analysis Guide for Developing Countries* (IRENA, 2015b) provides insight into cost-benefit analysis of smart grid systems in developing countries, which could be potentially applicable to Thailand.

Nevertheless, Thailand has already initiated various activities to deploy smart grids, one good example being the Smart Grid Roadmap announced by PEA. The objective of this roadmap is to apply advanced and new technologies to optimise power system operation in the country. PEA recently announced its latest investment of THB 2 billion (USD 58 million) in smart grid deployment in five Thai cities (Pattaya, Chiang Mai, Phuket, Nakhon Ratchasima and Hat Yai) (Metering, 2017). The first smart grid pilot project by PEA will be implemented in Pattaya due to the high-energy consumption rate in the city (Metering, 2015). As part of this project, PEA aims to install 120 000 smart meters in residential areas and construct a data centre for processing the energy data, which will essentially aid PEA to understand consumer behaviour and to utilise this data to improve the energy management activities (IEA, 2016).

Other efforts include the recent approval of a smart grid national plan by NEPC, focusing on implementation of three to five smart grid pilot test projects (the tentative locations include Muang district and Mae Sariang in Mae Hong Son province, Bangkok, Nonthaburi and Samut Prakan) with an estimated total investment of THB 5 billion (USD 145 million) over the next five years. Implementation will be done by state-owned power utilities such as EGAT, PEA and MEA (The Nation, 2016). The aim of these pilot projects is to reduce the country's peak power demand by a total of 350 MW (The Nation, 2016).

Apart from this, Thailand has pursued projects for solar-powered hydrogen energy storage systems. One such project involves four family houses in a Phi Suea housing development and shows a potential route for the future of renewable energy storage in the country (The Green Optimistic, 2015). Furthermore, in 2016, Southeast Asia's first megawatt-scale renewable hydrogen-based energy storage project was awarded by EGAT. This energy-neutral building will convert surplus electricity from wind generation – from the Lam Takhong Wind Turbine Generation Project – to hydrogen during off-peak hours. During peak hours the hydrogen fuel cells will be able to generate sufficient electricity for the centre (Global News Wire, 2016).

The establishment of pricing related to smart grids is an important aspect that is yet to be considered in the country (GIZ, 2013). Additionally, smart grid implementation involves various challenges, which include: low electricity tariffs with high capital costs and concerns on payback period; how to do both the implementation of renewable energy programmes in parallel to smart grid deployment; and adequate skills development to operate and maintain the smart grid systems in future (GIZ, 2013).

IRENA's publication on adapting market design to high shares of VRE (IRENA, 2017a) highlights that distribution companies will play a key role in the deployment and operation of grid-related infrastructure, such as public EV charging stations or distributed storage. Thailand aims to bring in nearly 1.2 million EVs over next two decades (Insideevs, 2016) and REmap identifies greater potential, with almost 1.5 million on the roads by 2036. In addition to the MoE promoting the 150 charging station installations nationwide, automobile companies plan to open charging stations to promote the current range of plug-in hybrid vehicles (Nationmultimedia, 2017). The vehicle-to-grid scheme allows EVs to participate in grid ancillary services such as frequency regulation, load shifting, demand response, or energy management support in the home (IRENA, 2017b)

Finally, the potential of renewables to revolutionise off-grid, mini-grid and island systems is now evident. Hundreds of Thai islands possess huge potential for hybrid energy system deployment. Small islands provide a valuable opportunity for testing new technologies and operational modes for renewables. Islands generally have isolated power grids, often with high shares of renewable power (IRENA and IEA-ETSAP, 2015). In principle, the electricity demand of such islands with a peak load of a few hundred kilowatts could be effectively met by variable renewables, such as wind and PV power and with adequate energy storage to balance supply and demand (IRENA, 2012). Generally, islands are powered by diesel generation, which is often oversized to meet peak demand and not meant to operate below 30% of capacity, forming an expensive generation option with high emissions (IRENA, 2015a). In such cases, battery storage seems to be an economic and viable option. Battery storage technology may be utilised to aid renewable energy integration, reduce reliance on diesel and gas generation, and lower the costs of electricity (IRENA, 2015a). A case study performed for an isolated island in Thailand reveals that a hybrid PV/diesel energy system can decrease the cost of electricity from USD 0.429/kWh to USD 0.374/kWh when compared to the existing diesel-based system, with PV contributing to 41% of the total output (Peerapong and Limmeechokchai, 2017).

Planning for a future with a higher share of VRE needs to start today. Resources such as those listed in this section are a starting point for policy makers to better understand the broad scope of technology solutions, regulations and market approaches that address the issue. However, further study and analysis need to take place to provide a better understanding of how electricity end users, local grid and transmission operators, and government regulators can start to plan for a power system with increasing proportions of variable renewable power technologies.

Buildings sector

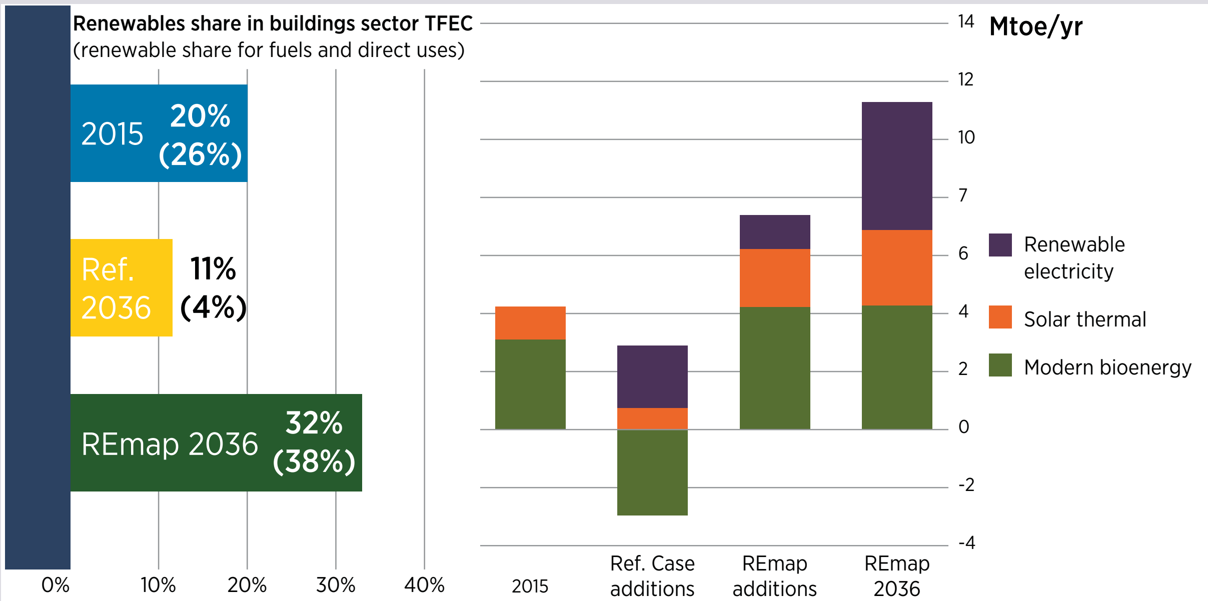
- *The buildings sector sees growth in final energy demand of 75% in the period 2015-36 in the Reference Case. Almost all of this increase is derived from two sources: oil products, mainly LPG; and electricity. Modern bioenergy decreases in the Reference Case, and as a result the share of modern renewables decreases from 20% to 11%.*

- *The REmap Options reverse the decline and result in almost a tripling of the renewable energy share of final energy to 32%. The main drivers are the use of modern bioenergy, including biogas and electricity for cooking thereby slowing the growth in LPG demand, and increased use of solar thermal for heating applications.*

Buildings sector energy demand in Thailand comprises a mix of electricity for appliances and cooling, limited thermal needs for water heating, and the use of fuels for cooking. The sector sees growth in energy demand of 75% from 2015 to 2036 in the Reference Case. The vast majority of this growth comes from either electricity, used in appliances or cooling, and oil products (mostly LPG) used for cooking. Also in the Reference Case, the amount of bioenergy consumed in the sector is reduced, mostly replaced with LPG. The result of these developments is a decrease in share of renewables in the Reference Case as can be seen in Figure 25. Traditional uses of bioenergy are also phased out during the period.

The REmap Options reverse the decline and result in a tripling of the renewable energy share. The main source is bioenergy for modern uses such as for cooking with biogas instead of LPG, electricity used for cooking, and increased use of solar thermal for applications such as hot water, which can include uses in the tourism and commercial sub-sectors. Despite these increases in renewable energy, the use of LPG still almost quadruples over the period; however, renewables do slow LPG's rise considerably by reducing it from a sixfold increase. Consequently, the sector's energy mix would be diversified compared to what it would otherwise be.

Figure 25. Renewable share in buildings and additions to final energy consumption, 2015-2036



Notes: The figure shows two renewable energy shares; the renewable share in sector total final energy shows the share as a percentage of all energy consumed in the sector including fuels, direct use and electricity; the share in parentheses shows the renewable share of final energy consumed in the sector excluding electricity, i.e. only for fuels and direct use.

Solar thermal is a key technology that has been in use in limited forms for water heating in Thailand, but has significant additional potential. REmap sees the addition of around 12 gigawatts thermal (GW_{th}) of systems, or around 0.25 million medium-sized systems. These are installed in buildings that have larger heating demand, such as hotels, commercial buildings and apartment complexes.

Another key technology in the buildings sector is bioenergy. The buildings sector accounts for a significant share of bioenergy use in Thailand (over 40% in 2015). Solid biomass and charcoal for cooking prevail in the residential sector. Estimates for supply of bioenergy are unreliable, with a range of 140-440 PJ.

The alternatives to traditional biomass in cooking are many. LPG is a modern fuel that causes significantly less indoor air pollution and is thus preferred to the use of traditional bioenergy, especially if biomass is collected unsustainably and is used in rudimentary cookstoves. But another good option, especially in rural areas, is to switch to modern cookstoves using solid biomass (fuelwood). These modern cookstoves are up to four times more efficient compared with traditional cooking methods, reducing cooking times and indoor air pollution. Ethanol gels have gained attention in the recent years with promising results in various African and Asian countries.

Biogas for cooking and other residential uses is also promoted in several countries and is an alternative that requires sustained attention and effort for long-term, durable effectiveness. In general, long-term systems tend to be abandoned due to lack of training, maintenance and technical support. The use of household or community-based biodigesters for biogas production also requires a reliable source of substrate, which is not always the case in many households and communities. Therefore, deployment of biogas at the household or community level must be followed by long-term technical support and maintenance to ensure that the biodigesters will operate for many years and deliver the biogas yields that are consistent with the household or community demands.

Electric cooking is another option. It is a clear trend in developed countries but uptake varies widely. The challenge for widespread deployment in developing countries is the need for a grid connection. Older electric coil technologies with 4 rings typically have 1.5 kW capacity and may require 0.5-1.5 kW during operation. New induction cooking technologies have dropped significantly in price in the last few years, and their efficiency is higher and electricity demand lower. Whereas electric coils need 2.0 kW to deliver 1.1 kW of heat (55% efficiency), natural gas a similar 50% efficiency, and LPG around 40% efficiency, induction efficiency is closer to 90%. Therefore, modern electric cooking technologies can be a means of reducing the use of LPG or other fuels and saving consumers money. Therefore, REmap assumes that the uptake of electric cookstoves in urban and suburban areas can be increased significantly to around 2 million units by 2036.

One of the largest sources of electricity demand in the buildings sector is for cooling. While almost the entirety of this increase in cooling demand will be met by traditional air conditioners, which are seeing increases in their efficiency, they still require significant amounts of electricity and solutions do exist to meet cooling demand through novel technologies and approaches. For instance, district cooling is an option for new residential developments, large commercial users and hotels, where a centralised, high-efficiency cooling unit provides either chilled water or cooled air to numerous blocks or buildings. A recent IRENA study outlined in more detail the opportunity for this technology (IRENA, 2017d). Technologies such as cold storage can be considered in certain cases. During the night or at times when electricity is plentiful (from variable renewable power generation such as solar and wind) ice is produced, stored, and then used when cooling is needed and electricity is in short supply or costly.

Industrial sector

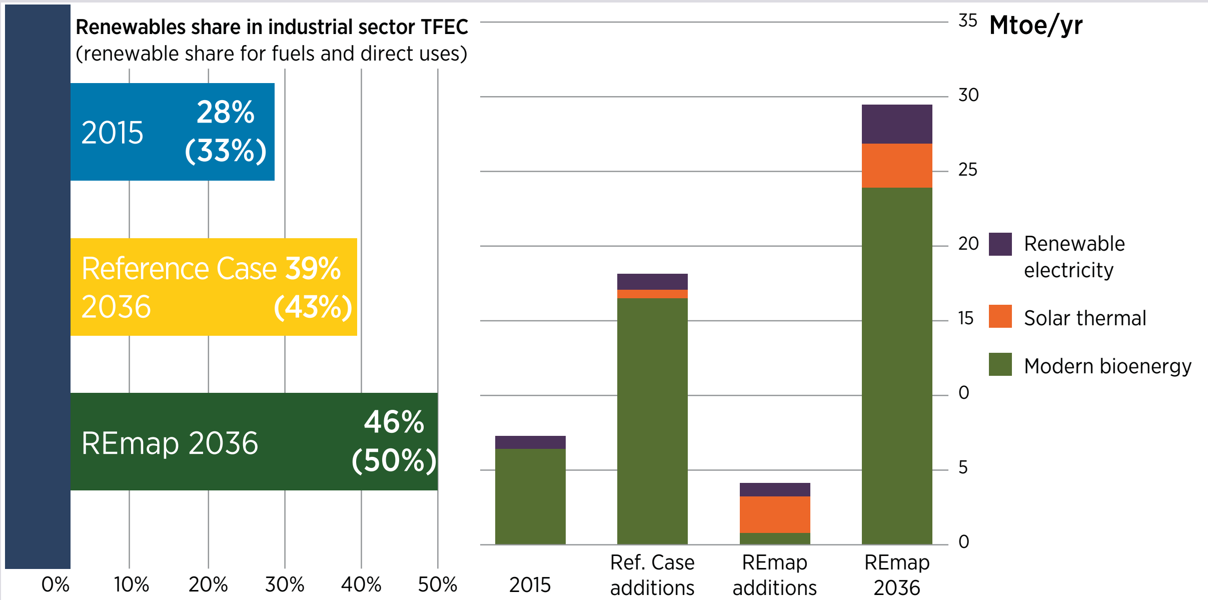
- *The industrial sector sees the largest growth in energy demand of any sector, with an increase of around 145% occurring between 2015 and 2036. In the Reference Case around half of this growth is met by coal and natural gas, 40% with bioenergy and the remainder with electricity.*

- *Given the large growth in bioenergy in the Reference Case, the REmap Options assume little additional bioenergy use. The main technology in the REmap Options is solar thermal used for low-temperature industrial uses. Overall the result is a small increase in the renewable share. However, the sector already has the highest share of renewables due to the significant bioenergy use occurring in the Reference Case.*

The industrial sector sees the largest growth in energy demand of any sector, with an increase of over 145% occurring by 2036. Fossil fuels meet around half of this growth, with bioenergy supplying 40% and electricity around 10%. The increase in sector energy demand is the result of a general uptick in industrial activity resulting from a rapidly growing and industrialising economy. The main driver for such aggressive growth in bioenergy in the Reference Case is the AEDP 2015 plans to dramatically increase liquid biofuel production for transport, which as an ancillary produces significant bioenergy residues which are used for process heat and co-generation.

Given the significant growth in bioenergy in the Reference Case, as can be seen in Figure 26, REmap assumes limited additional potential. The main technology assumed to provide additional renewable supply in industry is solar thermal, specifically low-temperature technologies used mainly in food processing for pre-heating and drying. However, these additions are limited to an increase of only around 3 Mtoe, compared to bioenergy with an increase of 17 Mtoe.

Figure 26. Renewable share in the industrial sector and additions to final energy consumption, 2015-2036



Notes: The figure shows two renewable energy shares; the renewable share in sector total final energy shows the share as a percentage of all energy consumed in the sector including fuels, direct use and electricity; the share in parentheses shows the renewable share of final energy consumed in the sector excluding electricity, i.e. only for fuels and direct use; non-energy use is not included in TFEC.

AEDP 2015 aims to increase significantly the use of biomass in process heat applications in industry. The use of biomass for heat applications in Thai industry is most predominant in biomass-based industries such as sugarcane, cassava and palm oil. As explained before, that use goes together with the production of electricity in co-generation plants that serve the energy needs of those industries, which usually produce enough biomass residues to supply their own energy needs and surpluses that could be used off site. In fact, co-generation in biomass-based industries should be a priority in the development of the AEDP.

Despite most of the existing potential having potentially already been exploited and considering that future expansion will come from on-site co-generation plants, mechanisms should be put in place to ensure that biomass resources are used at the highest levels of efficiency. The production of heat and power is not the core business of biomass-based industries and they usually do not have incentives to explore its full potential. Normally they would produce just enough heat and power to meet their own needs. It is thus essential that incentives be provided to ensure that resources are used to their fullest potential. Knowledge sharing on best practices and the establishment of sectoral performance benchmarks on energy intensity and waste utilisation would highly benefit the relevant sectors and could serve as a driving force to foster change. Incentive mechanisms could be devised in a way that takes into account efficiency and rewards those with the highest levels.

Transport sector

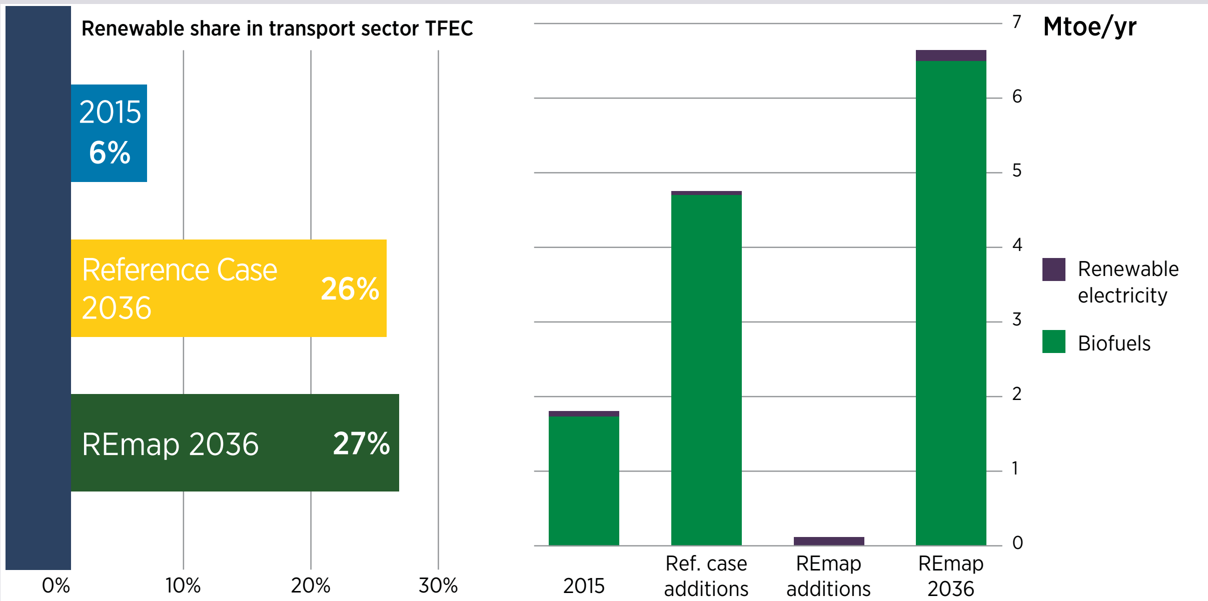
- *The transport sector sees the lowest level of demand growth of any sector, increasing only 14% between 2015 and 2036. Fossil fuels, mostly oil products, will continue to play a major role, providing around 75% of sector energy. However, the Reference Case sees significant growth in liquid biofuels and compressed biogas, with these fuels providing around one-quarter of sector energy demand.*

- *REmap assumes no additional biofuels use due to the strong growth already occurring in the Reference Case. Instead, REmap focuses on identifying the potential of EVs in various modes, and as a result the demand for electricity in the sector triples. The number of passenger EVs on the road by 2036 would total 1.5 million.*

The transport sector is traditionally the most challenging sector in which to increase renewable energy utilisation. The ubiquitous use of oil products, combined with the need for high energy density, means that only biofuels have in the past competed with oil products. Thailand has a history of producing biofuels, with blending mandates that require both bioethanol and biodiesel; however, the targets have in years past not been met. In 2015, around 6% of the sector's fuel demand was met with liquid biofuel.

Over the coming decades, the sector sees the lowest growth in demand of any sector, but an increase is still expected on the order of 14% by 2036. The slow increase is due to higher efficiency of the automobile stock, despite an uptick in car ownership. However, in the Reference Case the fuel mix does start to shift. Due to the aggressive liquid and gaseous biofuel targets of AEDP 2015, the share of renewable fuels will increase to one-quarter of transport energy demand. Liquid biofuels will supply 6.5 Mtoe and compressed biogas 2 Mtoe.

Figure 27. Renewable share in the transport sector and additions to final energy consumption, 2015-2036



Biofuels

The largest increase in renewable energy by far will be from the use of biofuels (mostly biodiesel, bioethanol and compressed biogas), which will increase from around 6% of sector energy to 26% in the Reference Case by 2036. Given this large increase already taking place in the Reference Case, REmap assumes no additional bioenergy use in transport.

In fact, the use of biofuels in transport is a very important aspect of AEDP 2015. Thailand has been promoting the use of bioethanol and biodiesel for many years and AEDP 2015 intends to significantly increase the use of these two fuels by 2036, from 3.5 million litres (L) per day currently to 11.3 million L per day in the case of bioethanol and from 3.4 million L per day to 14 million L per day in the case of biodiesel. AEDP 2015 also emphasises the use of biogas in transport, in the form of compressed biogas. Currently the use of compressed biogas in transport is relatively small, but in the long run the plan is to place it on a par with bioethanol on an energy basis.

The country currently has 23 bioethanol refineries with a total nominal installed capacity of

4.69 million L per day, and 12 biodiesel refineries with a total nominal installed capacity of 6.52 million L per day. Despite a short-term surplus of capacity, significant increases in the refining capacity will be required to sustain the intended AEDP targets. In the period between 2011 and 2015, the installed nameplate capacity of bioethanol production increased by 50%, from 2.7 million L per day to 4 million L per day. That is substantial growth that will need to be maintained to achieve AEDP 2015 targets. In the case of biodiesel, recent trends in installed capacity show a constant capacity of 6 million L per day. That trend must be challenged and investment increase. Another challenge to accomplish the targets is on the feedstock supply side. Ensuring sustainable primary biomass supply to produce bioethanol, biodiesel and biogas can be challenging and should be carefully planned, as discussed in the previous chapter.

The development of compressed biogas will also require significant expansion and upgrading of existing biogas production capacity. In addition to anaerobic digesters, the production of compressed biogas requires upgrading plants that turn biogas into compressed biogas, which entails the development of adequate technology suppliers and technologies for long-term operation. A distribution network to ensure that the fuel reaches its end-use markets is also essential, taking in consideration the geographic distribution of compressed biogas production and existing gas pipelines. Quality standards for blending compressed biogas with natural gas should also be developed from the early stages of the programme.

As previously explained, although the use of gaseous fuels (natural gas and LPG) in transport is not uncommon in Thailand, the development of a wider compressed biogas market may be more challenging. The conversion of vehicles to use gaseous fuels, such as compressed biogas, is only widely adopted if there is confidence that the fuel will be available in a sustained manner over large areas of the country. The adoption of compressed biogas in captive fleets, such as taxis, buses and transport companies, is often preferred so that fuel demand and refuelling locations can be planned under the control of the fleet operator.

Electric mobility

Whereas in the Reference Case AEDP sees strong growth in biofuels, REmap instead emphasises electric mobility. EVs are an emerging technology that provides an important link with the power system when coupled with variable renewables such as solar PV or wind. EVs are also a means to drive down levels of air pollution in urban areas. The Reference Case sees 470 000 EVs (including battery electric vehicles [BEVs] and plug-in hybrid electric vehicles [PHEVs]) on the road by 2036. The Energy Efficiency Plan (EEP) of Thailand targets as many as 1 200 000. REmap increases the total of EVs to 1 490 000 by 2036, representing 10% of the car stock, providing 15 GWh of storage capacity.

It is not just electric cars that hit the roads – electric two-andthree-wheelersarealsodeployed,particularity in urban areas and cities, with REmap seeing over 1 000 000 on the road in the Reference Case and 3 500 000 million in REmap. Additionally, larger EVs will also see adoption. Electric buses are emerging as a key public transport solution that has uses in certain transport lines with certain ranges, or where overhead charging, intermittent charging or end-point charging is possible. And light freight vehicles for services such as package delivery or fleet uses will also see the adoption of forms of electric mobility.

4.3 Costs and benefits of renewable energy

The previous sections have provided an overview of the potential of accelerated renewable energy uptake and discussed the technologies across all energy sectors. This section outlines the associated costs and benefits of higher renewables deployment, and discusses the level of investment that would be required.

REmap assesses costs and benefits using a variety of indicators,[40] including:

- A substitution approach, detailing if there is an incremental cost or saving from a renewable energy technology compared to a substituted conventional technology. This view looks only at the associated cost of energy service, i.e. the relative cost of providing the same amount of energy from a renewable technology versus a conventional one. The sum of these costs shows whether there is an incremental energy system cost or saving.

- An externality assessment that quantifies reductions in external costs due to lower levels of air pollution and CO_2 emissions.

- An assessment of the level of investment needed to deploy all the renewable energy capacity outlined in the Reference Case and the REmap Options. Any complementary infrastructure is not part of the assessment.

Costs and savings

- *The REmap Options result in both a reduction in energy system costs of around USD 1.2 billion annually by 2036, equivalent to USD -9.2 per megawatt hour (MWh), and a similar reduction in external costs in the range of USD 1.2-7.9 billion annually from reduced externalities. Therefore, the package of renewable technologies is both cheaper than the fossil alternatives, and also results in very significant reductions in external costs.*

- *The power and buildings sectors see the most cost-competitive renewable technology options, with key technologies including solar PV, solar thermal and biogas.*

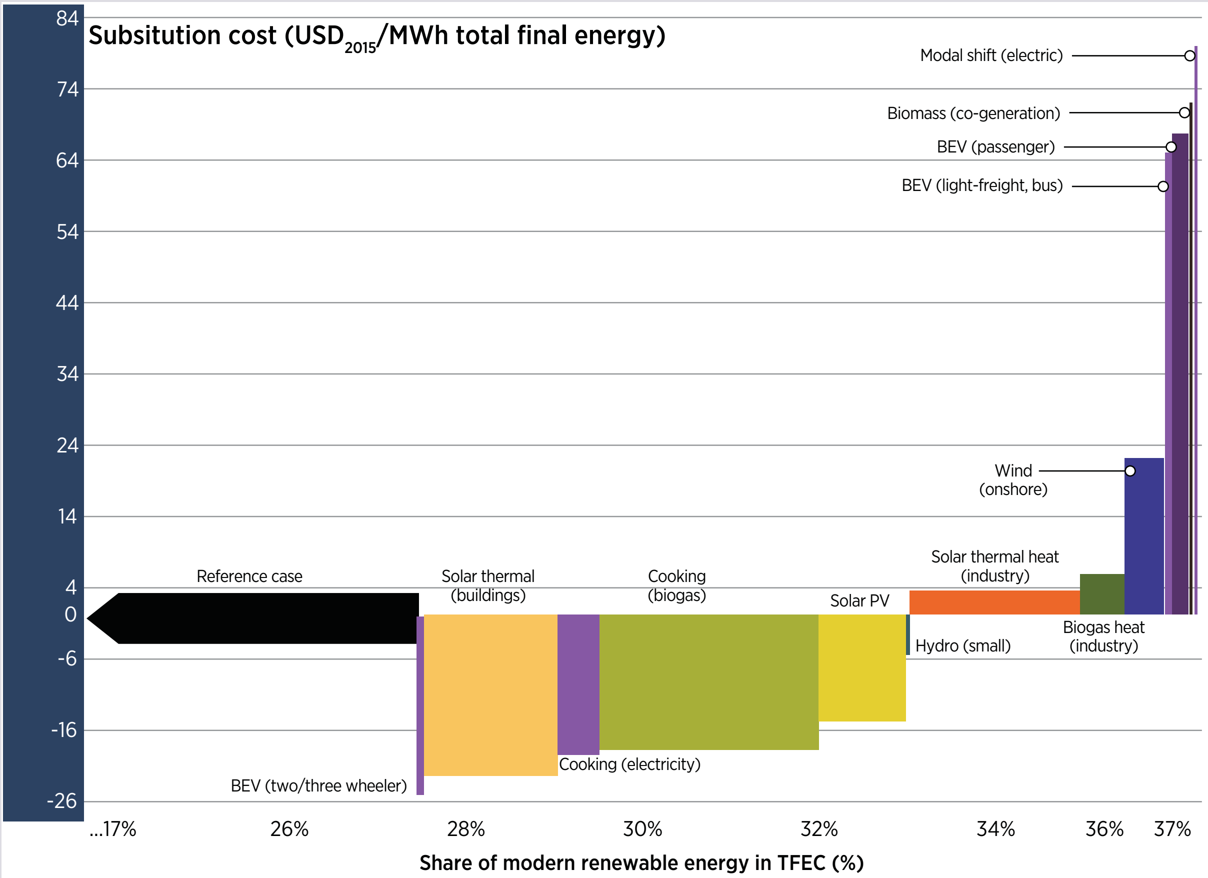
Substitution cost is one metric that compares the relative attractiveness of renewable energy technologies against conventional options. These conventional variants are technologies that exist in the Reference Case and are replaced by renewable technologies with the REmap Options. Substitution cost therefore measures the relative cost or saving of this substitution, i.e. how the energy service cost would change if a renewable technology were deployed instead of a conventional one. It can be shown at the individual technology level using technology cost supply curves as seen in Figure 28, or through other metrics such as marginal cost of CO_2 mitigation.

A variety of factors can affect the substitution cost, including the capital cost of technologies, their performance characteristics, the assumed discount rate (weighted average cost of capital) and fuel costs. The cost is also driven by the type of conventional technology substituted, *e.g.* if coal is substituted, which has low fuel costs, the substitution cost will likely be higher than if oil, with high fuel costs, is substituted. The facilities that are substituted depend on factors that range from their type of energy technology and the sector in which they operate, to the age of the capital stock and planned new additions of technology. Because of rapid energy demand growth, this assessment only considers substitution of either a) capital stock reaching the end of its operation lifetime and needing replacement, or b) new capital stock required to be installed over the analysis period. Therefore, no additional costs are assumed to account for forced early retirement.

In addition, a further important driver for costs is whether the more cost-competitive renewables have already been deployed in the Reference Case, i.e. the low-hanging fruit, leaving costlier choices for the REmap Options.

[40] For an overview see Annex: REmap methodology, assessment approach and data sources.

Figure 28. Cost-supply curve for REmap options — government perspective



The result of this substitution approach is shown in Figure 28. The figure is a cost-supply curve showing along the y-axis the average substitution cost of the technology for a given renewable technology (the REmap Option) compared to a conventional variant. The cost is shown in USD per MWh of final energy. Along the x-axis is the share of renewable energy in TFEC. Therefore, the width of the bar directly corresponds to how much energy from that source is consumed in final energy. The larger the bar, the more energy is consumed, and therefore the higher the amount of capacity that is required.

The curve shows that Thailand increases its renewable energy share from 17% in 2015, to 28% in the Reference Case by 2036, and the REmap Options add an additional 9 percentage points to arrive at 37% renewable energy share of total final energy by 2036. For the purpose of presentation, the Reference Case growth has been scaled to better show the REmap Options. The average substitution cost of the grouping of renewable technologies, i.e. the REmap Options, is USD -9.2 per MWh, equivalent to a little under one cent per kWh. This means that if the package of renewable technologies identified in REmap were deployed, the cost per MWh of final energy across Thailand's energy system would be USD 9.2 per MWh lower. However, this effect is across the entirety of Thailand's energy market. If only the power technology options are considered, they have an average substitution cost of USD -3.7 per MWh. This means that the effect would be a lower overall wholesale power generation price on the order of around half a cent per kWh.

If specific technologies are examined, one sees how the cost-competitiveness of the REmap Options differs. The most affordable technologies include solar thermal systems in the buildings sector, which is a simple and affordable technology that competes well against any alternative, but in particular electric hot water systems. The other significant source of additional cost-effective renewable potential in buildings is biogas. The Reference Case sees very significant growth in the use of LPG, mostly for cooking. Biogas from anaerobic digestion is an affordable and indigenous source of local energy that can instead be used. Also for cooking, the use of electric cookstoves, in particular modern and efficient induction stoves, are a cost-effective means of reducing LPG use in the buildings sector. The end-use sectors also show significant additional potential for solar thermal heat used in industry for low-temperature applications. However, due to the higher temperature demands of industrial heat applications, combined with the limited production profile of these solar thermal systems, even meeting low-temperature needs (<150°C) sees their cost being higher than the conventional variants, albeit only marginally at just USD 3.3 per MWh.

Power sector technologies offer competitive options. Solar PV in large commercial and utility-scale applications is the cheapest form of electricity on offer in Thailand, and results in a substitution cost of USD -14.8 per MWh. Wind energy offers significant additional potential as well, but at a higher substitution cost of USD 21.6 per MWh. There is also slight additional potential of small hydropower, but its contribution is minor.

Transport sector technologies show a mixed picture. Due to significant growth in liquid biofuels in the Reference Case, no additional potential for biofuels is considered under REmap. EVs do not show significant potential in the curve; however, this is not because their deployment is limited (as detailed in an earlier section, they have significant potential), but rather as the result of what is displayed in the curve. For one, EVs are highly efficient and are on average three to four times more efficient than internal combustion engines, meaning it takes one-quarter the amount of energy to deliver the same amount of passenger or freight service. Additionally, the curve only shows the share of renewable electricity consumed by those vehicles, i.e. around one-quarter of their electricity demand. Therefore, if all electricity consumed by EVs were shown, then their contribution would be four times larger. For these reasons, this figure is not the best means of displaying the relative importance of EVs, or electric technologies in general. Furthermore, as demand technologies they do not produce energy, but they are shown in the curve because of their importance in increasing the renewable share of energy in transport (by shifting energy consumption to the power sector where ample renewable technology options are available) and their beneficial effect on air pollution.

Figure 29[41] shows how energy system costs and external costs are affected by the REmap Options. When the substitution costs for the grouping of REmap Options are summed, they result in a perspective on how those renewable technologies affect energy system costs. The result is a reduction in energy system costs of USD 1.2 billion annually by 2036. These system costs do not consider reduced externalities, which result from lower levels of air pollution and CO_2.

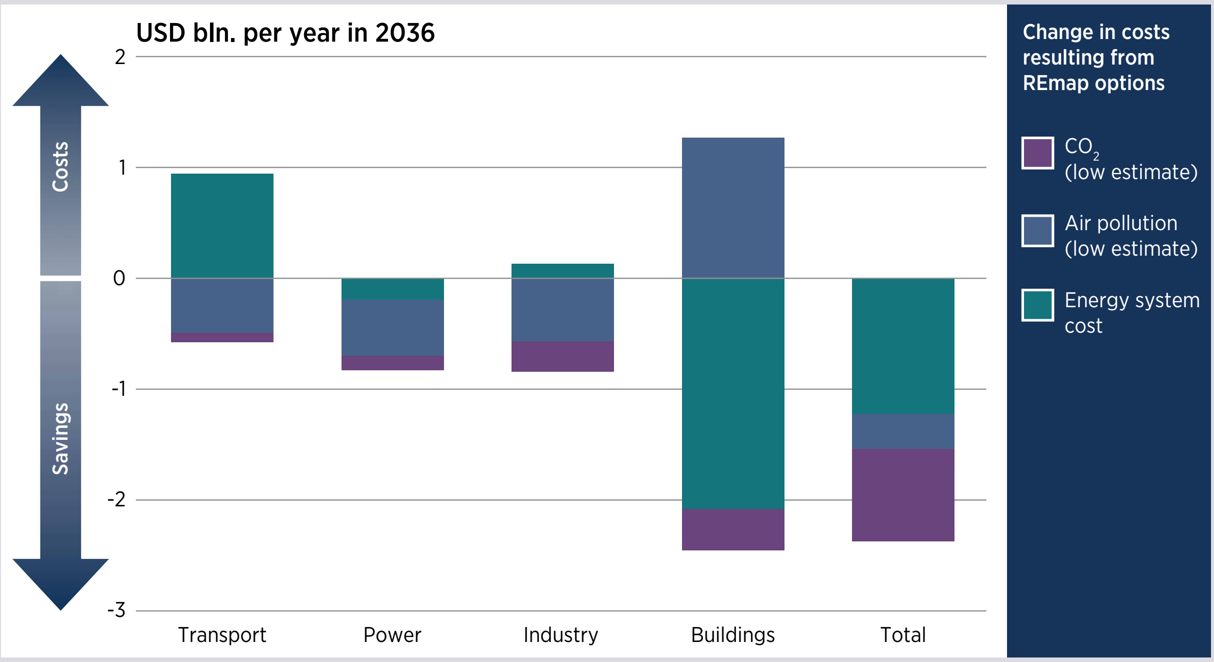
Lower levels of air pollution improve the conditions for human health and the local environment. Air pollution is a cause of ill health, particularly in cities, but it also damages crops. CO_2 is a greenhouse gas, which is the main contributor to global warming, and numerous studies have examined its effect and determined a range for the social cost of carbon. REmap assesses both outdoor and indoor air pollution using a methodology developed specifically for the purpose (IRENA, 2016c). CO_2 is assessed using a social cost of carbon ranging from USD 17 to USD 80 per tonne of CO_2.

The figure also shows how the REmap Options affect sector costs. Two sectors, transport and industry, have incremental energy system cost effects resulting from deployment of the REmap Options. This means the grouping of technologies identified in REmap for those sectors are more expensive on an energy service basis than the conventional alternatives.

However, in both transport and industry there are savings related to reduced adverse effects on health that are sizable and, in the case of industry, the health savings are five times larger than the incremental cost of energy for the sector. What is not quantified is the cost and benefit of reducing imports of oil and its products, such as diesel and petrol, and the larger macroeconomic benefits to jobs and GDP that would result from producing biofuels or electricity locally for transport uses.

[41] Please note that Figure 29 considers benefits resulting from the deployment of renewables that reduce external costs due to fewer adverse effects on human health from lower levels of air pollution and reduced environmental and social damage resulting from lower levels of CO_2. However, benefits from renewables can also include positive macroeconomic effects that result from lower levels of imported fossil fuels, increased employment and industrial activity in local industries and other societal effects. IRENA has, however, not conducted this type of analysis for Thailand.

Figure 29. Costs and benefits of REmap options



The buildings and power sectors have negative energy system costs, resulting in savings to the cost of energy in those sectors for consumers. While the savings in the power sector are marginal (mentioned previously at around half a cent per kWh), those in buildings are significant, due in large part to the use of biogas for cooking and solar thermal for water heating. All sectors, except buildings, see significant reduction in external costs related to air pollution. Reductions are similar in power and industry, where coal is, in part, substituted and offers significant improvements in air quality, and transport where electric mobility brings improvements to urban air quality.

In total, the REmap Options reduce energy system costs around USD 1.2 billion annually by 2036, equivalent to USD -9.2 per MWh, and external costs by USD 1.2 billion annually from reduced adverse effects of air pollution on human health and environment and social damage from CO_2 (using the low estimate). However, the external cost savings could be as much as USD 7.9 billion annually by 2036 if the high estimate is used. Therefore, when including both reduced energy system and external costs, total savings to the Thai economy from the renewable technologies identified in REmap are at a minimum USD 2.4 billion (if only the low estimates is used) – or as high as USD 9.1 billion (if the high estimate is used) – as compared to the fossil fuel-based alternative.

Air pollution and CO_2 impacts

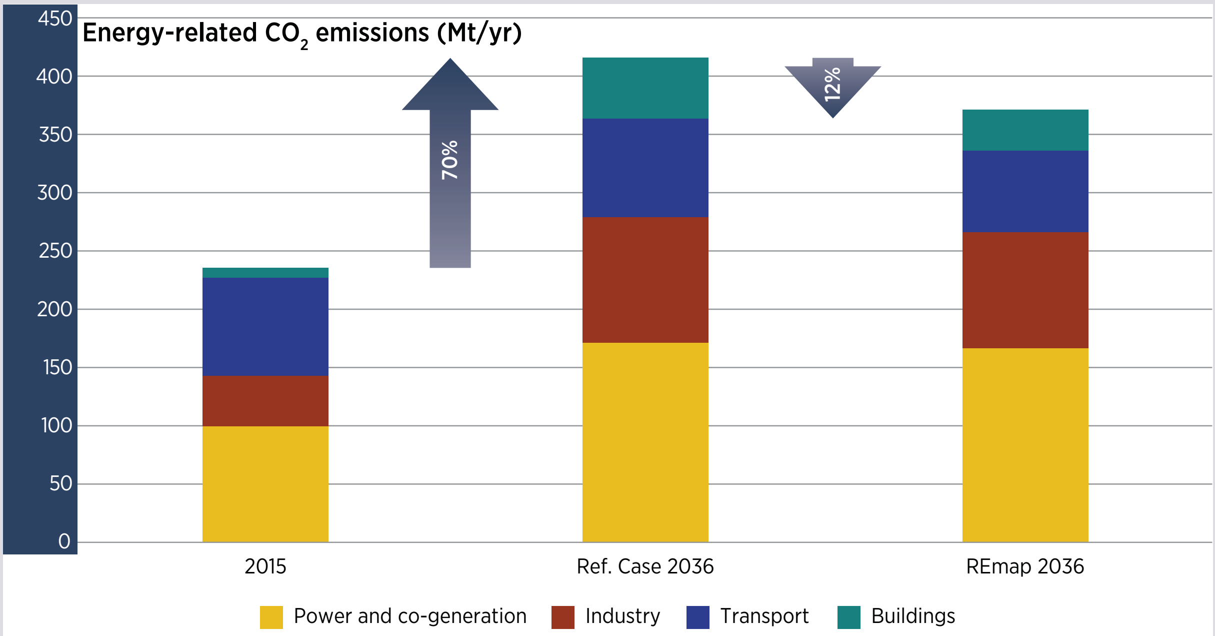
- *External costs related to air pollution and CO_2 are important factors when considering the cost and benefit proposition of renewable energy. For instance, the REmap Options on average reduce external costs related to air pollution alone by around USD 1.2 billion annually by 2036.*

- *Compared to 2015, energy-related CO_2 emissions increase by 70% in the Reference Case to 420 Mt by 2036, with the REmap Options slowing that increase to 50%, or 370 Mt of energy-related CO_2 in 2036.*

Thailand will see a significant increase it energy demand of almost 80% by 2036. Therefore, similar increases in energy-related CO_2 are also seen, with an expected 70% increase in the Reference Case to almost 420 Mt annually by 2036 (see Figure 30). The increase in CO_2 emissions outpaces fossil fuel growth (of 65%) because coal is expected to increase the most of all the fossil fuels, and coal is the most CO_2 intensive of all fossil fuels.

The REmap Options result in a decrease in energy-related CO_2 emissions of 12% over the Reference Case level in 2036. Thailand has set the goal to reduce carbon emissions by 20-25% over business-as-usual in 2030. For 2030, the REmap Options result in a reduction of 10% over the Reference Case. Therefore, additional efforts are needed if the country is to meet its intended goal of a 20-25% reduction by 2030. It is important to note that REmap does not assume that renewable energy will always substitute coal, rather it is also assumed that some substitution of natural gas takes place. During country consultation, some participants advocated that the country is more interested in diversifying its energy mix than abating CO_2 emissions, and for this reason coal should be considered as an important fuel. However, if the aim is energy diversification, the best option would be to consider higher levels of renewable deployment because they are indigenous sources of supply whereas coal will still need to be imported, and if the aim is CO_2 emission abatement then clearly renewable energy is the right choice.

Figure 30. Changes in energy-related CO_2 by sector, 2015-2036

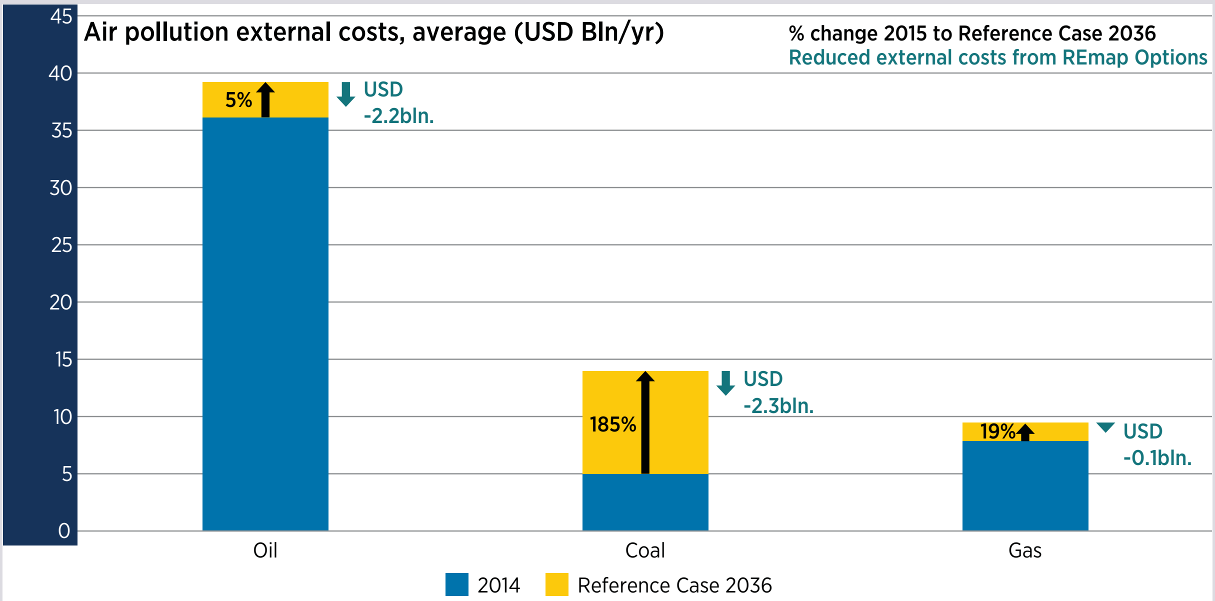


When assessing external costs, the more directly measurable effect of fossil fuels is on local air pollution. External costs related to air pollution from fossil fuels, largely resulting from adverse effects on human health, will increase by as much as 21% by 2036. Annual costs will increase from a range of USD 23-92 billion in 2015, to USD 28-108 billion by 2036. Figure 31 shows how these costs change in the different cases by showing the average costs under the low and high estimates.

Air pollution costs associated with oil are the highest, due largely to the effect oil use in transport has in urban environments. However, the increase in external costs for oil in the Reference Case is the lowest, increasing by only 5%, reflecting both the lower increase in fuel demand expected in the transport sector compared to the other sectors, and more efficient and cleaner internal combustion engines. Nonetheless the sector is still the largest to negatively affect human health, and, as the REmap Options show, provides significant benefits if renewable energy is deployed, in particular EVs. The resulting savings would amount to, on average, USD 2.2 billion annually by 2036 if all the REmap Options for transport are considered.

Coal use in Thailand is expected to increase the most of any fossil fuel by 2036. The result is the largest increase in external costs from air pollution of any fossil fuel, increasing 185%. Replacing coal with renewables results in significant external cost savings, on the order of around of USD 2.3 billion on average annually by 2036. Of all the fossil fuels, replacing coal with renewables results in the greatest savings. Lastly comes natural gas, which sees a modest increase in external costs of 19%, and a reduction in costs due to the REmap Options of only USD 0.1 billion annually by 2036.

Figure 31. Changes in air pollution external costs by fuel



Note: Figure shows average of low and high estimates for air pollution external costs and savings resulting from REmap Options for fossil fuels.

Investment needs

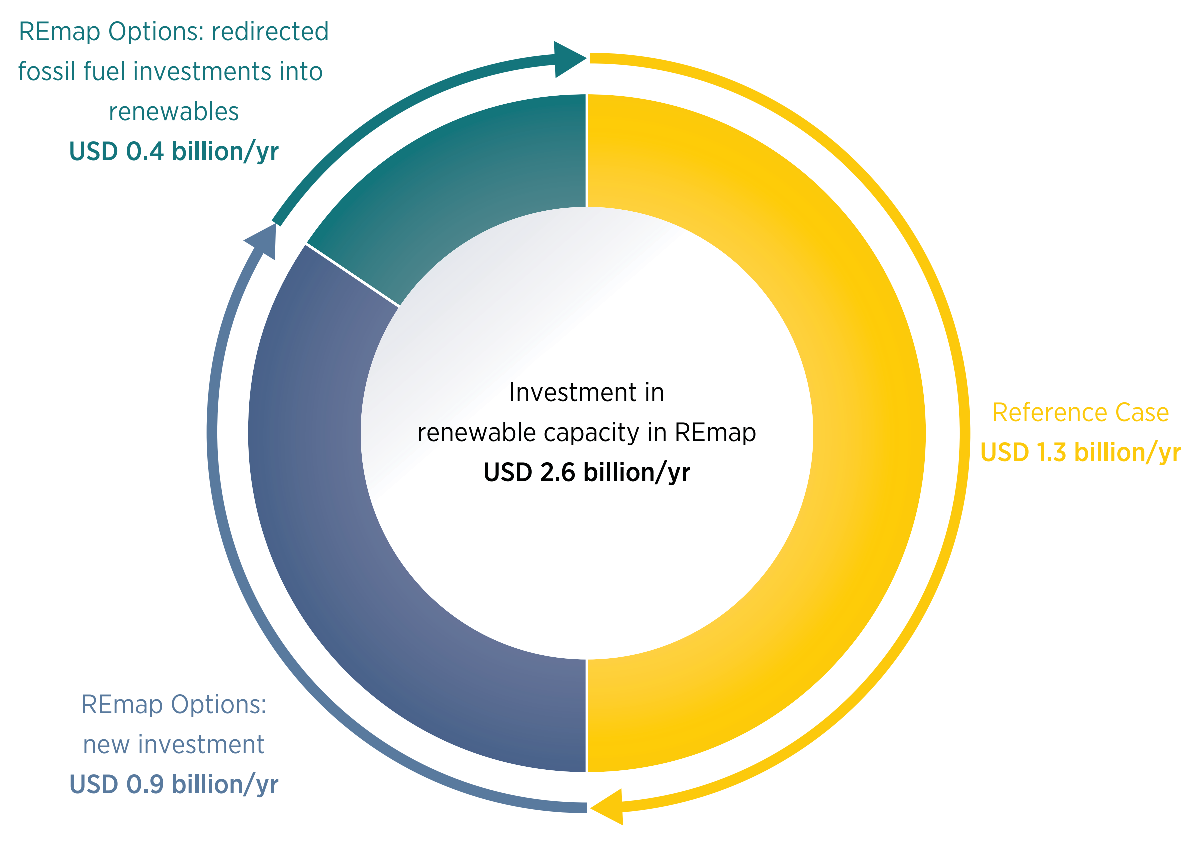
- *Thailand will need to invest significantly in its energy system over the coming two decades. The Reference Case will see investments in renewable power and thermal capacity averaging USD 1.3 billion per year to 2036. The REmap Options double that with an additional USD 1.3 billion per year, resulting in a total average investment need of USD 2.6 billion per year between 2015 and 2036 in renewable capacity for power and thermal uses.*

- *Of the incremental investment need for the REmap Options of USD 1.3 billion per year, USD 0.4 billion per year will be investments redirected from fossil fuels to renewables.*

Significant investment in the energy system across Thailand is required due to the growing demand for energy. Investment is required across the entire energy system, in electricity generation, transmission, capacity for thermal uses, cooling and cooking, and in the transport sector.

During the period 2015-36, investment in renewable energy capacity will need to average USD 2.6 billion per year (see Figure 32). Of this, around half, USD 1.3 billion, is expected to take place in the Reference Case. The REmap Options will necessitate the mobilisation of an additional USD 0.9 billion per year in renewable energy investment from new sources, with USD 0.4 billion per year of investment redirected from fossil fuel into renewables.

Figure 32. Average annual investment in renewable energy capacity: Reference Case and REmap, 2015-2036



KEY FINDINGS AND RECOMMENDATIONS

Biomass power plant, Thailand
Photograph: Shutterstock

05

This chapter presents the key findings of the REmap analysis, followed by a portfolio of strategic and specific recommendations for addressing the key challenges. This portfolio of recommendations was largely developed through respondent interviews, multi-stakeholder discussions and workshops, and technical expert reviews.[42] The aim of this section is to provide policy makers with "food for thought" for strategic thinking, as well as concrete actions that the government may take to overcome the emerging or potential challenges in scaling up renewable energy development and deployment in Thailand.

5.1 Analytical highlights

The analysis presented in Chapter 4 finds that Thailand has significant renewable energy potential, with a favourable set of circumstances that could enable the rapid scaling up of renewable energy beyond that envisioned in current plans. The analysis shows that renewables can be vital to help meet rapidly growing energy demand, with largely indigenous renewables. In doing so, energy system costs would be lower, and renewables would bring large benefits in terms of lower levels of air pollution and CO_2 emissions. Key highlights from the analysis are listed below.

Energy demand and role of renewables

AEDP 2015 sees energy demand in Thailand increasing by 78% under the assumption that GDP will grow by 126% by 2036. Growth in renewables outpaces this increase and the result is an increase in the renewable share of final energy in both the Reference Case and REmap. In REmap, renewables provide 37% of Thailand's TFEC in 2036, surpassing by a wide margin the government's current target of 30%.

[41] Please note that other minor or very specific recommendations are made, which may be found in the discussions and analysis throughout the report.

Electricity demand in AEDP 2015 grows by almost 90% to over 325 TWh annually by 2036. The renewable power mix moves from one dominated by hydropower and bioenergy, to a much more diverse mix of technologies that includes sizable generation from solar PV and wind. By 2036 in REmap, 25% of domestic generation is supplied from renewable sources, and if imported hydropower is included, then almost 30% of electricity is renewable. The two greatest sources of additional potential are solar PV, increasing from 6 GW to 17 GW in the REmap Options, and onshore wind, doubling from 3 GW to 6 GW. Therefore, greater attention should be paid to solar PV and wind power given the huge potential they present in the analysis.

Importance of bioenergy

Bioenergy remains the dominant renewable source in the end-use sectors due to its ability to be used for heat and transport fuels. AEDP 2015, the source of the Reference Case, proposes aggressive targets for bioenergy, particularly in transport and industry. As a result, the REmap Options assume no additional biofuels in transport, and in industry the use of biomass residues and biogas increases only slightly by around 3%. For REmap the only sizable uptake of bioenergy assumes that a share of traditional biomass use that is replaced in the Reference Case by LPG can instead be replaced with modern cookstoves and biogas digesters, resulting in an increase in modern bioenergy in the residential sector by reversing the uptake of LPG. Therefore, a follow-up study focusing on modern cookstoves and biogas as a replacement for traditional use of biomass should be conducted.

End-use sector importance

Solar thermal represents low-hanging fruit in the end-use sectors, as it can be scaled up significantly in buildings for water heating and in industry for low-temperature and pre-heating application.

In the transport sector, REmap focuses on identifying the potential of EVs and as a result the demand for electricity in the sector triples. The number of passenger EVs on the road by 2036 would total 1.5 million and electric two- and three-wheelers would total over 3.5 million.

Cost and benefit

In the Reference Case, energy-related CO_2 emissions increase by 70% by 2036 and air pollution from fossil fuels by 21%, the latter of which will cost the country on average USD 68 billion annually in health-related impacts.

The REmap Options are in general cheaper than their fossil fuel alternatives. Energy system costs would be reduced by USD 1.2 billion annually by 2036, equivalent to USD 9.2 per MWh, with a similar reduction in external costs ranging between USD 1.2 billion and USD 7.9 billion due to lower adverse effects on human health from air pollution and environmental damage from CO_2. The power and buildings sectors see the most cost-competitive renewable technology options, with key technologies including solar PV, solar thermal and biogas.

Thailand will need to invest significantly in its energy system over the coming two decades. To achieve the levels of renewable energy capacity deployment seen in REmap, an average of USD 2.6 billion per year between 2015 and 2036 will need to be invested in renewable capacity for power and thermal uses.

5.2 Strategic recommendations

With the global energy landscape becoming increasingly perplexing amid the ongoing energy transition, any energy-related plan needs to keep a certain level of flexibility to adapt to fast-changing circumstances, but, more importantly, to align itself as much as possible with key high-level political objectives and agendas at national, regional and international levels. This requires updating the AEDP on a regular basis to adjust the direction and the pace of implementation. But, it also suggests that the AEDP should take into consideration policy objectives other than simply energy, such as improving food security and farmers' living standards, and enhancing the competitive advantage of the industrial sector.

Although AEDP 2015 is one of the measures for Thailand to deliver its pledge of cutting 20-25% of greenhouse gases from the business-as-usual scenario by 2030, a **closer harmonisation of climate and energy policies could facilitate the realisation of their interrelated objectives.** This will not only help Thailand fulfil its international commitments to reduce greenhouse gases, but also reduce the external costs incurred by the country from the use of fossil fuels by USD 1.2-7.9 billion annually, according to the analysis presented in Chapter 4. From the energy perspective, Thailand should factor in the future constraint on carbon emissions when diversifying the energy mix. In practice, it is therefore advisable to **synchronise the timeframes and evaluation cycles for the AEDP and Thailand's NDCs** to mitigate energy-related greenhouse gas emissions.

A further strategic perspective is to **develop renewable energy manufacturing industries in Thailand,** which is also in line with the Thailand Industries 4.0,[43] through scaling up the size of the market for renewable energy. This would enable Thailand to capture the resultant social and economic benefits, including the creation of new local jobs and additional income streams.[44]

Currently, most renewable energy technologies are imported while a small portion of components are provided locally. Building on the country's existing manufacturing facilities, technical expertise and strong R&D capacity, Thailand should consider developing a strategic approach to increase the competitiveness of local manufacturing through market development, so as to minimise overdependence on imported technologies and maximise the benefits for local communities. This may include, for instance, the local bio-economy utilising the entire value chain of locally produced bioenergy, local expertise in solar thermal technologies, the development of solar PV and wind power generation technologies, and EV manufacturing capacity (including two- and three-wheelers) in Thailand. Over time, this would generate significant positive impacts on Thailand's development. Therefore, it is advisable to take a long-term macroeconomic approach to assessing the benefits that can arise from the energy choices to be made today. This longer-term macroeconomic benefit is further supported by the REmap findings, which show that renewables are, on the whole, less expensive than fossil fuels and would result in lower energy system costs of around USD 1.2 billion annually by 2036.

Lastly, to ensure the effective implementation of the interlinked key targets set in the TIEB – which consists of five individual plans including the AEDP, EEP and PDP –– there is **a need for stronger and higher-level of co-ordination and co-operation among the ministries and the relevant institutions.**

Among the five individual plans within the TIEB, the EEP serves as a starting point, contributing as an input for the development of the PDP. The target set in AEDP 2015 is to some extent contingent on both the EEP and the PDP. Plans for oil and natural gas would also have significant implications for all three abovementioned plans. Such interdependency would cause some concern as to implementation efficacy should no effective inter-institutional co ordination mechanism be put in place. For the EEP, it is worth noting that certain other ministries and authorities, such as the transport sector, may play a more important role than the MoE in meeting the energy-saving targets.

The system for monitoring progress and exchange of information, including relevant data among the key institutions, has been established and is in operation at the working level under the oversight of EPPO.[45] In addition, joint task forces were initiated enabling DEDE to work more effectively with other ministries for implementation of AEDP 2015.

However, there remains a lack of effective ministerial-level co ordination for harmonisation of policy objectives and long-term vision among the different ministries involved. This has a negative impact on the overall effectiveness of the TIEB implementation if overlaps in interest occur among ministries. For instance, the management of agricultural crops is under MoAC, while biofuel-based vehicle manufacturing sits with the Ministry of Industry and the use of such vehicles is under the oversight of the Ministry of Transport.

It is therefore recommended that the existing mechanisms designed to achieve ministerial-level co-ordination on energy-related issues should be

43 For further information see: www.industrie4thailand.com/.

44 Relevant reference can be found at www.irena.org/DocumentDownloads/Publications/IRENA_Leveraging_for_Solar_PV_2017_summary.pdf.

45 For instance, ERC is tracking power sector data while the Energy Business Department is collecting biofuel data and DEDE is collecting data on building energy use, efficiency and process heat among other metrics.

revisited, with the aim of exploring the possibility of using established mechanisms to harmonise policy objectives and the strategic agenda under the different ministries.

In addition, given that it is crucial to collect and share implementation data from all the relevant agencies to keep implementation on track, it would better to establish a mechanism to do so on a regular basis in place of the current ad-hoc reporting that is performed only when such data are requested by senior management at the ministries. Related to this point, Thailand should also keep abreast of development of renewable energy technologies and applications in other regions, countries and projects, especially those where dramatic cost reductions are achieved as presented in The Power to Change: Solar and Wind Cost Reduction Potential to 2025 (IRENA, 2016d). Comparative analysis on this front can provide valuable insights and inputs for the review and updating of the current AEDP, as well as for project developers and investors in Thailand.

5.3 Key challenges and specific recommendations

This section discusses the key challenges identified in the categories of energy planning, renewable energy resources, and technology applications. The specific recommendations are given on the basis of the systematic assessment of the current status of renewable energy development in Thailand through the RRA process, and the results of the REmap analysis which presents a renewable energy outlook to 2036 based on the one described in AEDP 2015, as well as with reference to international best practice and relevant IRENA studies.

Power grid planning

Challenges

At present, VRE accounts for less than 2% of total electricity generation in Thailand, with the REmap Options increasing this share to 12% by 2036. There is a growing concern among government agencies and utilities that higher shares of variable renewable generation require greater levels of grid flexibility. While many power systems around the world have easily incorporated shares of VRE of 10-15% without significant issues, there is a need to understand how Thailand's power system, and importantly its distribution-level systems, can better plan for increasing amounts of VRE.

The recently proposed requirements for all SPPs and VSPPs to provide firm or semi-firm capacity in their renewable energy projects by hybridising biomass with either solar PV or wind power is one of the measures that power system operators and utilities have taken. This is likely to push up overall project development costs to offer flexibility that may not even be necessary, thereby actually increasing prices. Furthermore, the implications for the extent to which project development will be affected, especially in cost terms, remain unclear. While technical considerations based on local power system dynamics need to be understood, it is important is to embrace new concepts, approaches and tools in power grid planning, operation and market design to improve grid operation performance.

Recommendations

Diversifying the sources of variable renewables can reduce the requirement for spinning reserves, but this does not necessarily have to be achieved at the project level, especially if one wants to achieve greater system-wide cost-effectiveness. Optimising the portfolio by setting a ratio for VRE sources, such as solar PV and wind, based on their output curves to maximise complementarity with one another can deliver cost-effective results at the system level.

However, other options are available, for instance matching VRE outputs with load as much as possible using intelligent control systems, including adopting demand-side management schemes. From a long-term perspective, there might be a need to establish an auxiliary market to enable independent regulating power providers to take a more active role in different market segments so as to ensure grid stability and reliability. Furthermore, such a market could incentivise the potential application of batteries or EVs among other energy storage facilities. It is therefore advisable that Thailand conducts a feasibility study on establishing a market for better utilisation of existing and potential reserve margins.

Lastly, Thailand should also weigh the pros and cons of accepting imported hydropower and potentially other forms of renewable energy sources as eligible renewables contributing to the national target. This issue is likely to emerge when it comes to discussion of allocating contributions to the regional renewable energy target agreed by the ASEAN Energy Ministers, i.e. achieving 23% renewables in TPEC by 2025. Moreover, this might also affect the way in which the rules for a renewable electricity certificate (REC) are set if a regional renewable electricity market were established and RECs were considered a suitable market-oriented measure for ASEAN to take. In the immediate and short term, were the definition of renewable expanded to include imported renewable electricity in meeting the domestic renewable energy target of Thailand, potential investors and developers would be incentivised to explore the resources along national borders or scale up existing installations close to the border lines that can provide electricity to broader customer groups and thus achieve better economic performance. This would also facilitate investment in enhancing grid interconnections with neighbouring countries.

Long-term price guarantee mechanisms for bioenergy feedstock

Challenges

Most of the industries utilising agricultural and forestry residuals as energy feedstock can increase to some extent the supply of feedstock by, for instance, improving harvesting methods (from burnt to green harvesting).

However, large-scale users of feedstock for either power generation or biofuel production would have to purchase biomass feedstock on the competitive market if they do not own any dedicated energy crops farm. The conflicts of interest among the various sectors may pose a supply risk to them, as a substantial proportion of the existing agricultural and forestry residues are treated as a commodity and their accessibility is subject to market conditions. Increasing the awareness of using biomass in industrial processes and the buildings sector and unused residues for other purposes might worsen the situation if no effective mechanism for sustainable management of the feedstock can be established.

Recommendations

First is the requirement for clear policy and legal frameworks on land tenure and use. This is one of the basic elements that enable long-term commitment and investment in agriculture, especially at the levels that are required to sustain a strong bioenergy sector that does not compete with food production. Loose land tenure and use frameworks do not provide the confidence necessary for developers to invest in the technical developments that are required to boost agricultural yields and maximise output from land in the long term.

Secondly, to address these challenges, the essential elements are a) to establish a fair and reasonable market environment with a clear pricing mechanism for biomass that can offer long-term purchase guarantees, based on projected demand, and b) to smooth out as much as possible the seasonal variation in feedstock yields. Such market environment would, for example, benefit from the creation of growers' associations and co operatives, which, with biomass buyers, help establish clear rules for the operation of the market.

To some extent, the commodity price volatility in international markets should also be factored out. This would help minimise the negative impact of oil price volatility on the farmers' economy, and in return enhance their confidence in investment in energy crops. Additionally, prices should in principle be stable or predictable over the long term, and should not be set too high or too low in relation to food prices. In this way, the price of feedstock can be controlled or guaranteed over the long term. Additionally, this can facilitate land-use planning by MoAC and MoNRE as far as dedicated energy crops are concerned.

The ultimate objective is to establish biomass supply chains that ensure the delivery of reliable, high-quality and affordable biomass fuels to those industries that are willing to use biomass, while at the same time diversifying income streams for local farms without introducing potential risks.[46] The development of such supply chains could benefit multiple users of different part of the biomass feedstock. Yet it should be made clear that food security for both human and animal/livestock must remain the top priority.

[46] Thailand does not generally encourage the import of biomass feedstocks.

Thirdly, a fair and sound regulatory framework should be put in place to ensure a fair distribution of the benefits between farmers and energy producers, particularly when deals go through processing collection companies (including agricultural co operatives that are operating as a collector in some places), processing mills, and other businesses involved.

Lastly, the application of new technologies for managing feedstocks and derived products should be encouraged, for instance solid biomass pellets, provided they can meet the expected/desired levels of quality assurance.

Incentives for thermal utilisation of renewable energy sources

Challenges

Renewable energy for thermal utilisation accounts nearly for two-thirds of the total of the increment by 2036, if the AEDP 2015 target is met as projected in the plan. The majority of it would come from biomass according to the plan. However, the current subsidy programmes cover only solar water heaters and dryers. Except in the case of biomass processing industries that traditionally utilise biomass residues for their own thermal needs, the lack of sufficient incentives for end users to switch to modern renewables for thermal utilisation impedes the development of this segment of market, although various technological options have been identified in AEDP 2015 and the analysis in this study. Furthermore, the REmap analysis shows that, in addition to the increases in AEDP 2015, significant additional potential exists for solar thermal heating solutions in both buildings and industry beyond that detailed in AEDP 2015.

Recommendations

Against this backdrop, Thailand should set the right policy framework for the use of renewable thermal energy,[47] and introduce a set of dedicated incentive schemes as it did for promoting the use of renewable energy sources in the power and transport sectors. However, the contrasts in market structure, opportunities and barriers between power and thermal use of renewables should also be recognised.

To achieve this, a statistical system is required that can collect and assemble the right set of energy metrics for renewable thermal use. Toward this end, it is recommended that Thailand conduct a comprehensive study reviewing its current data system, including the scope of technologies covered and the ways in which data are collected, assembled, reported and analysed for the applications of renewable thermal energy.

Demand assessment is another important element. For example, solar water heating in Thailand offers an economically attractive option for the tourism industry, particularly in the southern Thailand; by the same token, so do solar dryers for the agricultural sector, and potentially solar thermal for cooling in the buildings sector given the country's high cooling demand during daylight hours. Therefore, studies are required to look further into the feasibility of potential applications, followed by a promotional strategy.

Based on the results, the right set of policies and incentive schemes for the use of renewables in sectors other than just electricity could be developed and effectively implemented, and the market for renewables for thermal use could be built.

Long-term plan for electric mobility

Challenges

Thailand has developed a strong automobile industry. The government has set ambitious targets promoting the use of biofuels in AEDP 2015 while at the same time aiming to have 1.2 million EVs (including BEVs and PHEVs) in the EEP. To some extent, this has confused the car manufacturers, who are increasingly uncertain about the government's long-term development strategy and policy and technology choice for the transport sector. This has been recognised as the greatest challenge, in part because all the cars and engines manufactured in Thailand are designed by overseas parent companies and it would require a great deal of time for them to adapt to a change in technological preference.

[47] Including solar thermal for cooling systems using absorption chillers.

From the government perspective, EVs present obvious advantages when it comes to reducing demand for imported transport fuels, exhaust gas emissions and transport noise in cities, and more importantly, benefiting from the advantages to power system management from the dispatchable electric energy stored in the batteries of EVs. With the global trend towards EV development and the potential regional and global market, it can be anticipated that the Thai government will increasingly step up its support for the development of EVs. However, there is a concern from the automotive industry with regard to the potential risk of creating competition for market share between EVs and biofuel vehicles if policy and the supporting schemes are not carefully designed.

Recommendations

Despite EV technologies and applications having rapidly evolved in many regions across the world, they remain in their infancy compared to the use of conventional transport vehicles, and are often suitable only for urban transport due to current technological and infrastructure constraints. However, with better and proactive planning for technological and infrastructure development, EVs could have an important role as an alternative to petroleum-derived transport fuels in Thailand.

EVs have various challenges such as battery capacity, mileage constraints, safety issues, and the need for charging stations. For the future development of EVs, technological innovation in the transport and power sectors are key. Therefore Thailand should strengthen its R&D capacity in EVs and develop the local expertise and knowledge in the field of EV design and manufacturing, and its interactions with other fields such as power system management and smart grids.

Secondly, Thailand should avoid a rapid change in policy direction. To this end, it is recommended that Thailand develop a long-term strategic development plan or roadmap for the transport sector, covering vehicles, fuel types and the necessary infrastructure. If the corresponding policies could ensure that EVs gradually penetrate the local market while aiming at overseas markets through exports, this would provide the industry with enough lead time to plan for the transition. This would also help the power sector, especially the distribution network operators, to prepare for accommodating and managing EV charging. The bottom line is to develop a long-term clear and consistent policy framework for transport sector development, with concrete step-by-step action plans for each of the development stages. They must be endorsed or jointly developed by the key ministries. With these, the automobile industry will be able to prepare its business plans accordingly.

Lastly, in the current context of automobile industry development in Thailand, four specific recommendations can serve as a starting point:

1. Tap into electric two- and three-wheeler markets (including tuk-tuks) and establish the local manufacturing capacity to deliver quality products at acceptable prices for Thailand. There is no competition with conventional car manufacturers in this market segment. As projected in the REmap analysis, there could be as many as 3.5 million electric two- and three-wheelers on the road by 2036.

2. For electric four-wheelers, Thailand could start with the market for fixed-route means of transport with a predicable distance range, such as public buses, light freight vehicles for delivery services, and sightseeing or tour buses. This would also help the industry collect operational data for further improvement, and demonstrate the benefits of EVs to the potential users, and reduce air pollution in cities.

3. Thailand might want to consider incentivising the voluntary replacement of obsolete vehicles on the road with EVs by providing a certain amount of subsidy.

4. Thailand should increase investment in charging facilities for EVs, including on-street charging for urban EVs and two-/three-wheelers as well as fast-charging stations.

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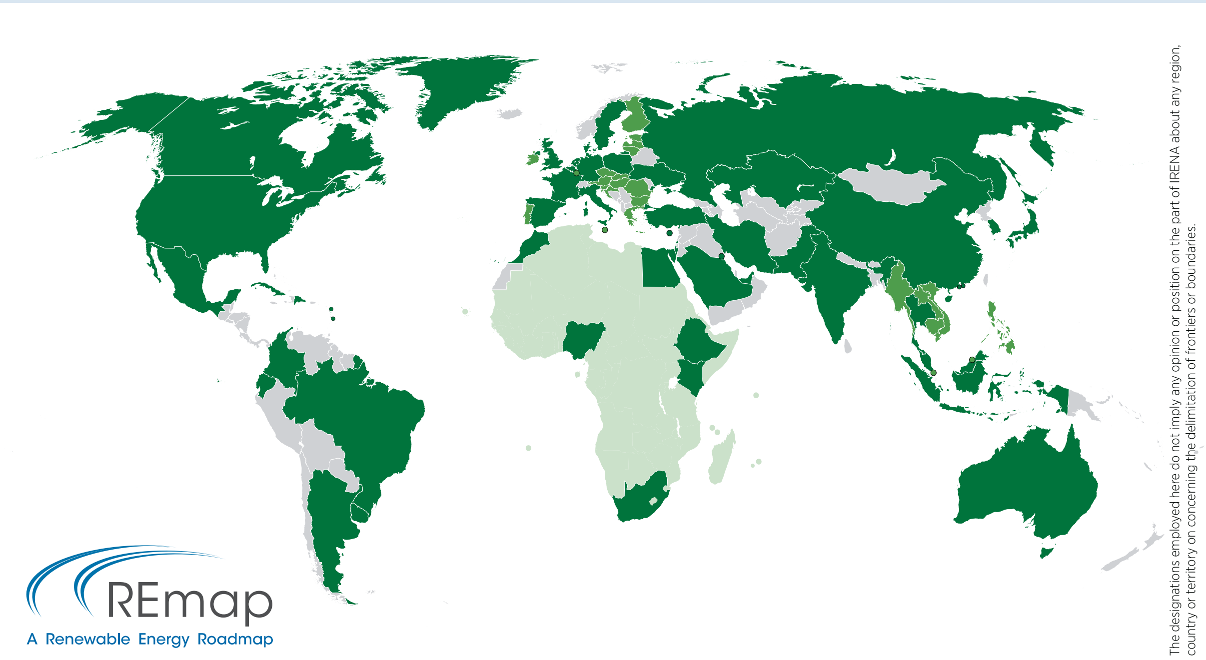
ANNEX: REmap methodology, assessment approach and data sources

This annex details the REmap methodology and summarises the key assumptions and methods used for the Thailand analysis. REmap is a roadmap of technology options to increase the global share of renewables. It involves a bottom-up, iterative analysis of 70 countries (as of early 2017). For selected countries the analysis is deepened and detailed in in-depth country reports, working papers, or other formats. This report is the first to summarise in-depth country analysis with a combined IRENA Renewable Readiness Assessment. Therefore, the REmap contribution to this report is limited to providing a perspective on energy use developments based on the REmap analysis that is presented in Chapter 4.

REmap engagement with Thailand began in early 2016 with preparations for the REmap ASEAN regional report, co-authored with the ASEAN Centre for Energy (ACE). This regional REmap roadmap, Renewable Energy Outlook for ASEAN: A REmap Analysis (IRENA and ACE, 2016), was released in October 2016 and was the culmination of numerous consultative workshops and meetings with ASEAN member states. The focus of the roadmap was to provide a perspective to these member states on how they could achieve their aspirational objective of reaching a renewable energy share of 23% in TPES by 2025 – a significant increase over the 10% share in 2014 (the target's base year).

With the release of the report, the 10 ASEAN member states were added to the REmap country grouping, which as of early 2017 includes 70 countries representing over 90% of global energy demand. Figure 33 details those countries, with the dark green countries being dedicated REmap countries, middle green showing countries that are included in regional roadmaps such as the ASEAN REmap outlook, and light green including countries covered by IRENA's numerous activities in Africa that also feed into the REmap analysis.

Figure 33. REmap countries (map)



The REmap analysis for this report builds on the initial analysis conducted for Thailand as part of the REmap ASEAN regional report by expanding and deepening the scope of the analysis and assessment for Thailand. As part of the joint RRA-REmap process, IRENA has interacted with the Government of Thailand over the course of 2016 and 2017 through two consultative workshops and numerous meetings to deepen understanding of the potential of renewables in the country.

The REmap analysis for Thailand utilises an internally developed IRENA REmap tool that incorporates data and analysis done by IRENA and Thai experts for energy system developments and renewable potential in the country. It provides assumptions and a standardised REmap approach for assessment of technologies in terms of their costs, investments and benefits.

The REmap analysis assumes two key future years:

- 2025 – to provide a near-term perspective on renewable energy development in Thailand and to allow comparability and insights into Thailand's role in the ASEAN region's aspirational target for renewable energy for that year

- 2036 – to provide a perspective on renewable energy in relation to Thailand's AEDP.

The REmap analysis starts by building the energy balance of a country, using 2015 as the base year of the analysis, based on national data and statistics. The country then provides its latest national energy plans and targets for renewables and fossil fuels, collated to produce a business-as-usual perspective of the energy system, referred to as the **Reference Case**. This includes TFEC for each end-use sector (buildings, industry and transport) and distinguishes between power, district heating and direct uses of energy with a breakdown by energy carrier for the period 2015-36.

Once the Reference Case is ready, the additional renewable energy potential by technology is investigated for each sector. The potential of these technologies is described as **REmap Options**.[48] Each REmap Option replaces a non-renewable energy technology[49] to deliver the same energy service. The resulting case when all of these options are aggregated is called **REmap**.

Throughout this study, the renewable energy share is estimated in relation to TFEC[50] in general, but also occasionally in relation to TPES to allow for comparison with shares associated with the ASEAN renewable energy target (for 2025 for instance). Modern renewable energy excludes traditional uses of bioenergy.[51] The share of modern renewable energy in TFEC is equal to total modern renewable energy consumption in end-use sectors (including consumption of renewable electricity and district heat, and direct use of renewables), divided by TFEC. The share of renewables in power generation is also calculated. The renewable energy share can also be expressed in terms of the direct use of renewables only. The renewable energy use by end-use sector covers the areas described below.

- **Buildings** include the residential, commercial and public sectors. Renewable energy is used in direct applications for heating, cooling or cooking purposes or as renewable electricity.

- **Industry** includes the manufacturing and mining sectors, in which renewable energy is consumed in direct-use applications (*e.g.* process heat or refrigeration) and electricity from renewable sources. It also includes agriculture.

- **Transport sector**, which can make direct use of renewables through the consumption of liquid and gaseous biofuels or through electricity generated using renewable energy technologies.

Metrics for assessing REmap Options

To assess the costs of REmap Options, **substitution costs** are calculated. This report also discusses the costs and savings of renewable energy deployment

48 An approach based on options rather than scenarios is deliberate. REmap is an exploratory study and not a target-setting exercise.

49 Non-renewable technologies encompass fossil fuels, non-sustainable uses of bioenergy (referred to here as traditional bioenergy) and nuclear power. As a supplement to this report's annex, a detailed list of these technologies and related background data are provided on the REmap website.

50 TFEC is the energy delivered to consumers as electricity, heat or fuels that can be used directly as a source of energy. This consumption is usually subdivided into transport, industry, residential, commercial and public buildings, and agriculture. It excludes non-energy uses of fuels.

51 The Food and Agriculture Organization of the United Nations (FAO) defines traditional biomass use as woodfuels, agricultural by-products and dung burned for cooking and heating purposes (FAO, 2000). In developing countries, traditional biomass is still widely harvested and used in an unsustainable, inefficient and unsafe way. It is mostly traded informally and non-commercially. Modern biomass, by contrast, is produced in a sustainable manner from solid wastes and residues from agriculture and forestry and relies on more efficient methods (IEA and World Bank, 2015).

and related externalities due to climate change and air pollution. Experts devised four main indicators: **substitution costs, system costs, total investment needs and needs for renewable energy investment support.**

Substitution costs

Each renewable and non-renewable technology has its own individual cost relative to the non-renewable energy that it replaces. This is explained in detail in the REmap methodology (IRENA, 2014a) and is depicted in the following equation:

Cost of Technology/ REmap options **USD/year in 2036**	=	Equivalent annual capital expenditure **USD/year in 2036**	+	Operating expenditure **USD/year in 2036**	+	Fuel cost **USD/year in 2036**

For each REmap Option, the analysis considers the cost of substituting a non-renewable energy technology to deliver an identical amount of heat, electricity or energy service. The cost of each REmap Option is represented by its **substitution cost**:[52,53]

Cost of Technology/ REmap options **USD/year in 2036**	=	Cost of REmap options **USD/year in 2036**	-	Cost of substituted conventional technology **USD/year in 2036**
		Energy substituted by REmap options **GJ/year in 2036**		

This indicator provides a comparable metric for all renewable energy technologies identified in each sector. Substitution costs are the key indicators for assessing the economic viability of REmap Options. They depend on the type of conventional technology substituted, energy prices and the characteristics of the REmap Option. The cost can be positive (additional) or negative (savings) because many renewable energy technologies are, or could be, more cost-effective by 2036 than conventional technologies.

System costs

On the basis of the substitution cost, inferences can be made as to the effect on **system costs**. This indicator is the sum of the differences between the total capital and operating expenditures of all energy technologies based on their deployment in REmap and the Reference Case in 2025 and 2036.

Systems costs **USD/year in 2036**	=	Subsititutions costs: government perspective **All technologies USD/GJ in 2036**	x	REmap options **All technologies GJ/year in 2036**

Investment needs

Investment needs for renewable energy capacity can also be assessed. The total **investment needs** of technologies in REmap are higher than in the Reference Case due to the increased share of renewables. On average, these have greater investment needs than the non-renewable energy technology equivalent. The capital investment cost in USD per kW of installed capacity in each year is multiplied with the deployment in that year to arrive at total annual investment costs. The capital investment costs of each year are then added up for the period 2015-36. Net incremental investment needs are the sum of the differences between the total investment costs for all renewable and non-renewable energy technologies in power generation and stationary applications in REmap and the Reference Case in the period 2015-36 for each year. This total was then turned into an annual average for the period.

Average investments needs **USD/year in 2016-2036**	=	Renewable capacity installed **Total GW 2016-2036**	x	Average capital expenditure **USD/GW 2016-2036**
		20 **Number of years 2016-2036**		

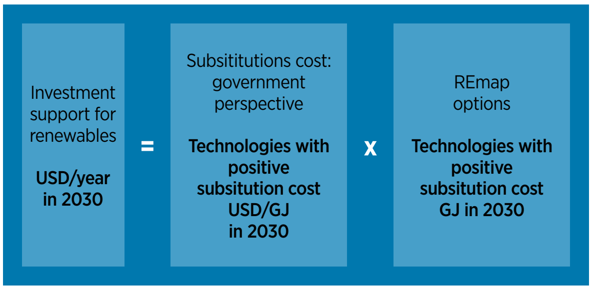
Renewable energy investment support needs

Renewable energy investment support needs can also be approximated on the basis of the REmap tool. Total requirements for renewable investment

[52] Substitution cost is the difference between the annualised cost of the REmap Option and the annualised cost of the substituted non-renewable technology used to produce the same amount of energy. This is divided by the total renewable energy use substituted by the REmap Option.

[53] 1 gigajoule (GJ) = 0.0238 toe = 0.238 gigacalories = 278 kWh; USD 1 was on average equivalent to THB 33 at the time of writing this report.

support in all sectors are estimated as the difference in the delivered energy service cost (*e.g.* in USD per kWh or USD per GJ from a government perspective) for the renewable option against the dominant incumbent. This difference is multiplied by the deployment for that option in that year to arrive at an investment support total for that technology. The differences for all REmap Options are added together to provide an annual investment support requirement for renewables. The renewable option is not subtracted from the total if it has a lower delivered energy service cost than the incumbent option. By the 2030s, this is an increasing trend.



Government and business perspectives

Based on the substitution cost and the potential of each REmap Option, country cost-supply curves are developed from the perspective of governments. This **Government perspective** allows a comparison across countries and a country cost-benefit analysis; it shows the cost of the transition as governments would calculate it. This perspective excludes energy taxes and subsidies and a standard discount rate of 10% (for non-OECD countries) was used.

Externality analysis

Several externality reductions obtained through REmap Options are considered. They include health effects from outdoor or indoor exposure to pollution in the case of traditional bioenergy, as well as effects on agricultural yields. In addition, the external costs associated with the social and economic impacts of CO_2 are estimated (IRENA, 2016a).

Further documentation and a detailed description of the REmap methodology can be found at www.irena.org/REmap. Further details on metrics for assessing REmap Options can be consulted in the appendix of the 2016 global report (IRENA, 2016a). Finally, energy supply and demand numbers in this report are generally provided in petajoules (PJ) or exajoules (EJ), the standard for REmap. In Thailand, commonly used units are tonnes of oil equivalent (toe). The relevant conversion factors are listed below:

- 1 GJ = 0.0238 toe
- 1 GJ = 277.78 kilowatt hour (kWh)
- 1 PJ = 0.0238 million toe
- 1 PJ = 277.78 gigawatt hour (GWh)
- 1 EJ = 23.88 million toe
- 1 EJ = 277.78 terawatt-hour (TWh).

Main sources of information and assumptions

The following key sources have been used to prepare the REmap analysis for Thailand:

- **Base year 2015:** Thailand energy statistics provided by the government.

- **Reference Case:** AEDP 2015; forecasts provided by government in response to IRENA data questionnaire.

REmap Options: Country consultation and feedback during February 2017 workshop; Renewable Energy Outlook for ASEAN (IRENA); 4th ASEAN Energy Outlook (ACE); solar thermal use in industry updated based on solar heat for industrial processes data; Renewable Energy in Manufacturing (IRENA); Biofuel Potential in Southeast Asia (IRENA); Renewable Route to Sustainable Transport (IRENA); Technology briefs for Electric Vehicles, Liquid Biofuels, Solar Thermal (IRENA);

Key technology cost and performance

The table below shows the main assumptions for the main technologies assumed in the buildings, industry and power sectors for capacity deployment or substitution.

Technology (in 2036)	Capacity factor (%)	Overnight capital cost (USD/kW)	O&M costs (excl. fuel) (USD/kW/yr)	Conversion efficiency (%)
Industrial Sector				
Solar thermal	20	300	5	100
Biogas heat, digester	70	200	5	85
Biomass, co generation	50	900	25	80
Coal, boiler	80	300	8	90
Natural gas, boiler	80	100	5	90
Buildings sector				
Solar thermal, thermosiphon	16	150	5	100
Biogas, cooking	10	40	2	48
Biomass solid, cooking	10	15	1	30
Petroleum products, boiler	30	175	6	85
Natural gas, boiler	30	150	5	90
Electricity, boiler	30	150	4	85
Electricity, cooling	50	150	4	250
Petroleum products, cooking	10	10	1	50
Power sector				
Hydro, small	56	2 500	50	100
Wind, onshore	28	1 500	30	100
Solar PV, utility	18	1 000	10	100
Solar PV, rooftop	16	1 400	18	100
Bioenergy, co generation	70	2 750	70	80
Coal	70	1 300	52	38
Natural gas	60	1 000	40	55

Note: O&M = operation and maintenance.

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