Report

KRABI GOES GREEN

Towards A Model Town, With More Than 100% Renewable Energy

GREENPEACE

REPORT

KRABI GOES GREEN

Towards A Model Town, With More Than 100% Renewable Energy

RESEARCH TEAM

Assoc. Prof. Dr Chalie Charoenlarpnopparut
Sirindhorn International Institute of Technology, Thammasat University
Suphakit Nuntavorakarn
Healthy Public Policy Foundation
Akanit Kwangkaew
Sirindhorn International Institute of Technology, Thammasat University
Titiwetaya Yaikratok
Healthy Public Policy Foundation
Somnuk Krodsua
Save Pakasai Group, Krabi
Mr. Athiras Dumdee
Qualified Committee of Thailand Oil Palm Board
Kittichai Angchuan
Krabi Provincial Administrative Organization
Amarit Siripornjuthakul
Advisor to Krabi Tourism Council

Editorial Board

Assoc. Prof. Dr Chalie Charoenlarpnopparut, Tara Buakamsri, Chariya Senpong

Editor (English Version)

Sameer Man Singh

Designers

Rataya Yubanklong / Jade Peganan

KRABI GOES GREEN NETWORK
ANDAMAN GOES GREEN NETWORK

www.greenpeace.or.th

CONTENTS

©Niwat Wattanayamanaporn

EXECUTIVE SUMMARY

Renewable energy development is strongly associated with some of the key Sustainable Development Goals (SDGs) set by the United Nations in 2015. This report aims to show the results and findings of a study done on electricity consumption and generation plans in Thailand's Krabi Province during the next 20 years (2018 - 2037). The report attempts to prove that it is possible for Krabi to build an electricity supply system based completely on renewable energies in the near future.

In the analyses leading to the preparation of this report, the electricity generation potential of five renewable energy sources, namely modern biomass, biogas, solar, wind, and mini-hydropower were studied, based on which an electricity generation plan was formulated using a systematic and an evidence-based approach. The analysis consists of two parts: (1) Hourly demand of electricity over a one week period of each month for 20 years (2018-2037) (2) Capacity to deliver the hourly supply of electricity over the same period from each of the renewable sources.

The following assumptions were considered for the study: (1) The grid operator is capable of planning and controlling the electricity generation of all power plants in Krabi (2) Excess electricity energy can always be exported to nearby provinces (3) There is decisive political will, supportive government policies and regulations on renewable energy, and (4) The electricity grid has no limitations on energy carrying capacity.

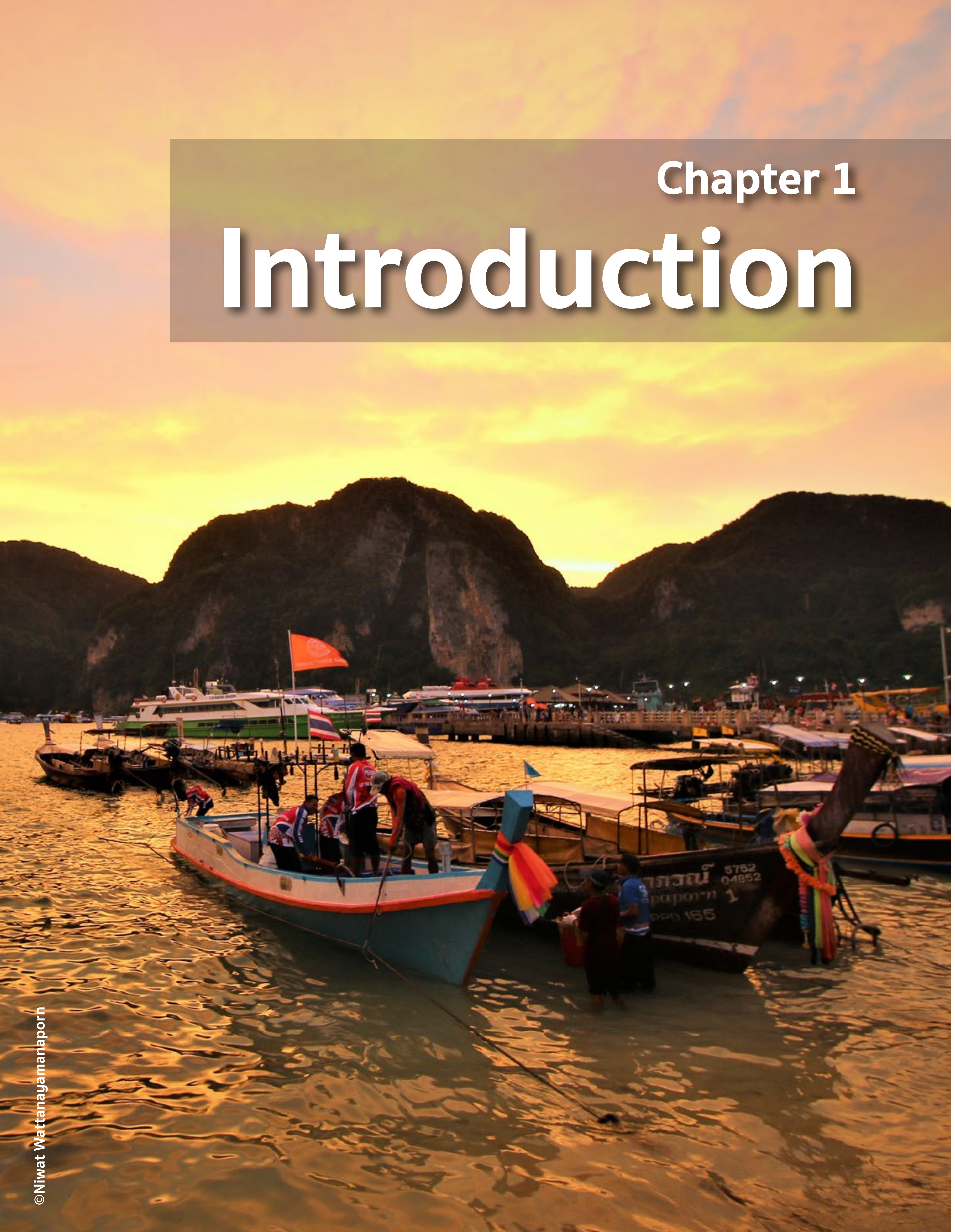
The study projects a total electricity generation potential of 1,676 Megawatts (MW) installed capacity from all five renewable energy sources. An hourly simulation of electricity generation shows that Krabi will achieve its 100% renewable energy goal by 2026, provided that the renewable energy development is well supported at a suitable growth rate. By 2021, Krabi will start to become 100% dependent on renewable energy for at least two hours a day.

Despite the fact that the total annual costs of renewable energy generation and energy efficiency scenario is higher than that of coal or natural gas during the initial period, it is considerably lower when taking into account a cost-benefit projection over a long term of 20 years.

By adopting a 100% renewable energy province-wide model of sustainability, Krabi can benefit at both socio-economic and environmental fronts including lower import burden, a higher contribution to economic growth, higher employment, as well as lower GHG emission.

Krabi's successful transition to an electricity supply system based on renewable energies will require a pragmatic public policy that (1) Prioritises renewable energy to be fed into the grid prior to the fossil energy counterpart (2) Incentivising renewable energy at a proper rate that balances the electricity cost regulation and investment (3) Reorienting the state enterprises related to electricity generation systems to espouse a renewable energy mindset and (4) Development and modernisation of smart grids and efficient electricity management systems at grid level.

Chapter 1
Introduction



©Niwat Wattanayamanaporn

The key objective of this report is to study the electricity consumption in Krabi Province and inform the planning process of electricity generation in the next 20 years (2018 - 2037). By studying the potentiality of the local renewable energy industries, the report aims to predict the possibility of developing Krabi in becoming self-reliant for its energy needs and a pioneer province in Thailand in moving towards 100% clean energy.

The analyses presented in this report consists of two parts:

1. The hourly needs for electricity in Krabi per week per month.

2. The capacity to distribute electricity generated from renewable energy industries in Krabi

and to respond to the demand which is different at different times.

The assumptions used in the study are:

1. The power network system will enable effective operational controls and help manage the electricity generation.

2. Surplus electricity produced can always be re-distributed to neighbouring provinces.

3. Government policies are supportive towards the renewable energy industry and do not pose direct or indirect hindrances.

4. The transmission line system and the grid can handle electricity needs without limitations.

The report is structured with the first part dealing with the origin and significance of the development of the renewable energy industry in Thailand and the current and future electricity consumption trends in Krabi. The second part is dedicated to studying the potential of different renewable energy industries in Krabi. Lastly, the report presents an analysis of energy plans, cost-benefit ratios for local economies, and directions to the development of the renewable energy industry towards envisioning a model town Krabi with 100% renewable energy sources. It does so by forwarding policy recommendations and ways to remove hindrances for Krabi's sustainable development and resilience.

1.1 The origin and significance of renewable energy

Energy is an important factor in the development and livelihoods of humans – especially electricity which has taken on a hitherto unprecedented role in the modern world. Electricity is the backbone that drives modern economy with important roles in transportation, production, communication and service sectors. Although three-quarters of the current global electricity demand is fulfilled by fossil fuels such as coal, natural gas and oil, there is a continued downward trend in its use. Renewable energy is now seen as the key alternative to replace fossil fuel energy which is in decline mainly due to the rising awareness about global warming from greenhouse gases and their linkages with the burning of fossil fuels. The recent technological advances and increasing investments in the renewable energy industry have significantly reduced the costs involved in renewable energy production, making it competitive with electricity produced from fossil fuels. A key evidence of this is the investment in new power plants in 2016 with two-thirds of its production originating from the renewable energy sector.

On 25 September 2015, 193 member states and other parties agreed to adopt the 17 United Nations Sustainable Development Goals (UNSDGs) to be achieved by 2030, of which there are six that are important and related to clean renewable energy development.

● Goal 3: Good health and well-being

In contrast to conventional power plants, renewable energy plants use clean energy from nature such as wind, solar and biomass, which have less impact on the environment both in terms of producing greenhouse gases as well as causing pollution and health impacts on people living in close vicinity. The prevailing practice is to compensate these people by payments for treatments or setting up of funds which are inadequate. Despite these reasons, when a new power plant is considered, a big power plant that causes pollution is often adopted for management and security reasons while impacts on the health of people and the environment are undermined. Adopting

©Niwat Wattanayamanaporn

clean renewable energy can be a better alternative that promotes good health and the well-being of communities.

● Goal 7: Affordable and clean energy

Renewable energy technology is clean and has less impact on health and the environment than fossil fuels. The recent times have seen a steep and continued cost reduction in renewable energy production owing to the competitive supply chains and technological progress. In addition, renewable energy technology is suitable for small-scale production and local distribution near the sources of the fuel and can be produced in places far from transmission lines. For example, electricity can be generated from solar power and biogas on islands or in the countryside.

● Goal 8: Decent work and economic growth

A distinct feature that makes renewable energy suitable for small-scale productions is that it not only utilises local resources for fuels but also contributes to local economies by hiring local manpower and labour force. This helps solve socio-economic problems related to labour migration that lead to imbalances in population dynamics – especially in the countryside where there are instances of children and youth being left behind to live with the elderly due to out-migration of working-age adults. Additionally, the process of power generation from renewable energy is quite safe for workers and poses low levels of occupational hazards. From an economic perspective, the renewable energy industries provide better income distribution to the local areas as direct employment from local power generation and in the form of investments made in the construction and maintenance phases of projects. Additional benefits include selling of raw agricultural materials for power generation, e.g. biogas and biomass, and a boost in other businesses such as shops, restaurants and services.

● **Goal 9: Industry, innovation and infrastructure**

Investment in infrastructure and innovation are crucial drivers of economic growth and development. With over half the world population now living in cities, mass transport and renewable energy are becoming ever more important, as are the growth of new industries and information and communication technologies.

An expansion of the renewable energy industry will help develop the efficiency as well as lead innovation and new businesses in the local areas. Developing small power plants along with locally distributed power grids is consistent with development of infrastructure.

● **Goal 12: Responsible consumption and production**

Renewable energy resources have short life cycles from their origin until utilisation. Some renewable energy sources like wind and solar power are non-depletable whereas fossil fuel requires millions of years to be replenished. Biomass energy derived from agricultural leftovers and wastes maximises the use of each of the materials, contributing to responsible production and consumption practices.

©Niwat Wattanayamanaporn

©Paitoon Longpeng

©Niwat Wattanayamanaporn

©Niwat Wattanayamanaporn

▲ **Photoes 1-2-1 Showing Krabi's tourist attraction, sources of food and livelihood, and its ecological integrity**

● **Goal 13: Climate action**

Power generation from the renewable energy industries releases less carbon dioxide into the atmosphere. By contributing directly to reducing power shortages, renewable energy industries through distributed power production, small-scale power grids and off-grid power production can positively reinforce communities to become resilient to natural disasters and impacts of climate change.

1.2 Directions of the development of 'Krabi Goes Green' in the past

Krabi is one of the 14 provinces in the south of Thailand. With an area of 4,708.5 square kilometres (0.92% of the country's total size) and a population of around 470,000 (0.71% of total Thai population), it is rich in seafood and famous for its internationally known tourist attractions. Although small, Krabi is important from tourism and agriculture perspectives, thanks to its geographical disposition – the Khao Phanom Bencha mountain range, 160 km long Andaman coast, more than 150 small and big islands and mangrove forests which serve as nursery habitats for big fisheries.

The estuary of the Krabi river, covering an area of 133,120 rai, is included in the Ramsar list as a wetland of international importance[1]. Krabi's ecological system features sandy beaches, mudflats, water from the Krabi river and canals leading to the sea. It consists of 63,825 rai of mangrove forest area and more than 30,958 rai of seagrass beds, which ranks as the second largest in the country[2]. Krabi's biodiverse coastal and sea areas are home to more than 200 fish species and 80 types of corals.

1. https://www.ramsar.org/wetland/thailand
2. http://www.dmcr.go.th/upload/dt/file/file-1812-560139973.pdf

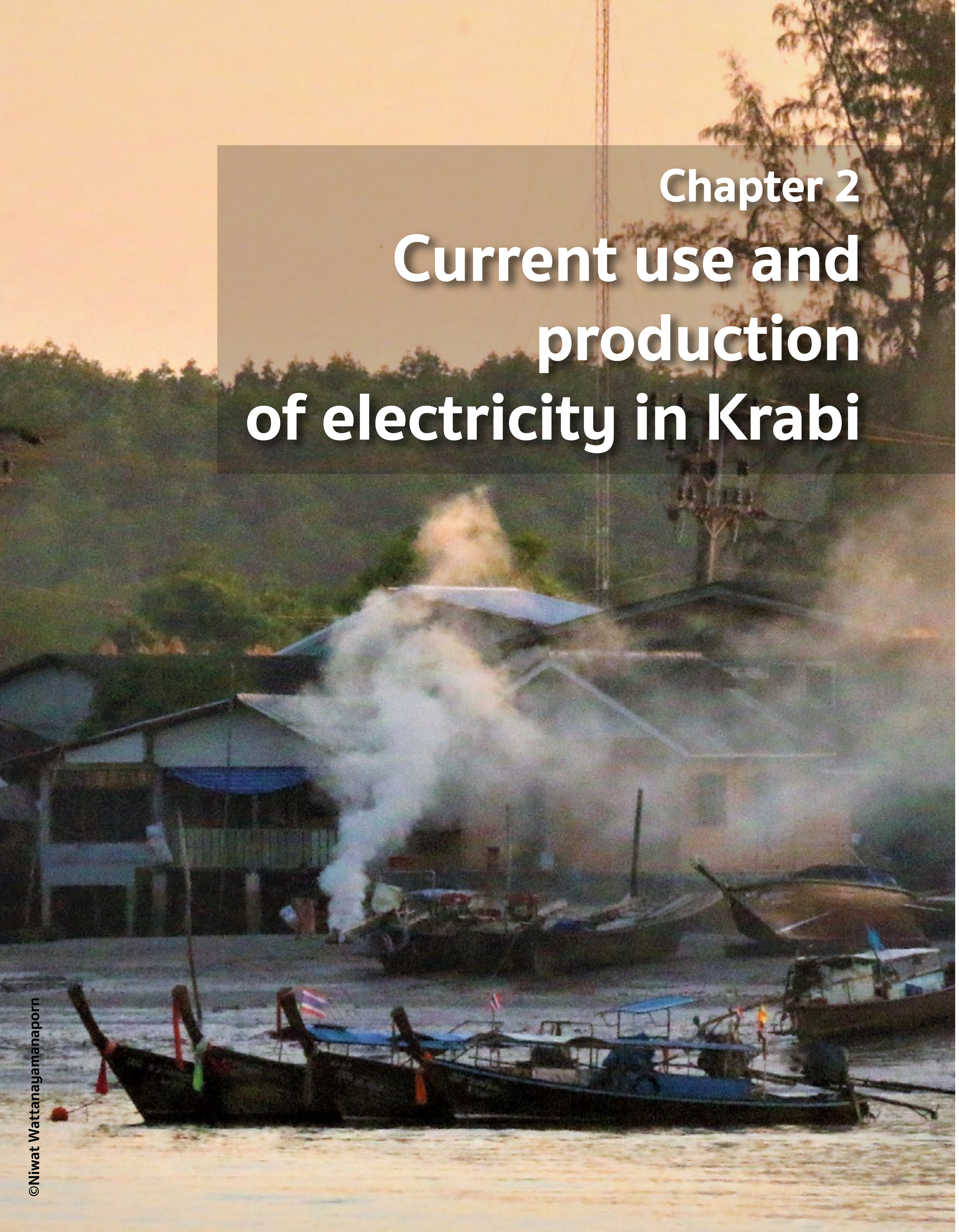
The estuary of the Krabi river is also an important nesting ground for bird migration[3] which is an important indicator of the richness of natural resources[4] and a part of the Partnership for the Conservation of Migratory Waterbirds and the Sustainable Use of their Habitats in the East Asian – Australasian Flyway.

The Krabi development strategy 'Krabi Vision 2020 – Standpoint and Directions to prepare for future development' with the participation of all sectors have set directions for its sustainable development to respond to economic growth with focus on agriculture, tourism and service businesses as key areas. By setting its own provincial strategies and management plans, Krabi is moving towards green economic development and sustainable tourism adhering to international standards and global practices in sustainable agriculture and livable societies in line with emerging conservation oriented development trends.

Goal 7 of the Krabi vision 2020 mentions Krabi as the origin and a pioneer province for clean and alternative energy industries in Thailand. Krabi is the country's source for biodiesel and as the main producer of alternative energy from agricultural crops has high energy security importance. It is one of the biggest growers and producers of palm oil which can be used as fuel for electricity generation and also has a high potential to produce renewable energy from solar, wind, biogas, agricultural crops and mini-hydro power. These renewable energy sources can be used for power generation in Krabi to sustainably serve the needs of its people and to boost green economy and tourism.

3. รายงานการสำรวจและประเมินสถานภาพและศักยภาพทรัพยากรทางทะเลและชายฝั่ง : ปะการังและหญ้าทะเล ปี 2558, กรมทรัพยากรทางทะเลและชายฝั่ง, กระทรวงทรัพยากรธรรมชาติและสิ่งแวดล้อม

4 . พื้นที่ชุ่มน้ำที่มีความสำคัญระดับนานาชาติ, สำนักงานนโยบายและแผนทรัพยากรธรรมชาติและสิ่งแวดล้อม, http://wetland.onep.go.th/KrabiEstuary_n.html



©Niwat Wattanayamanaporn

Chapter 2
Current use and production of electricity in Krabi

2.1 Electricity production

Krabi is rich in renewable energy natural resources such as biomass from palm oil industry, rubber wood and biogas extracted from the fermentation of wastewater from these industries. Additionally, it also has a good potential in the wind and solar energy sectors. The data on farm plants in Krabi shows that there are 985,285 rai of palm trees and 845,632 rai of rubber trees. At present, there are 30 palm oil factories with a total capacity to process 22,500 tons of crude palm every day. If efficiently utilised for power generation, Krabi could easily become a model town on being self-reliant on 100% renewable energy.

Electricity generation in Krabi at present depends on two important sources:

1) Electricity from the Electricity Generating Authority of Thailand (EGAT) through the electricity grids in the south. There is a secondary coal-fired power plant at Nua Khlong District which is occasionally run using fossil fuel oils.

2) Electricity purchased from very small power producers (VSPP) such as power plants using biomass and biogas from oil palm and other renewable energy sources.

In addition, electricity is also produced by the consumers (prosumers) who have decided to invest in producing electricity themselves using solar rooftops, solar cell panels on residential houses or on commercial buildings. Some communities also produce their own electricity from biogas or biomass. These productions are not included in the province's electricity generation capacity.

Examples of electricity production by prosumers in Krabi and other provinces in the south of Thailand:

- **Ruenmai restaurant, Krabi Province**

- 3,720-watt rooftop and floating solar installed
- Cost reduction: 4,000 baht per month
- Payback period: 6 years
- Type: Co-sharing with electricity from the grid line
- Usage: light bulbs, ice maker and other electrical appliances

©Titiwetaya Yailkratok

▲ Photo 2.1-2 Floating solar panels

● Lanta Mart, Lanta island, Krabi Province

- 48,000-watt solar cell installed without batteries
- Cost reduction: around 40% per month (previous electricity cost was 120,000 baht per month and reduced to 70,000 baht per month)
- Payback period: 5-6 years
- Type: Co-sharing with electricity from the grid line
- Usage: Air conditioners with direct circuit power supply, freezers and other electrical appliances. This is done along with energy efficiency and management for highest reduction of electricity consumption such as using insulation to prevent heat from coming into the building and pulling the heat from the refrigerators and freezers to outside air conditioning rooms.

©Chanklang Kunthong

▲ Photo 2.1-3 solar panels on the roof of Lanta Mart

● The Dearly Koh Tao Hostel, Surat Thani Province

- Installation of a 50,000-watt solar cell generator with batteries underway
- Cost reduction: 200,000 baht per month
- Payback period: 3 years
- Type: Located in an off-grid area with a diesel engine for secondary electricity generation. Prepared for co-sharing with transmission line if accessible in the future
- Usage: Air conditioners with direct circuit power supply, freezers and other electrical appliances. Used for all electronics in the 25-room hostel including air conditioners, refrigerators, freezers, water pumps, kitchens, swimming pool system, water supply system, drinking water system.

©Saichit Chawana

▲ Photo 2.1-4 solar cell panels on the roof of the Dearly Koh Tao hostel

● Chana Hospital, Songkhla province

- 20,000-watt solar cell without batteries
- Cost reduction: 12,000 - 15,000 baht per month from around 250,000 baht billed monthly

- Payback period: 6 years
- Type: Co-sharing with electricity from the grid line
- Usage: Air conditioners, washing machines and other electrical appliances This is done along with other measures to ensure maximum reduction of electricity consumption

©Supat Hasuwannakit

▲ Photo 2.1-5 solar cell panels on the roof of the Chana hospital

● Ban Nok Pao School, Surat Thani Province

- Nok Pao island has 40 households and a population of 100 people. It used to have 2,100-watt solar cells but it is no longer working. The island has since used diesel engines to generate electricity.
- A 900-watt solar cell with batteries has been installed. This is an investment of 60,000 baht donated in cash and labour by Solar Volunteers from Phatthalung, Trang, Surat Thani and Lanta island.
- Type: No transmission line on the island
- Usage: Computers and other electrical appliances
- Maintenance: Teachers and students have been trained on the maintenance by the Solar Volunteers

©Kannika Paekaew

▲ Photo 2.1-6 Volunteers are demonstrating and training on the maintenance of solar panels

● Thai-Indo Palm Oil Factory Co., Ltd., Krabi province

- Installed electricity generation capacity: 1 MW from biomass and 3.2 MW from biogas, 1 MW of which is sold to the EGAT
- Type: Electricity generated in a factory and sold to transmission line system
- Has up to 15 MW electricity production capacity and is ready to sell at least 3 MW to the transmission line system

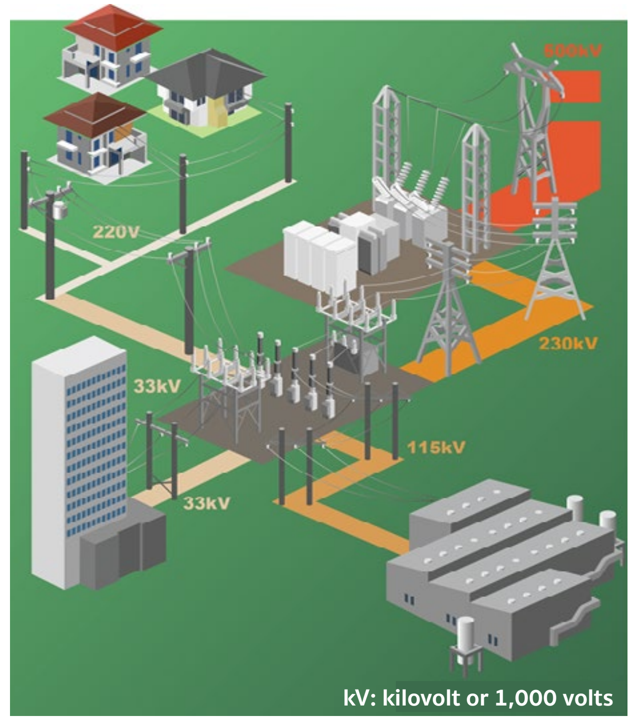
Status group	VSPP power plants in Krabi, as of 7 May 2018		
	Number of projects	Installed production capacity (MW)	Selling amount per purchase agreements (MW)
Power selling proposals have been submitted or accepted	0	0.00	0.00
Power Purchase Agreement (PPA) signed but in the pipeline for the Commercial Operation Date (COD)	4	18.80	18.80
Commercial Operation Date (COD) in effect	17	56.03	44.51
Total	21	74.83	63.31

▲ Table 2.1 Showing data for Very Small Power Producer - VSPP, number of projects and production capacity (installation and purchase agreement) according to the status groups

2.2 Current transmission system

The key land-use domain in Krabi Province is agriculture along with forests and a high density of communities living along the Andaman coast. The electrical grids in the area consist of high-voltage transmission lines along the north to south line distributed into a network of districts, connecting all of the province's eight sub-power stations. The high-voltage transmission system connects Phang Nga power station 1 to Krabi and Trang power stations.

Power transmission over long distances requires a transmission system that consists of various parts (see Figure 2.2-1). The country's high-voltage electrical system is connected by a network of 500,000 high-voltage transmission lines. Using high-voltages during transmission reduces power losses or spillage due to resistance and other factors like length of power lines and conductivity (power losses in the transmission line varies with the square of the electricity). Once the transmissions reach towns or villages, electricity is purchased at different currents from 220 volts (households and small businesses) to 115,000 volts (factories and big businesses) according to the power needs.



▲ Figure 2.2-1 Diagram shows the power network and voltage conversion from power plants to households and industrial plants in Southern Thailand

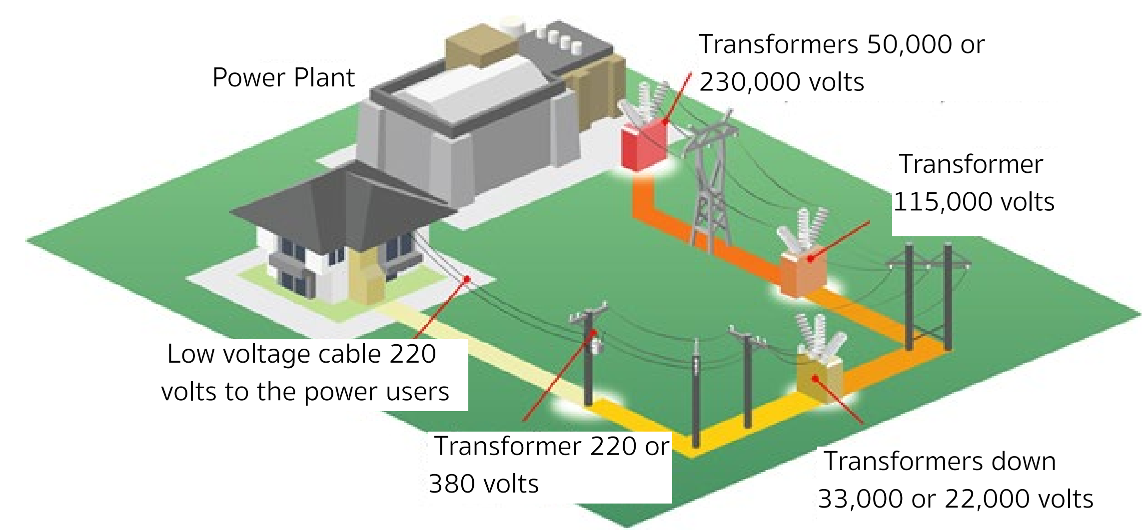
2.2.1 Areas of responsibility for power transmission system in Thailand

Power transmission in Thailand comes under the supervision of three major organisations with the following areas of responsibility:

(1) The Electricity Generating Authority of Thailand (EGAT) is responsible for the nation's large power generation system and power transmission to all regions. However, it does not directly distribute electricity to the public or industries.

(2) The Metropolitan Electricity Authority (MEA) is responsible for providing power supply in Bangkok, Nonthaburi and Samut Prakarn. It is also responsible for purchasing electricity from the EGAT and selling it directly to consumers as well as maintaining the security of the power supply system.

(3) The Provincial Electricity Authority (PEA) is responsible for providing power supply in 74 provinces other than those under the responsibility of the MEA. It is also responsible for purchasing power from the EGAT and selling it directly to consumers and maintaining the security of the power supply system.



▲ Figure 2.2-2 Shows the power transmission from the power plant to the power users

2.2.2 Structure of the electricity transmission system in Thailand

Thailand's power transmission system, also called 'transmission line', is the conduit for the transmission of electricity generated from power plants to the consumers in the households, communities and industries spread across the country. The power plant converts other forms of power into electricity which must be sent through these transmission lines to the consumers immediately after being generated. For long distance transmission such as power transmission across provinces or regions, high voltage levels are required. At closer distances it will use a lower voltage except in cases that require large amounts of power. The transmission line model is shown in Figures 2.2-1 and 2.2-2.

For simplicity, transmission systems can be classified according to their functions:

1) Power transmission system, which normally sends electricity at high voltage level via long distances.

2) The distribution system, which has voltage at a level lower than that of the transmission system. It distributes electricity to the electricity consumers, e.g. residential areas, industries, businesses, hospitals, etc.

In addition, the distribution system can also be classified as medium voltage and low voltage distribution system. The details are as follows:

● **Power transmission system (high-voltage distribution system)**

- Transmission line system with a voltage of 500,000 volts. Most of them are in the areas of responsibility of the EGAT.
- Transmission line system with a voltage of 230,000 volts. Most of them are in the areas of responsibility of the EGAT, except some that are under the MEA.
- Transmission line system with a voltage of 115,000 volts. These lie in the areas of the responsibility of the MEA and the PEA, and some under the EGAT.
-Transmission line system with a voltage of 69,000 volts. These lie in the areas of the responsibility of the MEA and the EGAT.

● **Power distribution system (medium-voltage distribution system)**

- The 22,000 volts system is located in the northern, central and northeastern parts of Thailand, and in some of the southern parts of the PEA's areas of responsibility.
- The 33,000 volts power supply system is located in the southern part of Thailand, which lies in the areas of responsibility of the PEA including Krabi Province.
- 12,000 and 24,000 volts supply systems are in Bangkok, Nonthaburi and Samut Prakan, which are the areas of responsibility of the MEA.

● **Power distribution system (low-voltage distribution system)**

The 220 or 380 volts power supply system is a low voltage electrical system used in households. It receives electricity from the medium voltage distribution system by reducing the current using a step-down transformer. The transformer is sometimes called a low-power transformer and can be seen on the electricity posts. See figure 2.2-2

In general, low-power distribution systems will be in the areas of responsibility

of the PEA and the MEA. The 220 volts power supply has a single phase and two wires: one Line (L) and one Neutral or Ground (N). The 380 volts power supply system has three phases with four wires, or three hot line and one neutral lines.

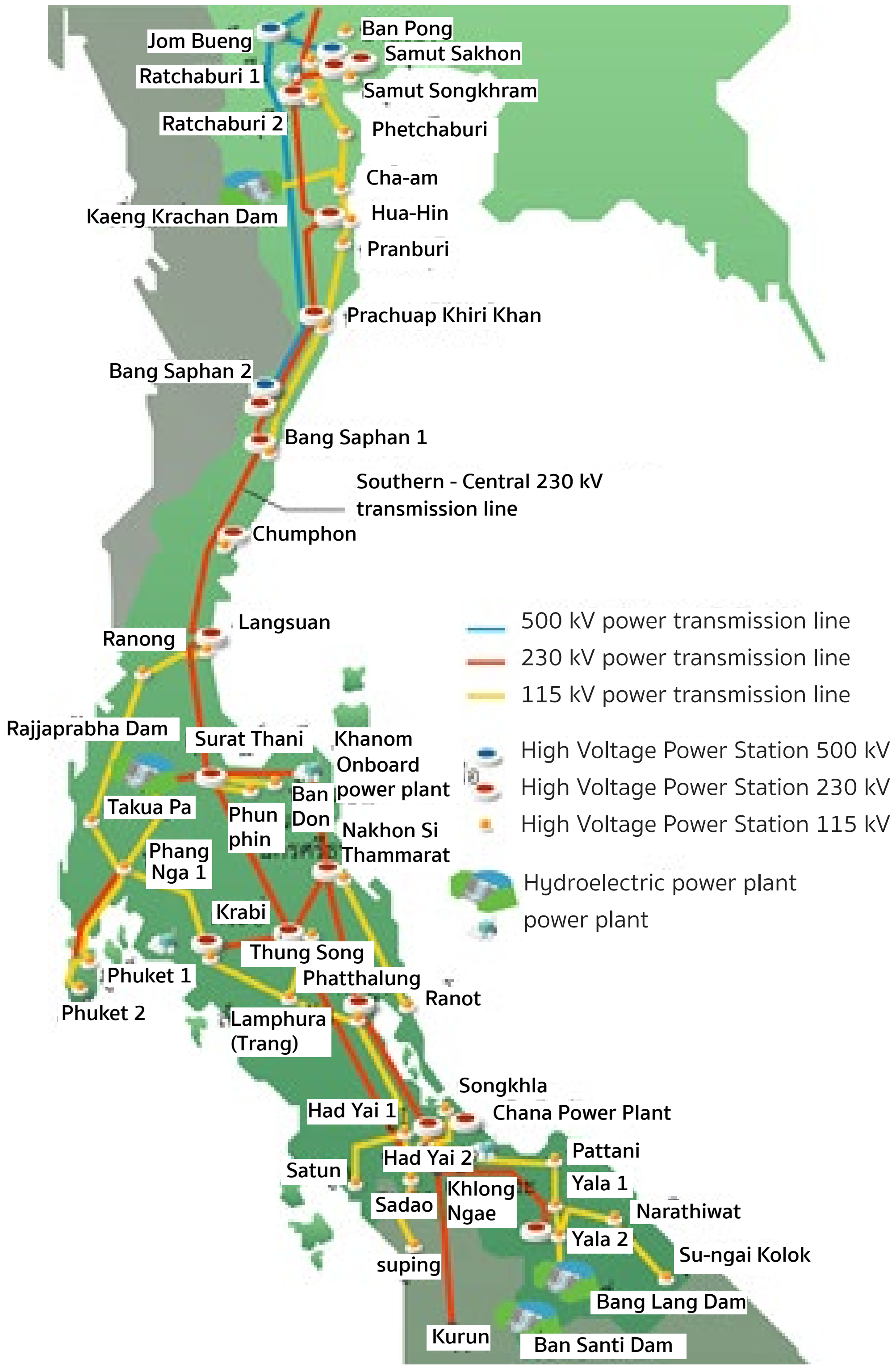
A three-phase system can sometimes have three wires since the neutral line could be used for grounding. It is therefore often misunderstood with the 220 volts system which has two phases since there are only two lines. It is however considered single phase in electrical engineering parlance, and not two phases.

2.2.3 The problem of insufficient electricity at the end of the transmission line

Inadequate power supply at the end of the transmission line, also known as 'power failure', is caused by a voltage lower than the normal operating voltage. Under these conditions the electrical appliances cannot work due to the power outage. The causes of the power outage/ failure are as follows:

● The distance of the area of power failure from the power station, electricity post and the transformer: Normally, the area closest to the power station is the area with the most voltage and has very little chance of power failure. The voltage is reduced as the distance increases because of the voltage losses through the length of the transmission lines. The greater the distance from the power station, the more chances of power failure. The longer the transmission line the more energy is lost. Reduced voltage occurs as losses in the form of heat.

● Phase imbalance in the electrical system: The electrical system consists of three phases (phase A, phase B and phase C). Ideally, in normal usage scenarios each phase should be used equally, but overuse of a particular phase can result in a voltage drop at the tip of the phase while other phases remain normal. This problem occurs due to improper monitoring of the power traffic/ load in each phase well before being activated.



▲ **Figure 2.2-3 Network map of power plants and key power stations in the south of Thailand**

● Transmission lines with too small cross-sectional sizes: This problem is usually caused by an unexpected growth in electricity consumption beyond the expected demand load. This results in current and voltage losses in the form of heat along the the transmission lines due to resistance and conductivity factors.

● Overloading of the transformers: This is either caused by an increase in the number of electricity users supplied by the transformer or a deterioration of its internal parts.

Solutions

● The normal solution to resolve inadequate electricity is to build a power station to provide high voltages to increase power at the points of failure. Due to high costs involved in this option, it is only suitable for expansion of cities or big industries that require high voltages. Choosing this option would require ensuring economic feasibility.

● In low-voltage distribution systems with insufficient line voltages, adding more transformers to get electricity from higher pressure can be a solution.

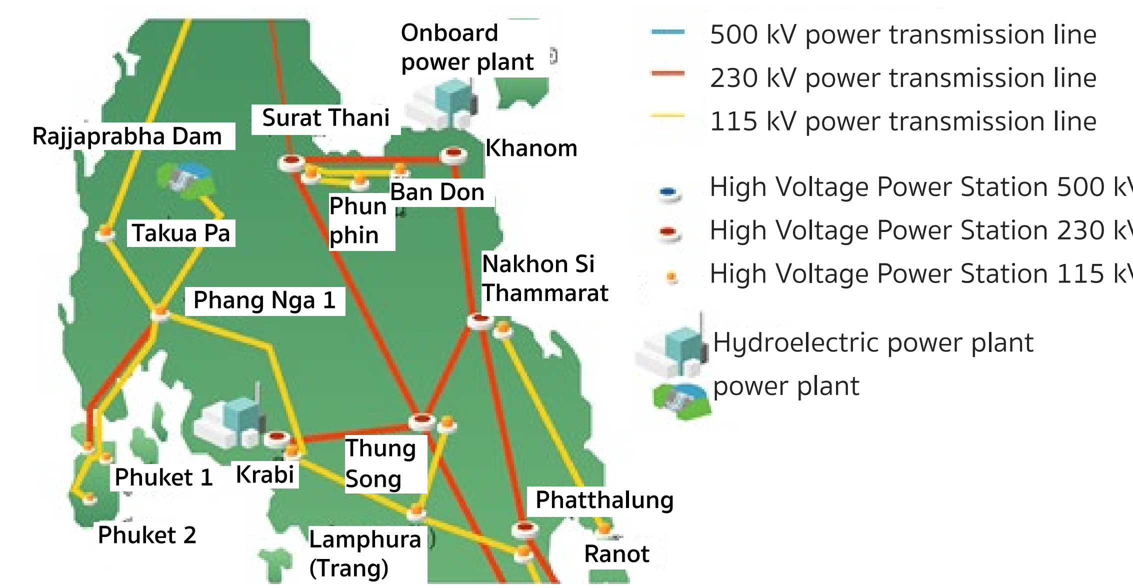
● Ensuring phase balancing and using the phase that can adequately support the needs.

● Increasing the number of transformers to meet the power needs and maintain balance in the electric power in the system.

● Regular maintenance to ensure that the transformers work efficiently.

● Adding transmission lines to increase power transmission capacity.

● Connecting transmission systems to create a 'looping of circuits' that can utilise multiple power supplies to provide stable protection against power failure.



▲ **Figure 2.2-4 Map showing the power grid, main power station and main power plants in Krabi Province and nearby areas**

©Niwat Wattanayamanaporn

2.2.4 Security of electricity and renewable energy

The stability of electrical and power transmission systems is crucial in order to deliver high-quality electrical services, which is top priority for the concerned agencies like the EGAT, the PEA and the MEA. At present, electricity security in Thailand has two critical components: a) the power source and b) the power transmission system.

Under the current power supply model of Thailand, as shown in Figures 2.2-3 and 2.2-4, the EGAT is responsible for the electricity generation and initial transmission via the transmission lines which constitutes both transmission and distribution systems. The PEA and the MEA are responsible for the distribution of the electricity produced by the EGAT.

In the future, increase in renewable energy sources should help make the electricity system more stable and reduce the power demand load at the centre. However, an increase in renewable energy is possible with the addition of an appropriate power transmission infrastructure. If the electrical systems are not optimised to support renewable energy, instabilities in the system could occur due to difficulties in controlling production times for some types of renewable energy in order to meet demands.

Therefore, it is important that there is a good production management process in place to ensure that the demands are met without unnecessary power distribution which may cause damage in various areas. In case of problems arising within the electrical system, maintenance and modifications should be made jointly by the government, the electricity authorities, responsible parties and the private sector to ensure the stability of the electricity system. This modality will help ensure that Thailand's future power systems are stable.

2.2.5 Adding power transmission lines and power stations

Efficient coordination of the transmission system is related to the power demand. At present, there is a continuous increase in electricity consumption as well as the number of consumers which results in a shortage of infrastructure capacities like transmission lines and power transformers. Since distribution systems are responsible for supplying electricity over long distances, there are problems related to power failure, power loss and leakage. To address this and to increase the stability of power supply, the Thai government promotes investment in the construction of power plants, transmission lines and distribution systems to capacitate the power systems in meeting the nation's development plans.

2.2.6 Development and management of the transmission system for 'Krabi, With More Than 100% Renewable Energy'

Developing and managing transmission systems are important factors for power security. Hence, new and upgraded systems should be planned and designed with a focus on analysing the needs of users in ways that efficiently support the addition of electricity from renewable energy sources in a distributive design – opposite to traditional systems that only support a centralised generation of electricity.

Such undertakings should be jointly planned by the government, private sector, as well as technical and economic experts while also taking into account the security, efficiency and compatibility of the electrical system.

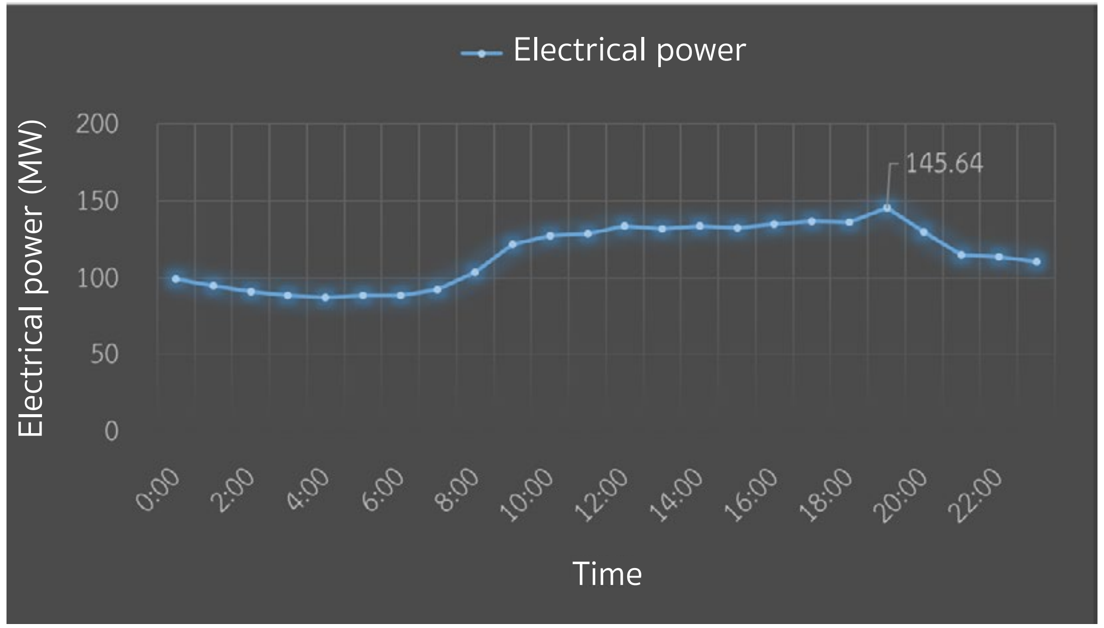


Figure 2.3-1. The electrical power hourly peak demand curve of Krabi Province in 2017 (on the day with peak electricity consumption)

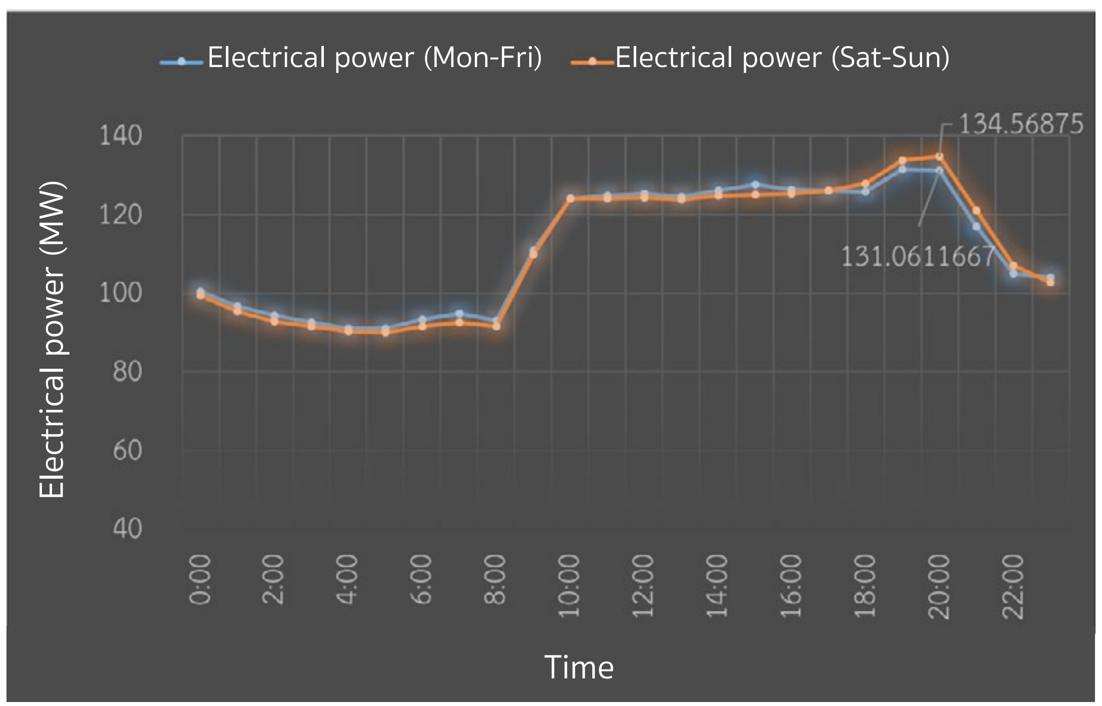


Figure 2.3-2 Average hourly electrical power demand curve of Krabi Province in 2017

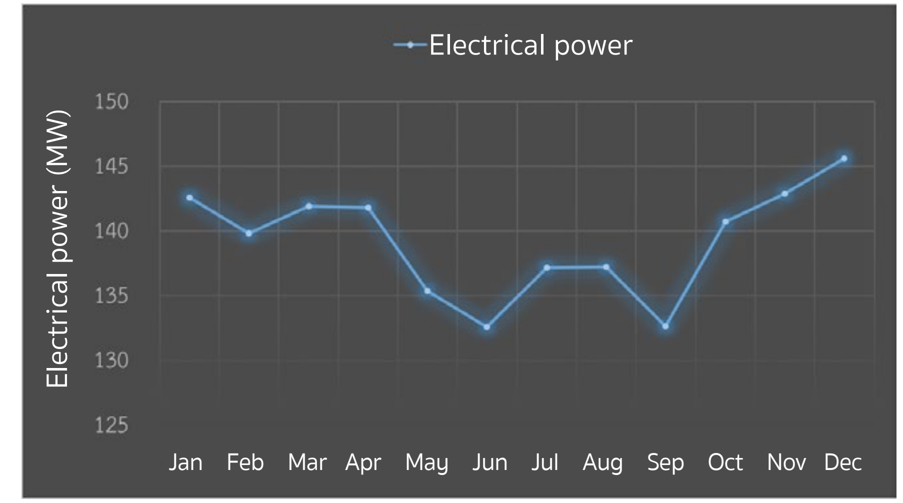


Figure 2.3-3 Graph showing maximum monthly demand for electrical power in Krabi Province in 2017

2.3 Electricity consumption in Krabi

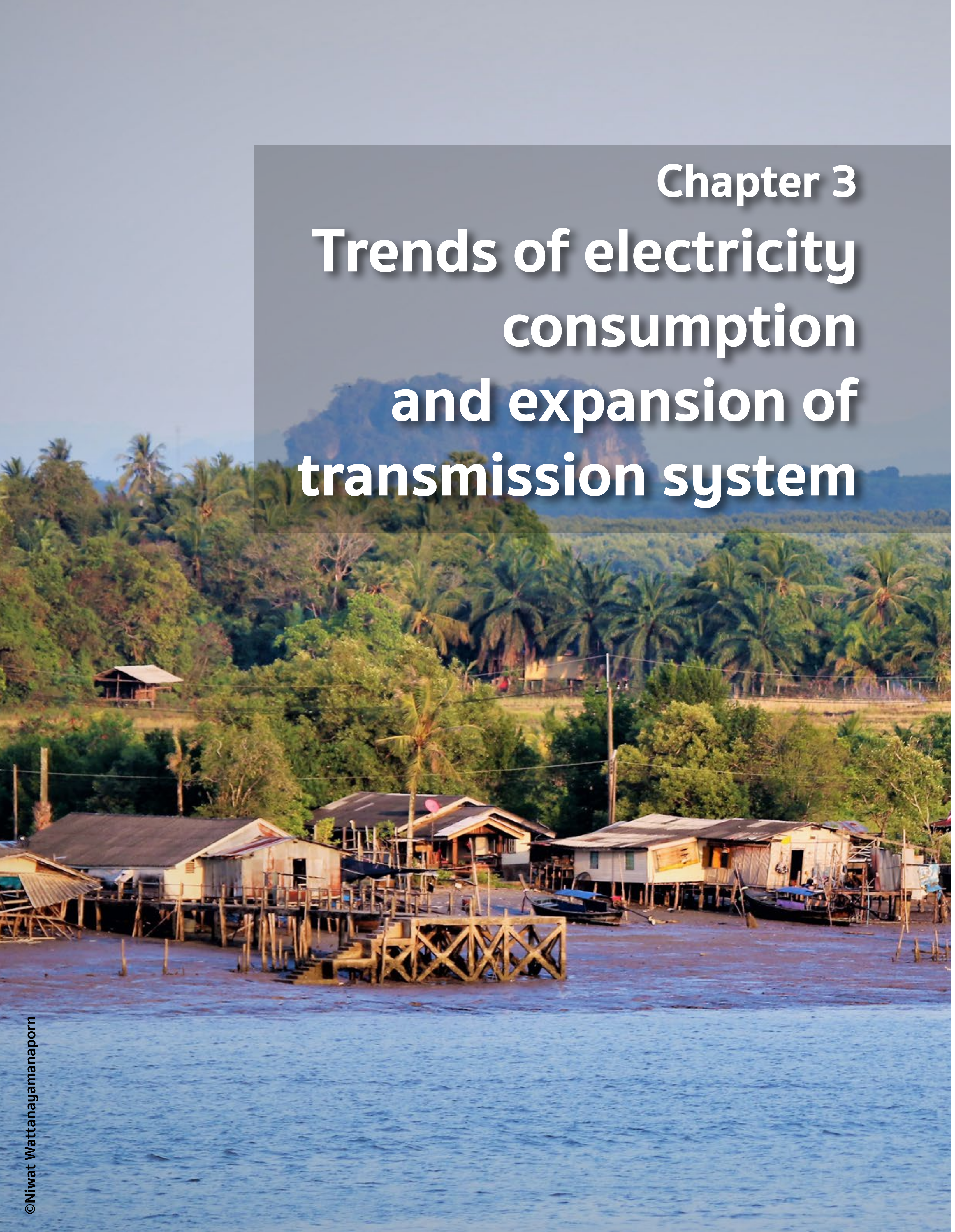
Krabi is a tourist city with a high number of hotels and shops and its peak electricity consumption occurs in December - Krabi’s peak tourist season. This is different from the overall peak of the country which lies in the months of April - May, with late evenings as the peak demand hours.

Figure 2.3-1 shows the peak hourly consumption behaviour of Krabi province. Krabi's electricity consumption lies in the 90 -145 MW range, rising sharply from 07.00 hrs. to 10.00 hrs., gradually increasing during the daytime. The highest electricity consumption is observed in the evening. It peaks at 19.00 hrs. with 145.64 MW of electricity consumed, while the lowest electricity consumption is about 90 MW at night from 24.00 hrs. - 06.00 hrs.

Figure 2.3-2 shows the average hourly electricity consumption comparison graph during weekends and weekdays of Krabi Province in 2017. It shows that the 24-hour electricity consumption looks the same throughout the week. Electricity consumption increases rapidly from 90 MW to 125 MW during 08.30 hrs. – 10.30 hrs. Then, a slight increase from 125 to 130 MW occurs during the daytime which increases at 18.00 hrs. and peaks at 20.30 hrs. The peak usage of weekends is higher than that of the weekday's peak at around 3.5 MW.

Figure 2.3-3 shows the maximum monthly demand for electrical power in Krabi Province in 2017. It shows that there are big differences that correlate with Krabi’s peak tourism seasons. The lowest electricity consumption occurs in June, with 132.63 MW and the lowest average electricity consumption occurs in the range of 132 to 137 MW from May to September. However, the electricity demand begins to rise again in September, reaching its peak in December with 145.64 MW of electricity and gradually decreases until the end of April when the tourist season ends.

Chapter 3
Trends of electricity consumption and expansion of transmission system



©Niwat Wattanayamanaporn

3.1 Future trends in electricity consumption in Krabi

Krabi is an important economic province in Thailand due to its tourism potential and hence has a sizeable electricity demand. It uses more electricity during Saturdays and Sundays, especially during late evenings with variations in demand depending upon the season and tourist flow.

The calculations to determine the electricity consumption trend (maximum power) in Krabi, is based on the calculation model used in the report – 'Renewable Energy Scenarios for the Thai provinces of Phuket, Rayong, and Nan', (Fraunhofer Institute for Solar Energy System-ISE, in cooperation with the Ministry of Energy of Thailand in 2015).

The process is as follows:

1. 1. The year 2560 is regarded as the base year for starting the calculation. There are three categories of consumers:
a.) Household electricity consumers, b.) Electricity consumers in business and service sectors, c.) Electricity consumers in the industrial sector. Each group has its needs for electrical power at proportional rates shown in Table 3.1-1 below.

2. In each user group, an increase in the maximum power is expected to be correlated with the Gross Domestic Product (GDP), population growth rate, and tourist growth rate in Krabi, which are based on the projection of the Office of the National Economic and Social Development Board and from the Ministry of Tourism using the Linear Logarithmic Regression model for prediction.

Figure 3.1-1 shows the monthly forecast of the maximum electricity demand in Krabi for a 20-year period. We find that the trend of monthly power consumption over the next 20 years (2018-2037) is not that different. It continues to be correlated with the tourist season of Krabi which has

Electricity user Group	Electricity consumption	Factors affecting the rate of increase in electricity consumption
Household Electricity consumers	25%	Gross National Product Growth and Population Growth Rate
Electricity consumers in business and services	50%	The increase of tourists in Krabi
Electricity consumers in the industrial sector	25%	Increase in Gross National Product

▲ **Table 3.1-1 Grouping of electricity users and the proportion of electricity consumed by each group.**

Year	Increase in GDP	Population Projections	Population growth rate per year	Projected number of tourists.	Increase in tourists	Maximum Power (MW)
2017	3.5%	469,769	0.3%	5,181,926	4.3%	145.6
2022	3.9%	475,433	0.1%	5,931,508	2.1%	171.9
2027	3.8%	477,337	0.0%	6,415,897	1.3%	197.0
2032	3.7%	474,954	-0.2%	6,774,460	1.0%	222.9
2037	3.6%	468,342	-0.4%	7,059,267	0.7%	250.5

Table 3.1-2 Results of Maximum Power Consumption projection for Krabi Province during the years 2018-2037

high electricity usage during August to November peaking in December, after which a gradual decline occurs from January to March. There is a high demand for electricity again in April which quickly drops at the end of the month. Electricity consumption is expected to be the lowest in May-July. A steady increase in demand for electricity is foreseen over the next 20 years.

Figure 3.1-2 shows the annual maximum demand forecast of Krabi Province during 2018 -2037. The demand for electricity in the next 20 years will increase steadily with a maximum demand for electricity at around 250.5 MW in 2037 – an increase of 100 MW to the present figure.

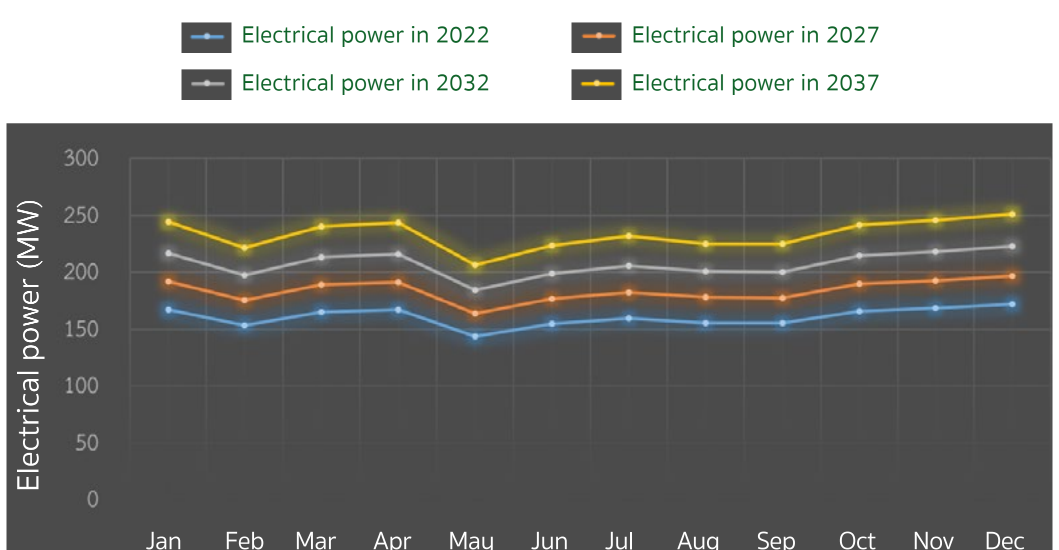


Figure 3.1-1 Maximum power consumption estimates of Krabi Province during the year 2018-2037

3.2 National Energy Efficiency plan and highest electricity consumption in Krabi

The government of Thailand has developed a plan for energy efficiency during 2015-2036. Called the Energy Efficiency Plan (EEP 2015), it aims to save and increase energy efficiency in four main target groups: residential, industrial, buildings and public sector. The annual goals for reducing electrical power and maximum electrical power are set in the country's Power Development Plan (PDP).

This report, therefore, uses the annual energy efficiency targets to analyse Krabi's energy efficiency targets by comparing the proportion of the province's peak power to that of the country. The energy consumption goal will lead to the reduction of the growth of Krabi's future maximum electrical power.

Figure 3.2-1 shows that Krabi's energy efficiency goals for the next 20 years can be divided into two periods as follows.

1. Energy saving during the first 10 years of the plan (2018-2027): In this period the power consumption gradually declines and reduces by about 15 MW by 2027. The targets of the following 10-year plan (2028-2037) have faster reduction rates of electricity consumption than the first 10 years with about 28 MW of electricity saved by 2037.

2. Energy saving in a 20-year period from 2018-2037: Figure 3.2-2 shows Krabi's maximum demand forecasts, in relation to the 20-Year National Energy Efficiency Plan (EEP 2015). In comparison with the normal usage patterns, it is seen that the annual maximum demand for electricity is reduced with a slight decrease in the first 10 years (2018-2027) and a more pronounced decrease occurring in the last 10 years (2028-2037). Electricity consumption in the year 2037 is predicted to be 43 MW lesser compared to the peak power demand in the absence of the Energy Efficiency Plan

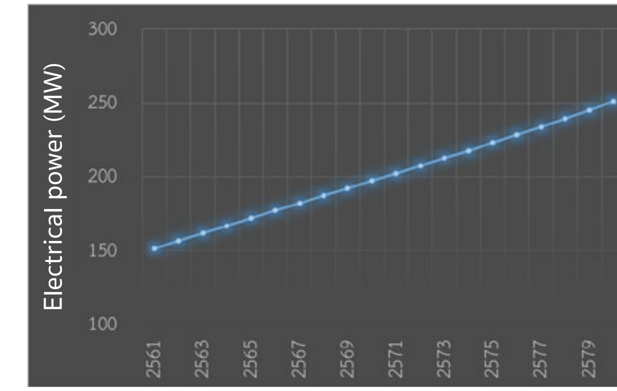


Figure 3.1-2 Annual highest electrical power demand in Krabi during 2018 to 2037

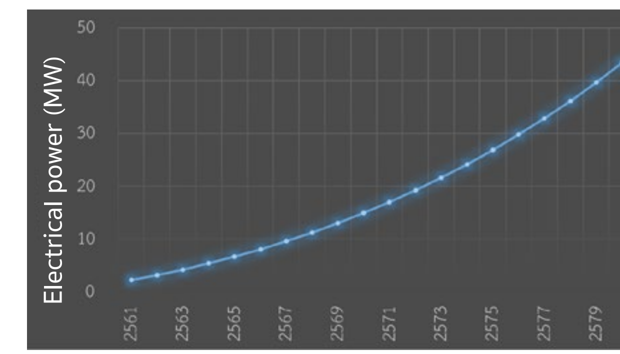


Figure 3.2-1 Shows the energy savings targets of Krabi Province over the 20 years (2018- 2037) proportionately compared to the national Energy Efficiency Plan (EEP 2015)

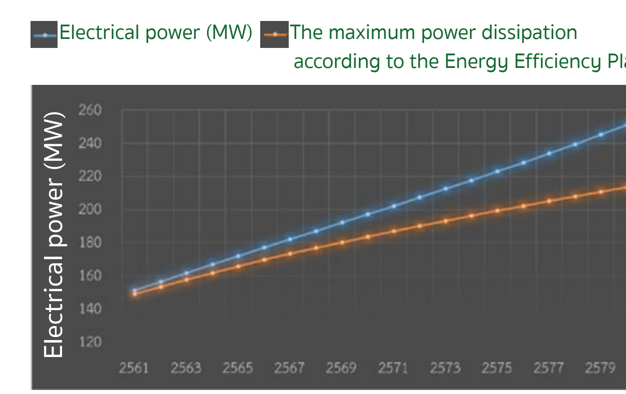
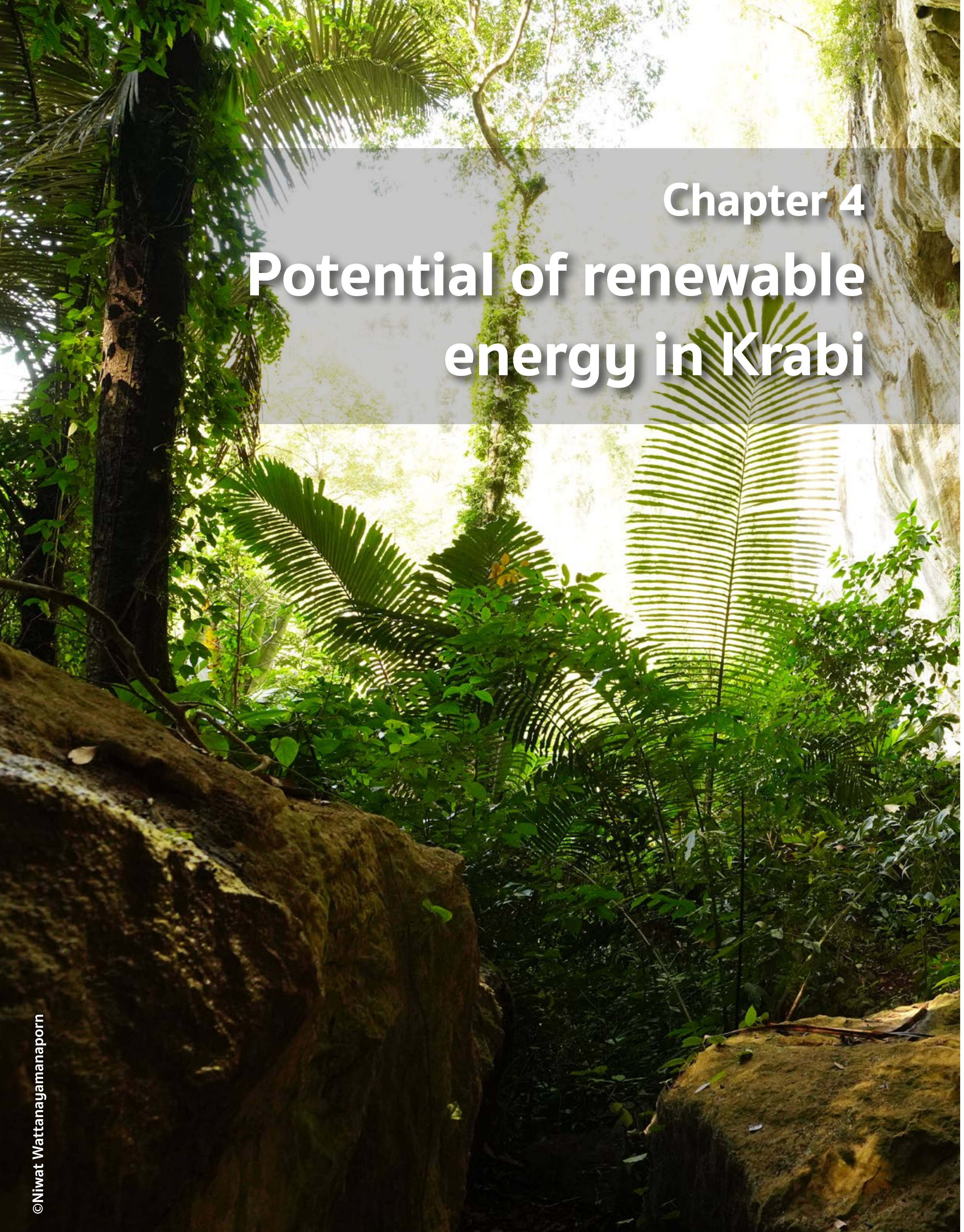


Figure 3.2-2 Shows maximum demand forecast in Krabi Province, which has a reduction in the proportion of the national Energy Efficiency Plan throughout the 20 years (2018-2037)

Chapter 4
Potential of renewable energy in Krabi



Item	Percentage	Kg/rai/year	Usability
Palm oil production	100	3,500	Separate components for different uses
Palm oil	17-20	595-700	Producing oil for consumption
Seeds in palm	5	175	Oil production for consumption.
Empty fruit bunches	22	770	Burning for heat to produce electricity
Palm Fibre	14	490	Burn for thermal power generation for use in the factories
Palm shells	5-6	175-210	Burn to high thermal power for electricity generation

▲ **Table 4.1-1 Conversion of palm oil to biomass and biogas extract from 1 rai of palm plantation**

4.1 Biomass energy

The most important source of biomass and biogas in Krabi is the palm oil industry. This is due to the consistency of quantity in the palm oil production – a rai of palm plantation can provide an average yield of 3,500 kg of biomass per year. The palm yield can be produced as biomass and biogas.

Additionally, palm plantations have an annual cutting of leaves and palm fronds. The palm trees are cut down every 30 years and are replaced. The resulting palm fronds, leaves and the trees can as well be used as biomass for electricity production.

One rai of palm plantation can accommodate 22 palm trees in an average and 24 fronds per tree will be cut. Since each frond weighs around 15 kg, there is a potential production of 7,920 kg of biomass from palm fronds per rai per year. Considering the total 1.0 - 1.2 million rai of palm oil plantations in Krabi Province, there is a potential for production of 7.9 - 9.5 million tonnes of palm fronds per year. This biomass can be converted to 97.8 - 117.3 MW electricity (Note: 1 million tons of palm fronds per year has a production capacity of 12.35 MW of electricity)

The palm trees, which are cut down and replaced at the age of 30 years have an average weight of about 1,360 kg per tree. Around 720,000 - 880,000 palm trees are cut down per year totalling a weight of 1.0 -1.2 million tons per year. These biomass burners can be used to generate up to 52.8 - 63.4 MW (note: 1 million tonnes of palm trunks have the potential to generate 52.89 MW of electricity per year).

Electricity generated from the biomass derived from the burning of empty fruit bunches, palm fibre and palm shells are calculated using the rates provided by the Department of Alternative Energy

Type of biomass	Heating value (MJ / kg)	Power generation rate (MW / tonne / year)	Biomass potential of Krabi Province (MW)
Palm trunk	7.54	52.89	52.8
Palm leaves and fronds	1.76	12.35	97.8
Palm empty fruit bunch	7.24	50.79	39.1
Palm Fibre	11.4	79.97	39.2
Palm shell	16.9	118.55	20.7

Table 4.1-2 Heat capacity and the potential of biomass power generation from different types of biomass in Krabi

Development and Efficiency, Ministry of Energy[5] as shown in Table 4.1-2. It is calculated at an average yield of 3.5 tons per rai per year. Krabi's one million rai of palm plantations can potentially yield 249.7 MW of electricity from biomass.

The model adopted in the development of biomass power in Krabi uses an equal annual increase rate from the current capacity of 17.5 MW to 218.9 MW (88% of capacity) in the 20th year (2037). In addition, Krabi also has the potential of biomass production from other plants, such as 445,531 tons per year of biomass from trees and roots of rubber trees which can be converted to 32 MW of electricity. An additional 1,868 tons per year of biomass from coconut shells, flowers and bunches can potentially generate 0.2 MW of electricity.

4.2 Biogas energy

In an overview of renewable energy in Krabi Province, biomass stands as an important source of energy feasible both in production and in economic value due to a large production already in place at present. The overview considers the process of fermentation of wastewater from the palm industry to determine the potential use of yield data per rai of land and compares it with the current biomass produced from palm factories which have not yet been developed for highest efficiency.

Energy from biogas can play an important role in producing electricity in response to the demand. This is because the generator is a gas engine and can thus be throttled to increase or decrease the production capacity as needed. It is therefore highly flexible in responding to the peak power demand. Biomass capacity can be calculated from the volume of biogas fermented water from palm oil mill residues. The production of 3,500 kg of palm bunch (per rai per year) can produce 58.8 cubic meters of biogas. Biogas has a heat capacity of 19 - 23.5 megajoules (MJ) per cubic meter. However, due to the low performance of gas engines (about 25 - 35%), only 2.05 kWh (unit) per cubic meter can be produced.

5. http://biomass.dede.go.th/biomass_web/index.html

A palm yield capacity of one rai can, therefore, produce 120.5 units of electricity for 13 hours daily (due to purchasing mechanism, factory owners choose to run engines during 09.00 hrs. - 22.00 hrs.), which is equivalent to a 28 MW power plant. Addition of filter cakes is done to increase the biogas volume which results in a 200% increase in biogas production. The production capacity can as well be increased by 4 MW by the addition of wastewater from rubber factories and from animal dung. The overall capacity is set at 60 MW.

In the development of biomass energy in Krabi, the model used is one with an equal increase of production, from 14 MW at present to 60 MW (full capacity) in the 10th year or 2027.

Item	Percentage	Kg/ rai/ year	Usability
Palm oil production	100	3,500	Separate components for different uses
Biogas fermented water	60	2,100	Fermented for 58.8 cubic meters of biogas

Table 4.2-1 Conversion of palm oil to biogas per 1 rai of palm plantation

Item	Quantity	Unit
Number of working days per year	330	Hour
Biogas production capacity	3.641	Million cubic metres per year
Heat value	19.8	MJ per cubic metre
Net performance of electricity generation system	34.2	%
Electricity generator installation capacity	1.40	MW
Electricity produced per year	7.61	Million units
Electricity to be sold to the PEA's system	0.96	MW

Table 4.2-2. Sample data of a 1-MW gas-electric power generation system from the Department of Alternative Energy Development and Efficiency Ministry of Energy (Sorce: http://webkc.dede.go.th/webmax/sites/default/files/คู่มือการลงทุนโรงไฟฟ้าแก๊สชีวภาพจากพืชพลัง.pdf)

4.3 Solar energy

By using solar panels (photovoltaic panel), solar energy can be used to produce direct current electricity which is similar to the electricity generated from batteries. It is then converted to alternating current and transmitted to the power users. The major limitation of using solar power is that it cannot be produced at night. Thus, it needs to be mixed with power from other sources or otherwise be used with batteries. Currently, large batteries can be produced which are good for grid-level storage, e.g. for use on islands or areas unreached by transmission lines.

Because of the high insolation in Thailand, almost any area in the country has a high potential for generating solar energy. The installation of solar panels can be done in all areas, any roofs, houses, hotels or business buildings for own electricity generation. Solar power helps reduce the burden of transmission lines and losses of electricity over long distances. Using the roofs for such purposes will also free up ground space for other uses.

Sector/ item	Quantity	Unit
Household sector		
Number of population	456,811	person
Number of households	91,362	household
Roof area which is suitable for installing PV panels (average 20 sq.m. / backs).	1,827,240	Sq.m.
(1) housing potential	634	MW
Business SMEs sector		
Small, medium and specialised businesses (average 50 kW per person)	9,353	places
(2) Potential of SMEs	468	MW
Large building sector		
Large enterprises (average 1,000 kWh)	23	places
(3) the potential of 23 MW	23	MW
Total potential (1) + (2) + (3)	**1,125**	**MW**

Table 4.3-1 Shows the calculation of solar energy for roof electricity

Although farm-based solar power production has lower investment cost per unit, they have more disadvantages than rooftop instalments. These include additional investment required on transmission systems, communities marginalised from distributive opportunities to become power producers, and opportunity costs on land-use.

In calculating the capacity of solar power, results of the survey on production efficiency in nearby areas are used for average hourly and monthly data. This takes into account seasonal effects in the forecast of hourly electricity generation. The model used for this study is one with a slow annual increase in the initial years, medium accelerated growth rate during the middle years (6th - 15th years) and growth saturation in the last years denoted by an S-curve. The highest capacity is projected using the number of households and consumer data in Krabi.

Figure 4.3-1 shows the solar power capacity for producing electricity per 1 kWh per day. Based on the solar intensity data in the Krabi area, the capacity to produce electricity from solar energy can be calculated from a minimum of 0.49 kW hr up to 0.8 kW. Considering the overview of electricity generation in one day, it is possible to start generating electricity from 07.00 hrs. This will rapidly increase from 8.00 hrs. - 9.00 hrs., reaching the maximum capacity during 10.00 hrs. - 13.00 hrs. after which a gradual decrease will occur until 17.00 hrs. when electricity can no longer be produced.

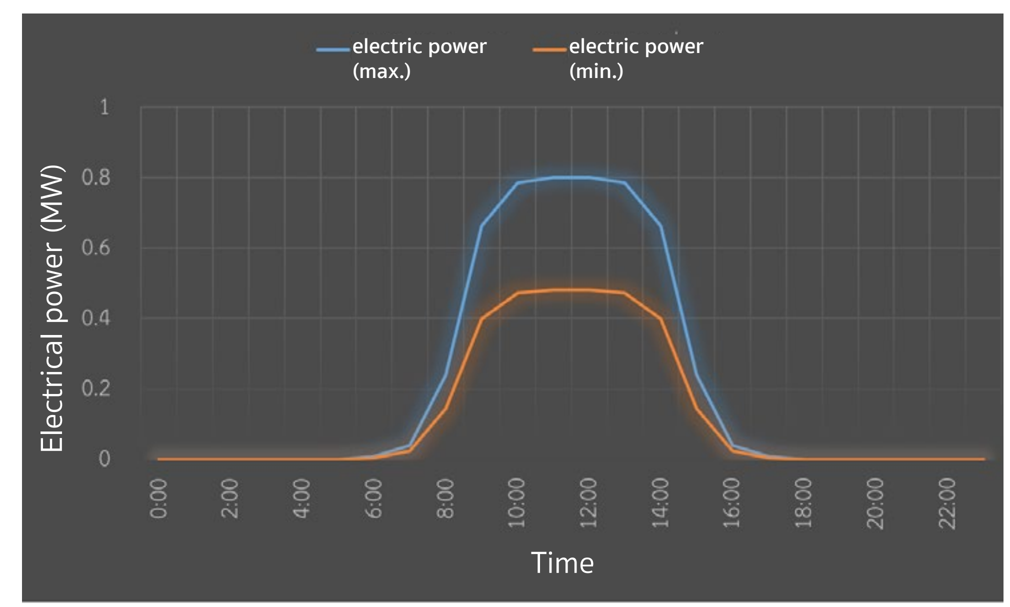


Figure 4.3 - 1 Graph showing hourly average power (max.-min.) produced per day from solar energy per 1 kW Installed power

Wind power level	At an altitude of 10 meters		At an altitude of 50 meters	
	Wind energy density (watts per square meter)	Wind speed (meters per second)	Wind energy density (Watts per square meter)	Wind speed (meters per second)
1	0-100	0.0-4.4	0-200	0.0-5.6
2	100-150	4.4-5.1	200-300	5.6-6.4
3	150-200	5.1-5.6	300-400	6.4-7.0
4	200-250	5.6-6.0	400-500	7.0-7.5
5	250-300	6.0-6.4	500-600	7.5-8.0
6	300-400	6.4-7.0	600-800	8.0-8.8
7	400-1000	7.0-9.4	800-2000	8.8-11.9

Table 4.4-1 Wind Power Standards by the United States Department of Energy, 1986, from solar energy per 1 kW installed power

4.4 Wind Energy

Wind power is an additional potential clean energy resource in Krabi. Conversion of wind energy into electric power is based on the now popular wind turbine technology installed on high towers. Ideally, the installation location should have constant wind speeds with average annual wind speeds ranging from 'grade 3' speeds of 6.4 - 7.0 meters per second at a height of 50 meters (see Table 4.4-1). Due to advancements in wind turbine design and technology, it is now possible to produce electricity at wind speeds less than 6.0 meters per second using small wind turbines that do not need electricity to start.

Although the wind potential for Krabi is not as good compared to areas on the Gulf of Thailand side, developing it could be cost-effective, especially along the islands with high demand for electricity such as Koh Lanta or Phi Phi. This is because they can produce electricity all day that can be used with other sources of energy such as Solar Photovoltaic (PV) systems. These can handle wind fluctuations using energy storage devices such as batteries or pumping water to high-level storage or wind turbines to generate electricity according to needs.

The assessment of the potential of wind power generation is based on data from other wind power plants in Thailand with a production factor of 20 - 25%. Krabi uses a production efficiency of 15% as a base for calculations of installed capacity. The projects that have been surveyed and designed have a total capacity of 40 MW which is equal to the generation capacity for the first four years. An increase at a rate of 10 MW per year is then expected upon provision of appropriate policy support and purchase of electricity.

Figure 4.4-3 shows the hourly efficiency of the wind turbine compared to the installed capacity. The average 24-hour generation capacity of the turbine is characterised by fluctuations depending on the time of day/ peak demand hours. The daily average is approximately 15% of the installed capacity and can be divided as per the following wind conditions.

- From 04.00 hrs. to 05.00 hrs., efficiency is in the range of 40 - 80% with 80% at 04.00 hrs.
- Electricity generated during the day time is lower than the average, at about 0 to 10 %.
- From 18.00 hrs. - 20.00 hrs. generation capacity increases again at 15 - 40% of the installed capacity.
- Night time has high fluctuations and production is less than the average between 20.00 hrs. and 21.00 hrs. which reverts to 15 to 40% between 22.00 hrs.- 23.00 hrs. and then gradually decreases to 0 at 03.00 hrs.

Figure 4.4-1 Map showing Krabi's wind potential along Khao Phanom Bencha mountain range

4.5 Mini-hydro energy

Hydropower is clean, controllable, cumulative, and highly flexible. But it requires sources with high enough levels of water throughout the year. Hydro-energy can be developed from water flows such as floodgates, canals and waterfalls which have a high potential difference.

This report only proposes and advocates the development of mini hydro-energy without considering the construction of dams and reservoirs. This is because the construction of large hydropower dams often cause environmental problems in the river and negatively impacts its ecology. It is therefore not a sustainable energy option and is always resisted.

There are small water sources spread across the hills and islands of Krabi. According to Assistant Professor Payom Rattanamanee, Prince of Songkla University, there are at least eight potential sources which can produce electricity at 100 - 1,500 kW each. And, there is also a micro-hydro energy potential in Krabi.

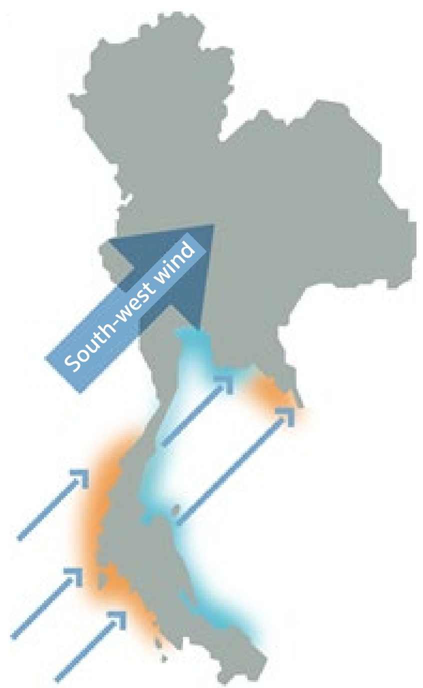


Figure 4.4-2 South-west wind direction which blows between mid-May to mid-October.

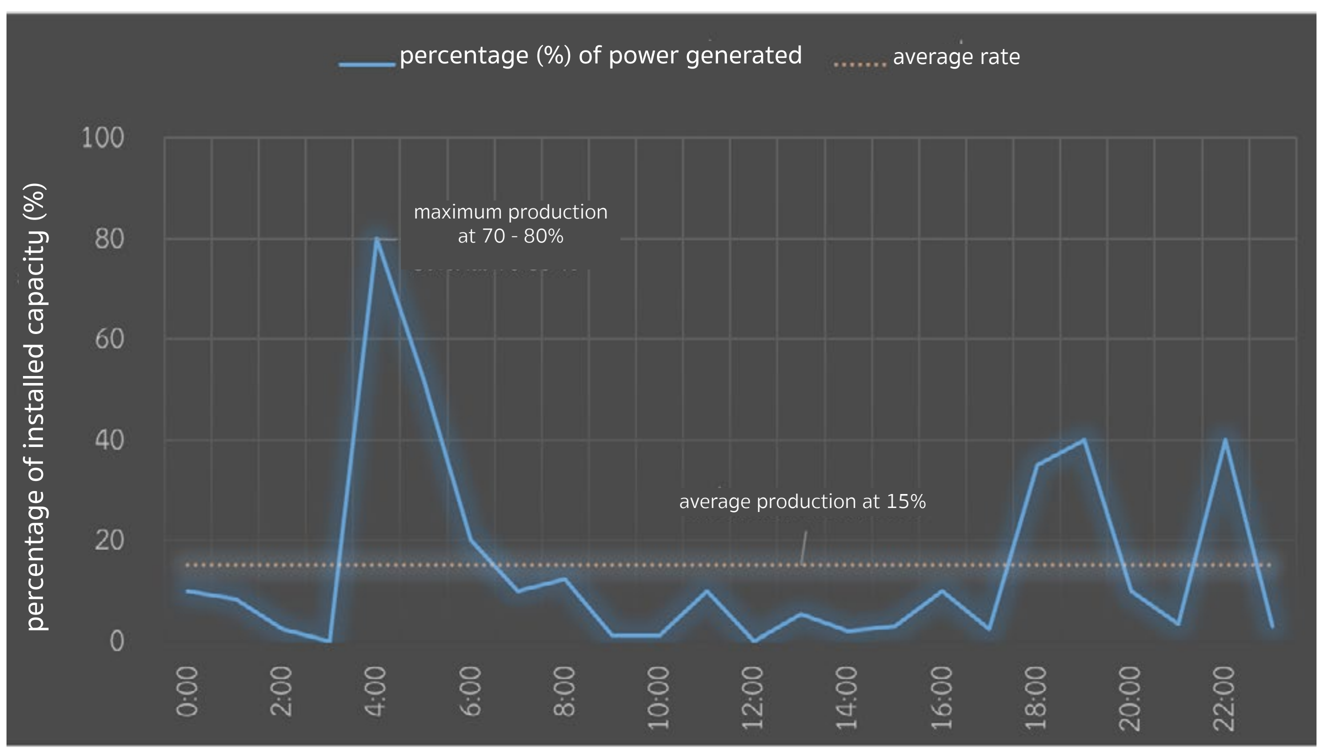


Figure 4.4-3 Graph shows the percentage of hourly electric power produced by the wind turbines in a day compared to the installed power.

4.6 Overview of the potentiality of renewable energy in Krabi

Potential of electricity generated by renewable energy from Krabi can be summarised as follows.

Type of energy source	Potential of electricity generation
Biomass (palm)	249
Other biomass	32
Biogas	60
Solar	1,125
Wind	200
Mini-hydro	10
Total	**1,676**

Table 4.6-1 Potential of electricity generated by renewable energy in Krabi

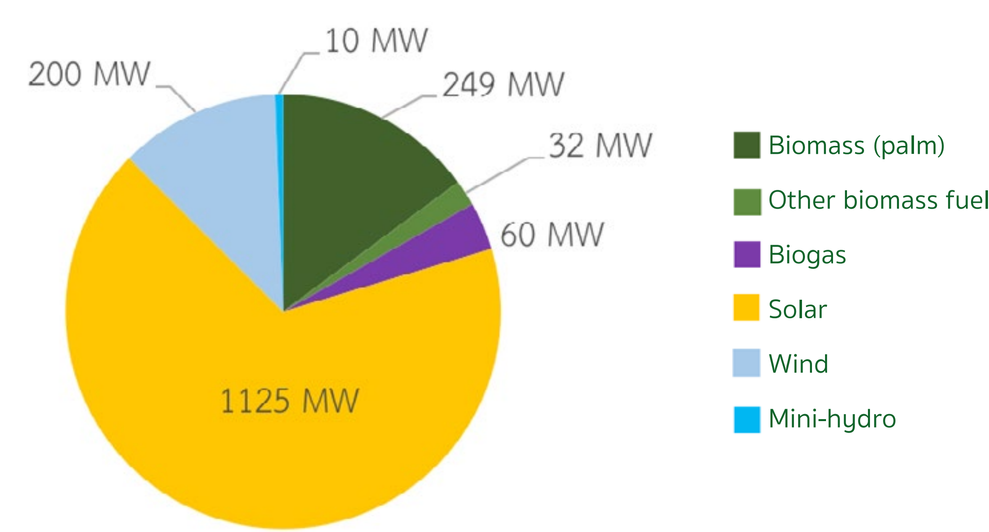
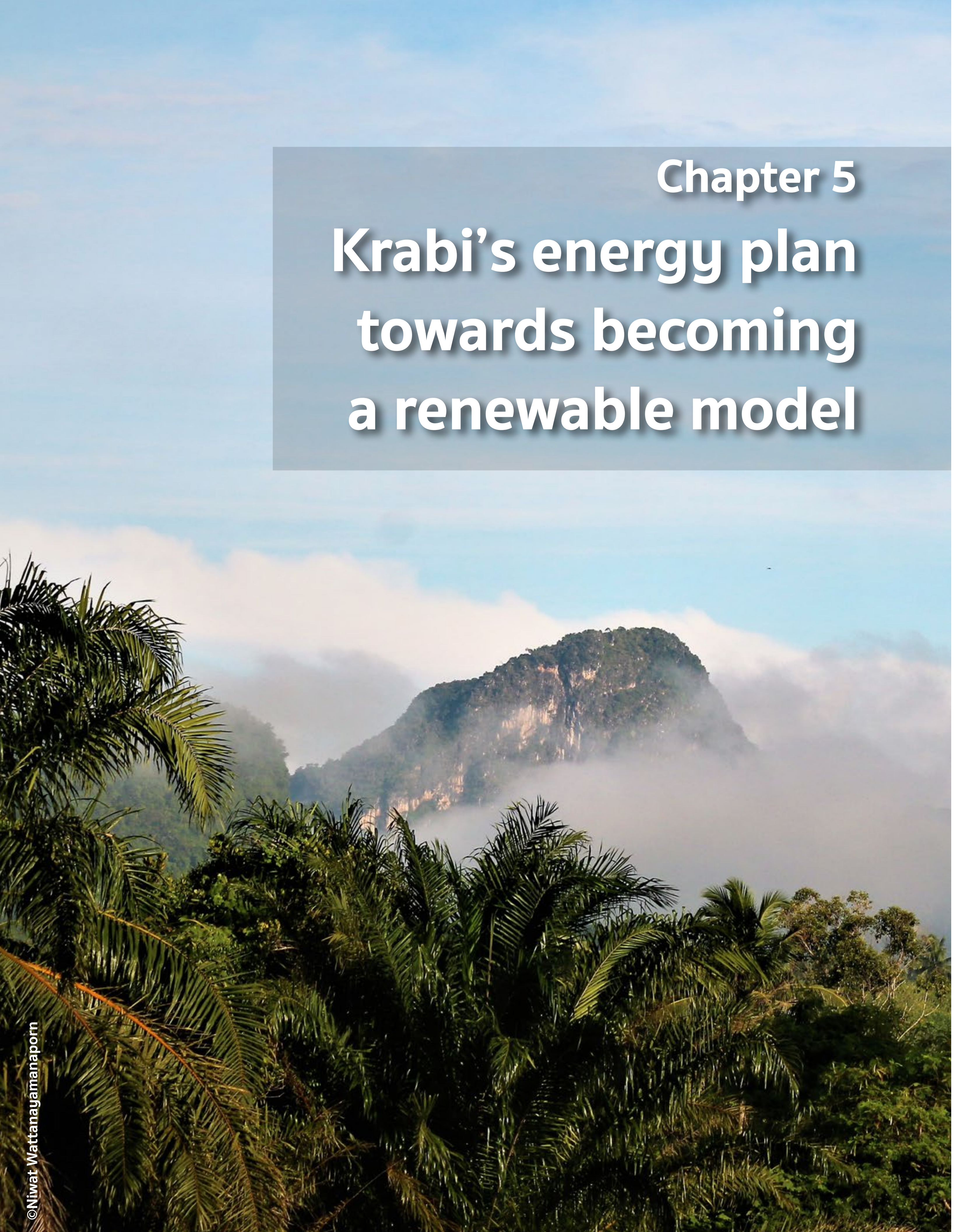


Figure 4.6 Summary of potential electricity generated by renewable energy in Krabi



Chapter 5
Krabi's energy plan towards becoming a renewable model

5.1 Renewable energy development and energy efficiency goals

The development of renewable energy in Krabi as envisaged in the 'More Than 100% Renewable Energy Krabi' plan outlined in this report analyses and proposes the development of five renewable energy sources, namely biomass, biogas, solar, wind and mini-hydro. The plan proposes a gradual development during 2018 - 2022 and faster development until slowing down in the last five years.

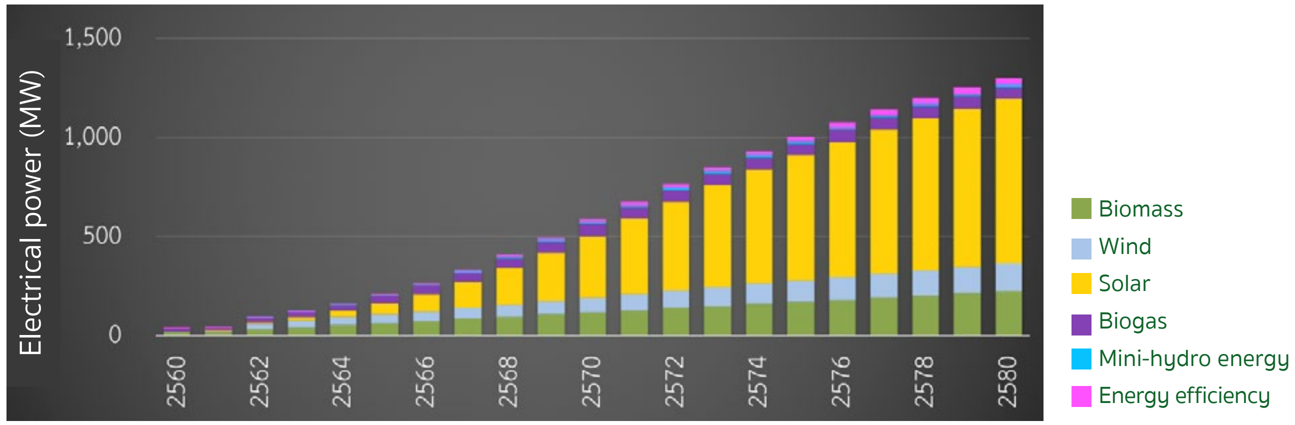
Concurrent with the renewable energy plan is the implementation of the National Energy Efficiency Plan 2015 - 2022 (EEP 2015). Considering the ratio of electricity consumption in Krabi to analyse and design energy usage models, targets of the installed capacity of renewable energy and energy efficiency are as denoted in Table 5.1-1 and Figure 5.1-1, as well as the annual electricity generation shown in Figure 5.1-2.

The graph in Figure 5.1-1 shows the projected growth of installed capacity of renewable energy from biomass, biogas, mini-hydro, solar and wind in Krabi from 2018 to 2037.

From an overall picture of 20 years, the installed capacity of solar power has the biggest increase in growth at about 800 MW, followed by biomass with about 200 MW and

Year	Biomass	Wind	Solar	Biogas	Mini hydro	Total renewable energy	Energy Efficiency
2017	17.5	0.0	0.003	14.9	0 3	2.4	1.2
2022	60	46	56	35	4	200	6.6
2027	113	77	309	60	9	568	14.9
2032	166	109	630	60	10	974	26.8
2037	219	140	829	60	10	1,258	43.4
Percentage compared to the capacity	78	70	74	100	100		

Table 5.1-1. Targets for Renewable Energy Development and Energy Efficiency according to the 'More Than 100% renewable energy Krabi' plan (units: MW)



▲ **Figure 5.1-1 Installed capacity of renewable energy and energy efficiency in Krabi Province during 2018-2037**

wind energy with about 150 MW. Biogas on the other hand, shows a significant increase during the year 2018 to 2027 when it reaches full capacity at 60 MW and continues at a consistent rate until 2037.

5.2 Hourly analysis of electricity generation and consumption during 2018 - 2037

A simulation of hourly power generation from all potential power sources shows the proportion of electricity produced per hour by each of the sources throughout the year. Figure. 5.2-1 shows the power demand levels in each hour in a week's period in 2021.

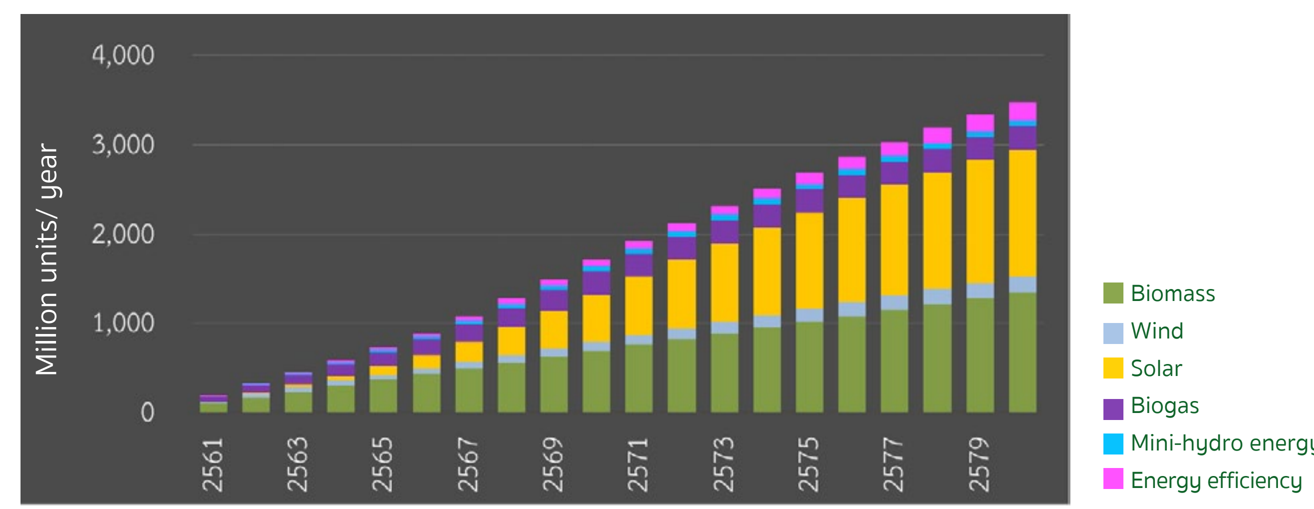
Figure 5.2-1 shows the electricity generated from renewable energy compared to the predicted demand for electricity in Krabi in 2021. Considering the overall picture of seven days, it is evident that Krabi can rely on renewable energy at 95 - 100% during 10.00 hrs. - 12:00 hrs. and 02.00 hrs. - 5.00 hrs. when there is an excess of electricity produced from renewable energy. The times with high demand needing electricity supplementation from other sources is from 14.00 hrs. - 17.00 hrs. and 19.00 hrs. - 21.00 hrs. There is not much difference in the daily trends throughout the week.

Development of renewable energy vis-à-vis energy efficiency initiatives can produce electricity to meet the growing energy demands of an entire province. Figure 5.2-3 shows renewable energy production as compared to the demand for electricity in Krabi in 2026. Looking at the seven-day scenario, Krabi Province can rely 100% on renewable energy to produce electricity within the province every hour. Additional electricity in a surplus of 100% can be sent through the transmission lines to other provinces such as Phuket and Phang Nga

Figure 5.2-5 shows the electricity generated from renewable energy in one week. Considering the demand for electricity in Krabi in 2037, the province can rely on 100% renewable energy throughout the day. Figure 5.1-1 shows the installed capacity of renewable energy and

energy efficiency in Krabi during 2018-2037. Renewable energy electricity generated from solar, wind and biomass can respond to and meet the demand within Krabi and also transmit surplus electricity to other provinces and regions of the country.

The daytime production capacity in Krabi is 800 - 900 MW, which is more than three times that of the nighttime production capacity. This rate of production can result in a surplus of about 85.8 million units of electricity per month in 2026 which can increase to 222.9 million units per month in 2037 as shown in Figures 5.2-7 and 5.2-8. In that scenario, Krabi can transmit surplus electricity to other provinces and regions to help lower the dependency on electricity from fossil fuels. If surplus electricity could be stored in a grid-level battery, it could be utilised at the times of high demand. This would help Krabi become a 100% renewable energy town before 2025. A study on the current trends in the battery market in Thailand has found that the price of batteries will fall from about USD 300 per kilowatt hour (kWh) to USD 200 per kWh by 2022. This can be correlated with the projected growth and the move towards renewable energy technology in Thailand.



▲ **Figure 5.1-2 Electricity generation from renewable energy and energy efficiency of Krabi Province during the year 2018 - 2037**

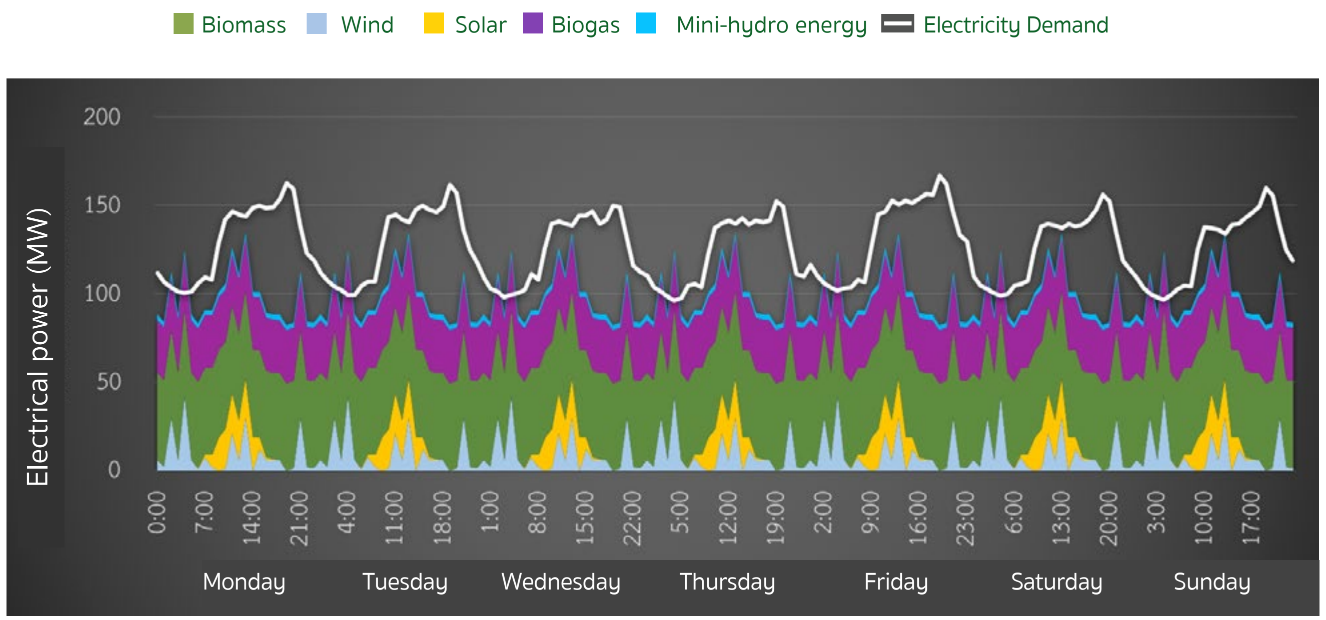


Figure 5.2-1 Graph showing electricity generated hourly by renewable energy compared to the demand for electricity in Krabi in 2021

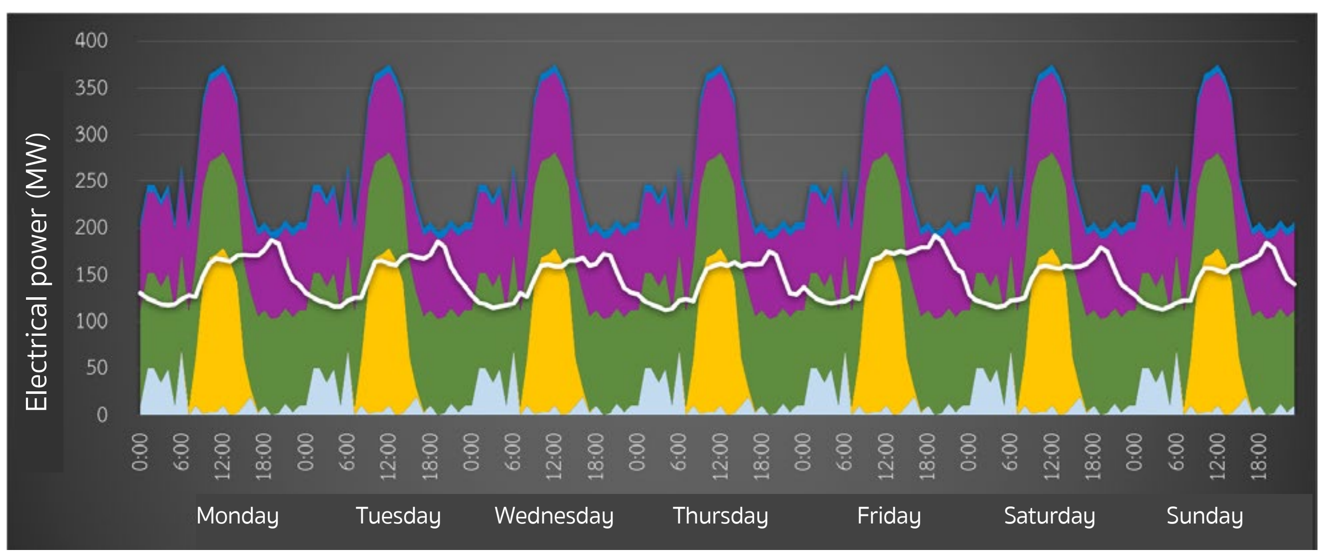


Figure 5.2-3 Graph of electricity produced from renewable energy as compared to the hourly demand for electricity in Krabi Province in a week in 2026 (the year of self-sufficiency with 100% renewable energy)

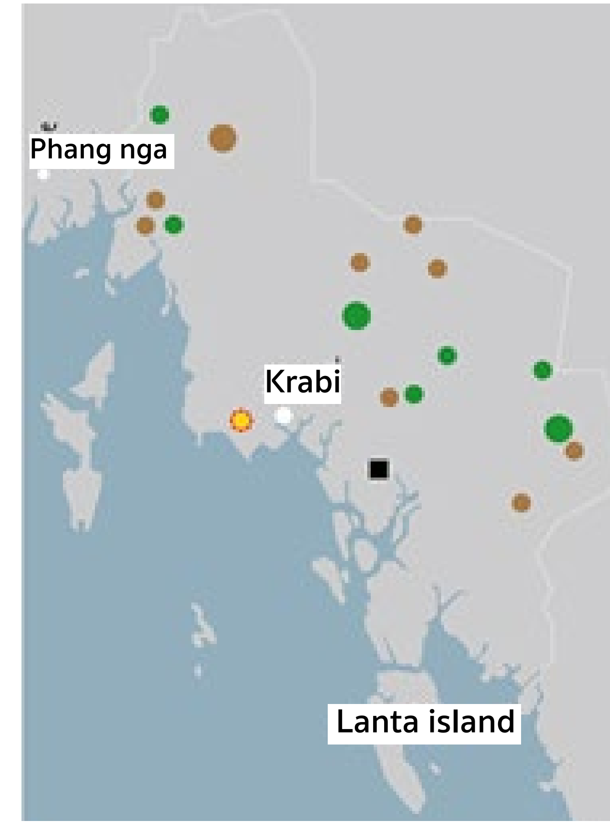


Figure 5.2-4 Map showing the distribution of renewable energy power plants in Krabi Province in 2027

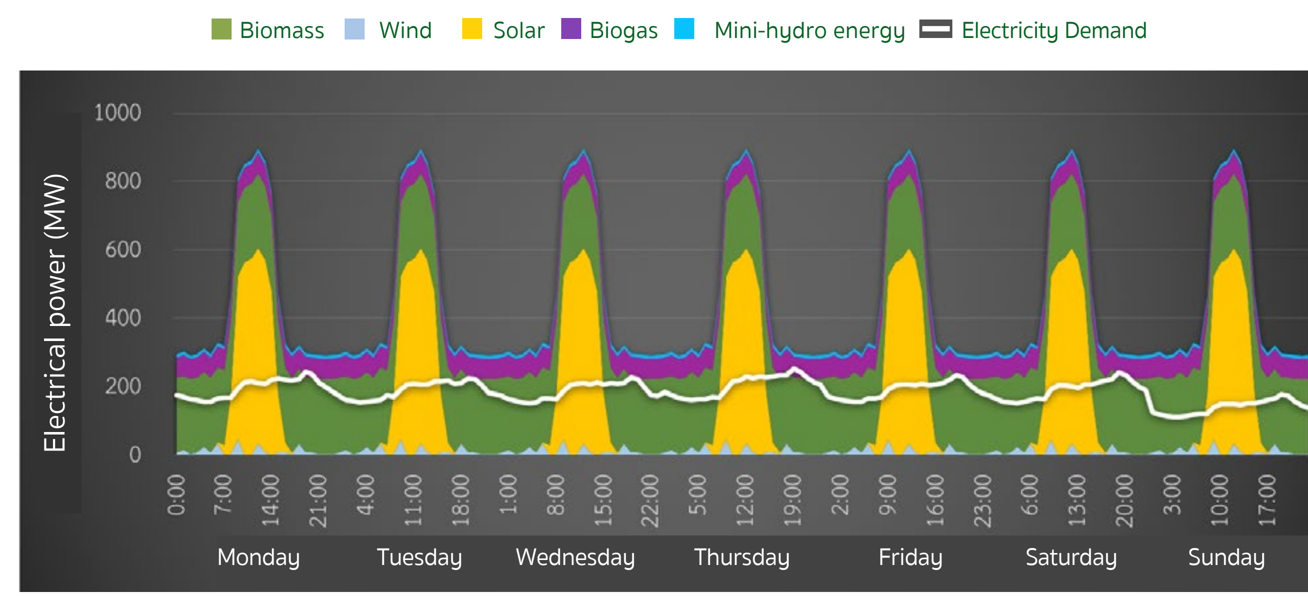


Figure 5.2-5 Graph of electricity produced from renewable energy as compared to the hourly demand for electricity in Krabi Province in a week in 2037

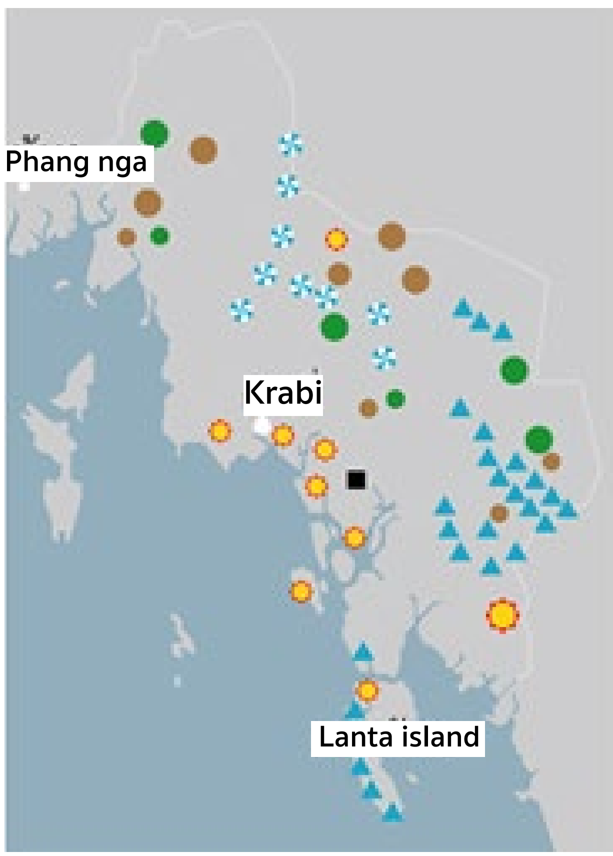


Figure 5.2-6 Distribution diagram of renewable energy plants in Krabi Province in 2037

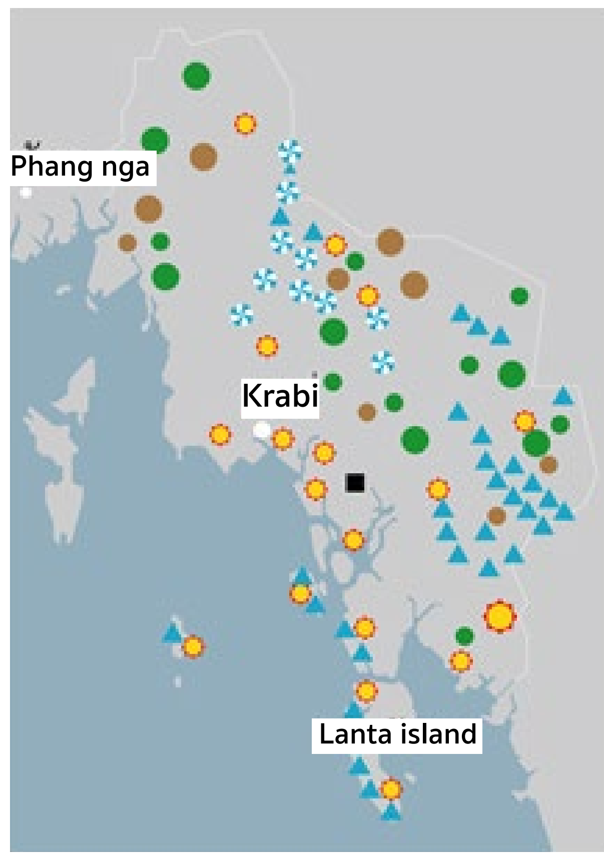


Figure 5.2-6 Distribution diagram of renewable energy plants in Krabi Province in 2047

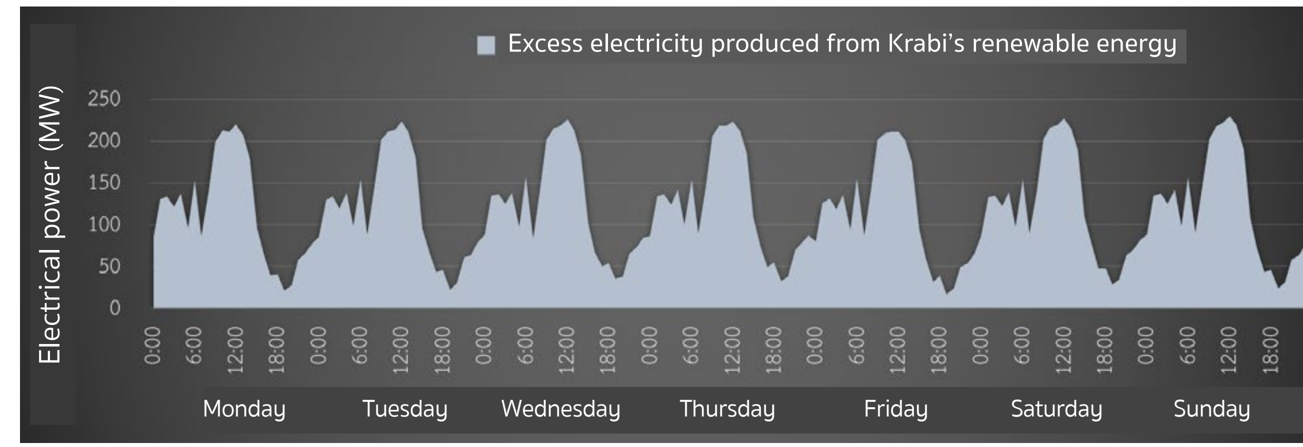


Figure 5.2-7 Forecast of hourly excess electricity produced from Krabi's renewable energy in a week in 2026

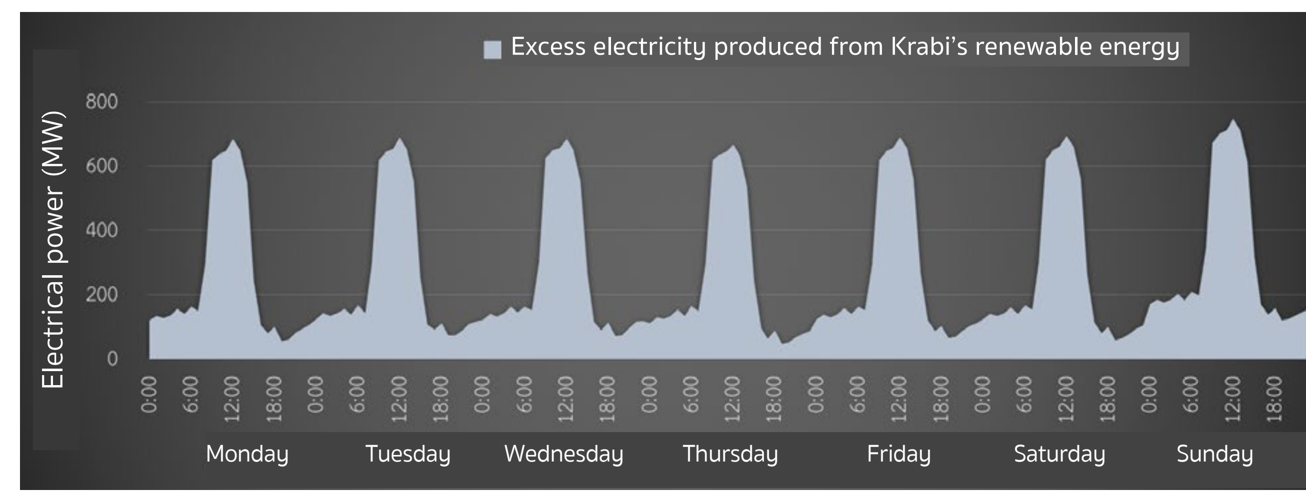


Figure 5.2-8. Forecast of hourly excess electricity produced from Krabi's renewable energy in a week in 2037

©Niwat Wattanayamanaporn

5.3 Cost analysis of 'More Than 100% Renewable Energy Krabi' plan

Cost analysis in this section and the benefits analysis in the next section have the analytical details which are shown in Table 5.3-1. The information has been collected and analysed using data from several research papers listed below.

1) Alternative Analysis Report of the Power Development Plan in 2014

2) Renewable Energy Scenarios for the Thai Provinces report by Fraunhofer ISE, 2015

3) Renewable Energy Outlook: Thailand report by the International Renewable Energy Agency (International Renewable Energy Agency), 2016

4) Renewable Energy Job Creation in Thailand, June 2018

The three costs involved are the investment, operation of electricity generation/ maintenance of power plants, and fuel costs. The proportion of imported content in each of the costs will as well be analysed. The remaining proportion will be the domestic content, which directly benefits the economic growth of the country.

Item	Unit	Biomass	Biogas	Solar	Wind	Mini-hydro	Energy efficiency	Coal	Natural gas
Cost of investment	Million THB/ MW	55.502	70	99	85	61.833	25	63	27
Import proportion	Percentage	50	20	40	60	30	50	70	70
Investment reduction rate	Percentage/ year	2	2	4	3	1	-1	0.55	0.42
Cost of operation & maintenance	THB/kWh	0.51	1.2	0.03	0.65	0.62	0.5	0.18	0.1
Import proportion	Percentage	10	5	10	15	10	15	15	15
Investment reduction rate	Percentage/ year	2	2	4	3	1	-1	0.55	0.42
Fuel costs	THB/ kWh	0.786	0	0	0	0	0	0.67	1.125
Import proportion	Percentage	10	0	0	0	0	0	90	70
Investment reduction rate	Percentage/ year	2	0	0	0	0	0	0.55	-0.5
Direct employment	Jobs/kWh	871	1,272	766	262	200	450	94	125
Greenhouse gas emissions	Grams/ kWh	46	-33	30	10	2	0	960	512

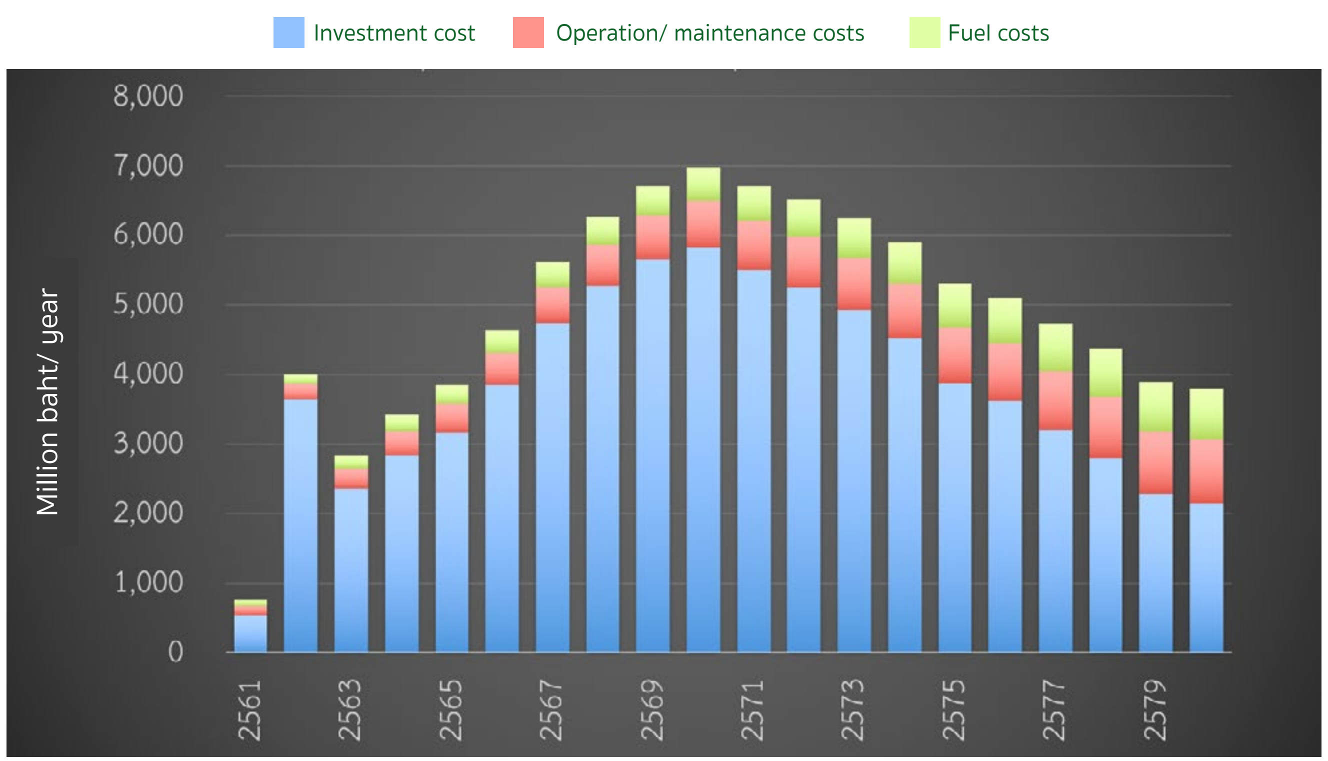
Table 5.3-1 Coefficients for cost and benefit analysis of each type of energy

The learning rate reflects the cost reduction rate for each type of investment each year. For example, according to a report by the International Renewable Energy Agency in 2018, the average cost of solar energy decreased from USD 3,915 per kW in the US in 2012 to USD 2,134 per kW in 2016 with a 14% cost reduction rate. Wind energy also saw a cost reduction of 4% during 2013 - 2016.

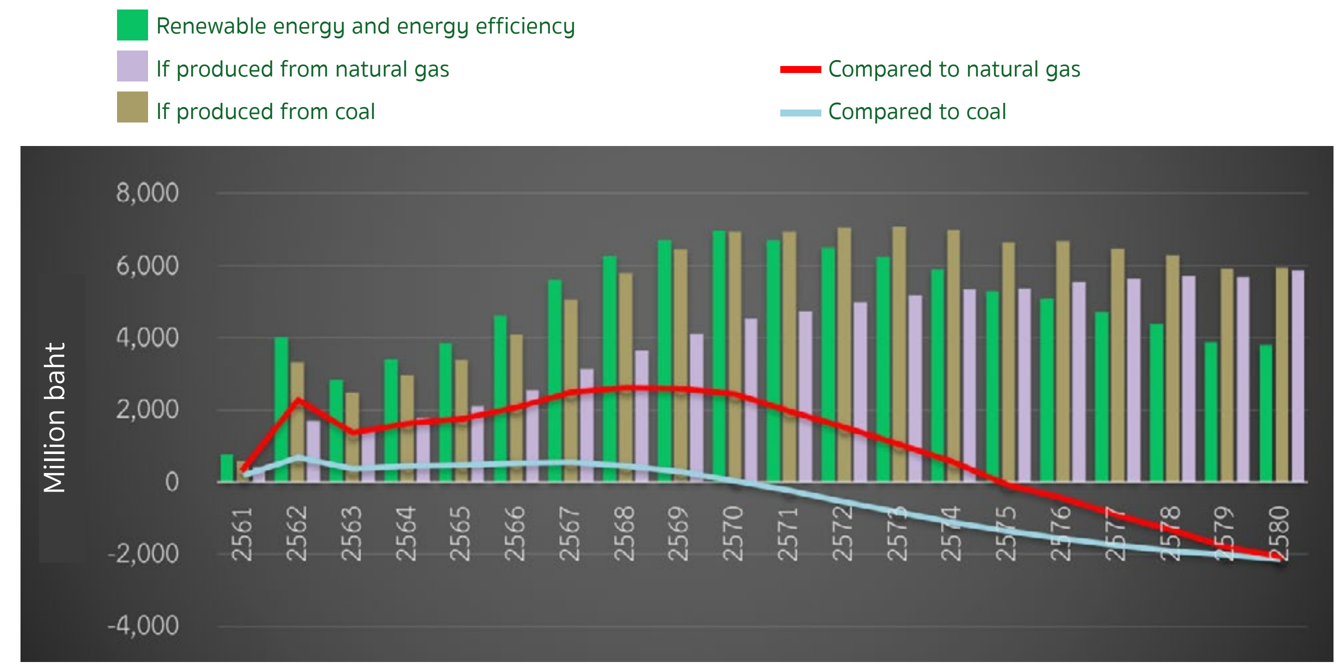
Development of renewable energy and energy efficiency has three costs – investment costs, operation/ maintenance costs, and fuel costs. Investment costs are the highest of the three and fuel costs only apply in biomass whereas development of other renewable energy and energy efficiency do not involve any fuel costs.

The current total cost in 2018 is THB 763 million and the maximum increase will be in 2027 at nearly THB 7,000 million. This will decrease to THB 3,796 million in 2037 as shown in Figure 5.3-1.

Neither the electricity authorities nor the governments are the direct investors for the development of renewable energy. It is the oil palm factories, building owners and households who are the investors themselves. Other potential investors include private companies, factories, local governments,



▲ **Figure 5.3-1 Total costs of development according to 'More than 100% Renewable Energy Krabi' plan**



▲ **Figure 5.3-2 Total cost analysis compared with coal and natural gas generation**

cooperatives, temples, schools, financial institutions, funds and other consumers.

In comparison, as shown in Figure 5.3-2, the total cost for generating the same amount of electricity from coal is 15 - 30% lower in the first five years. Then it will be similar to the costs of renewable energy until after 2027, when the total cost of renewable energy and energy efficiency will be lower by 25 - 35% than the cost of electricity from coal. When looking at the overall cost throughout the 20 years, the total cost of renewable energy and energy efficiency will be THB 9,600 million less than that of coal.

The costs involved in producing electricity generated from natural gas each year is lower than that of renewable energy and energy efficiency, mainly due to lower investment costs. The total cost of renewable energy and energy efficiency will be lower in the final six years due to the rising prices of natural gas as opposed to decreasing fuel costs for renewable energy and energy efficiency.

5.4 Benefit analysis of 'More Than 100% Renewable Energy Krabi' plan

Renewable energy and energy efficiency can be produced from resources available within the country and are spread over local areas. Many of the technologies involved in the renewable energy industry can be developed and operated by the Thai people in rural settings, especially biogas and mini-hydro energy systems. Likewise, solar, biomass and energy efficiency have been developed for more domestic and local consumption (domestic content).

In comparison, coal and natural gas's technologies are mainly imported from overseas – all coal fuels and a portion of natural gas fuels need to be imported. Renewable energy alternatives and energy efficiency, therefore, help reduce the country's import burden. Compared to coal-fired power generation, it will reduce the import burden by approximately THB 112 - 3,226 million each year.

The 20-year analysis shows that it will reduce the import burden by THB 42,000 million. Compared to natural gas, the renewable energy industry will reduce the import burden by approximately THB 19,000 million as shown in Figure 5.4-1.

The higher initial investment costs and low-import costs needed in renewable energy alternatives and energy conservation has an effect on the economy of Thailand, e.g. approximately THB 300 - 3,000 million per year more than that of coal and natural gas. When looking at the 20-year analysis, renewable energy alternatives and energy efficiency will benefit the economic growth of the country at an estimated THB 32,000 million higher than the coal's and THB 37,000 million higher than natural gas.

With such a projection of economic growth, and the fact that many of the technologies are Thai owned, there exist a lot of opportunities for employment. By analysing direct employment at the power plants, excluding indirect employment in related businesses, renewable energy alternatives and energy efficiency projects steadily increase employment to about 2,700 jobs per year. It generates approximately 2,400 jobs higher than coal-fired power plants and 2,300 jobs higher than natural gas as shown in Figure 5.4-3.

Renewable energy and energy efficiency
If produced from natural gas
If produced from coal
Compared to natural gas
Compared to coal

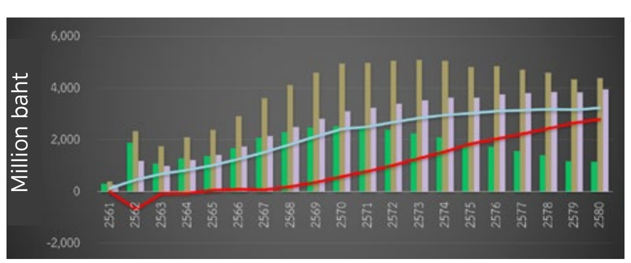


Figure 5.4-1 Import burden of the country as compared to coal and gas power generation

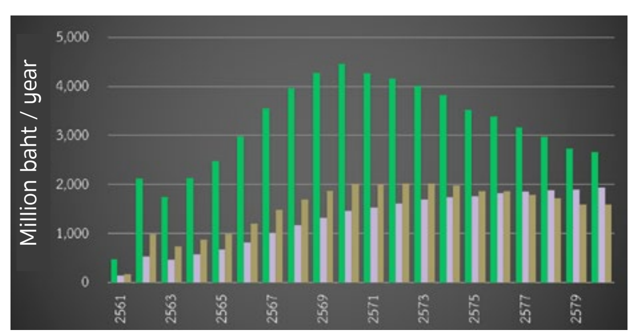


Figure 5.4-2. Benefits To the country's economic growth

Renewable energy sources being spread throughout the country will help the decentralisation of employment opportunities from the cities to the fringe areas. The renewable energy industry will not only limit its hiring to technical manpower but will include managerial, administrative and labour areas.

Renewable energy development not only gives economic benefits but also benefits the environment. An important benefit is that it helps reduce greenhouse gas emissions that cause climate change and 'global warming'.

Developing 'More Than 100% Renewable Energy Krabi' plan will significantly help reduce greenhouse gas emissions. In 2026 when Krabi becomes self-reliant with 100% renewable energy, it will help reduce greenhouse gas emissions by approximately 1,400,000 tons of carbon dioxide per year as opposed to coal-fired systems. Likewise, it can reduce greenhouse gas emissions by about 720,000 tons of carbon dioxide per year as opposed to natural gas.

Further development of renewable energy up to 2037 will reduce greenhouse gas emissions by up to 3,200,000 tons of carbon dioxide per year in comparison to coal, and 1,680,000 tons of carbon dioxide per year compared to natural gas.

A study of Krabi as a model town for 'More than 100% Renewable Energy Krabi' shows good potential and gives direction to develop Krabi in a way that is in line with the province's development strategy derived from the collective vision of its people. It also points at the importance for Thailand to study the potential of renewable energy in all its provinces and regions in order to bring real information to the fore to sustainably invest in renewable energy. This is important to reduce the burden of impact on the economy, society and the environment – costs everybody will have to bear in the long run. The study of renewable energy potential in Krabi will lead to a joint study of the 14 southern provinces in the future in order to jointly determine the directions of fair energy development for the regions and the country.

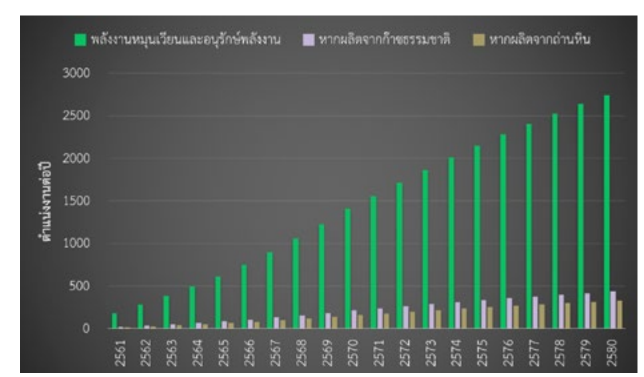


Figure 5.4-3. Direct employment of the 'More than 100% renewable energy Krabi' energy plan as compared to coal and natural gas electricity production

Renewable energy and energy efficiency
If produced from natural gas
If produced from coal

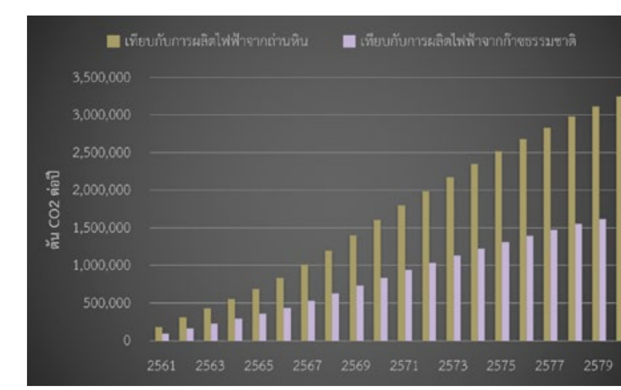
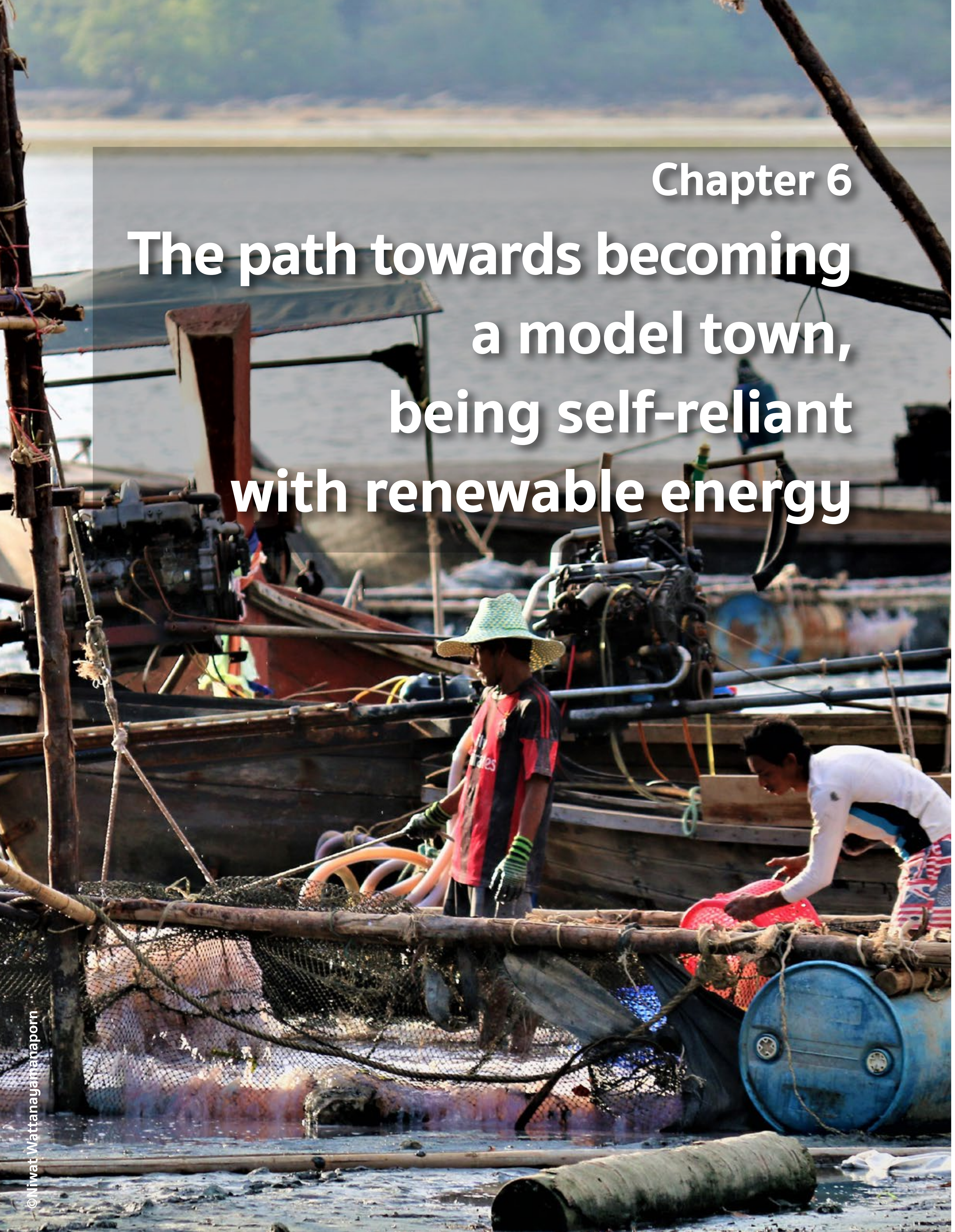


Figure 5.4-4. Reduction of greenhouse gas emissions in the 'More than 100% Renewable Energy Krabi' energy plan

Chapter 6
The path towards becoming a model town, being self-reliant with renewable energy



©Niwat Wattanayanaporn

Promotion and public sector investment in public infrastructure are important aspects of initiatives like the development of renewable energy and energy efficiency. Policies that attract and motivate investments along with improvements in rules and regulations can help achieve the renewable energy development goals. Crucial elements like the development of Smart Grid infrastructure can make energy transmission and management of networks in the provinces more efficient. This should work in tandem with the development of the transmission lines to increase the overall security of the electrical system.

6.1 Policies and promotion

6.1.1 The public policy of Krabi's people

Electricity from renewable energy is often compared with electricity from fossil fuels only in two economic perspectives: short-term costs per unit and 24-hour electricity security. The less considered environmental and social perspectives, as well as the medium and long-term economic view, include an increase in self-reliance on domestic energy resources, reduction of import burden, decent job creation, reduced social inequalities, climate change mitigation, opportunities for advances in energy research and development, etc.

Making the government and Thai society look at the different dimensions of sustainable and sufficient energy development and energy development plans such as the ones outlined in this report presents an important opportunity to communicate and share knowledge among different groups of energy consumers from the private sector, local people, communities, children, youth, etc., in Krabi and other provinces. The aim is to give people access to a wide range of information on different renewable energies, on energy efficiency and electricity management in order to understand more about power development, and how people can jointly determine the direction of the renewable energy development as co-owners, co-investors, co-beneficiaries and be responsible for the results of the energy development.

The energy developed according to the principles of sustainability and self-sufficiency can solve many issues that people of Krabi are confronted with today and in the future, namely:

1) The price of crops: In particular, the palm oil price falling – the price can be increased by increasing the purchase price.

2) Energy expenditure: to be turned into revenue over the next 25 years from the sale of energy we produce.

3) The problem of the children of Krabi: Graduates can work and open up renewable energy and energy efficiency businesses. These include areas like technicians, administration, environment, engineering, safety, etc.

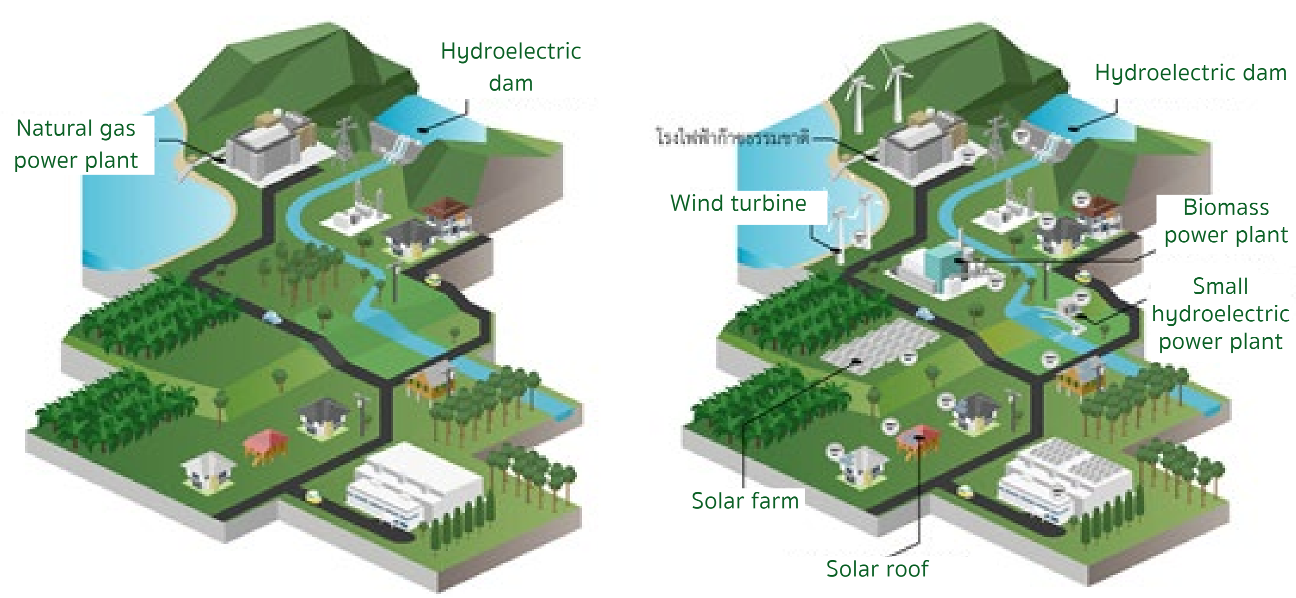
4) Attract tourists and add value to tourism in a province that helps reduce global warming.

6.1.2 Modification of the government's policy and energy policy mechanism

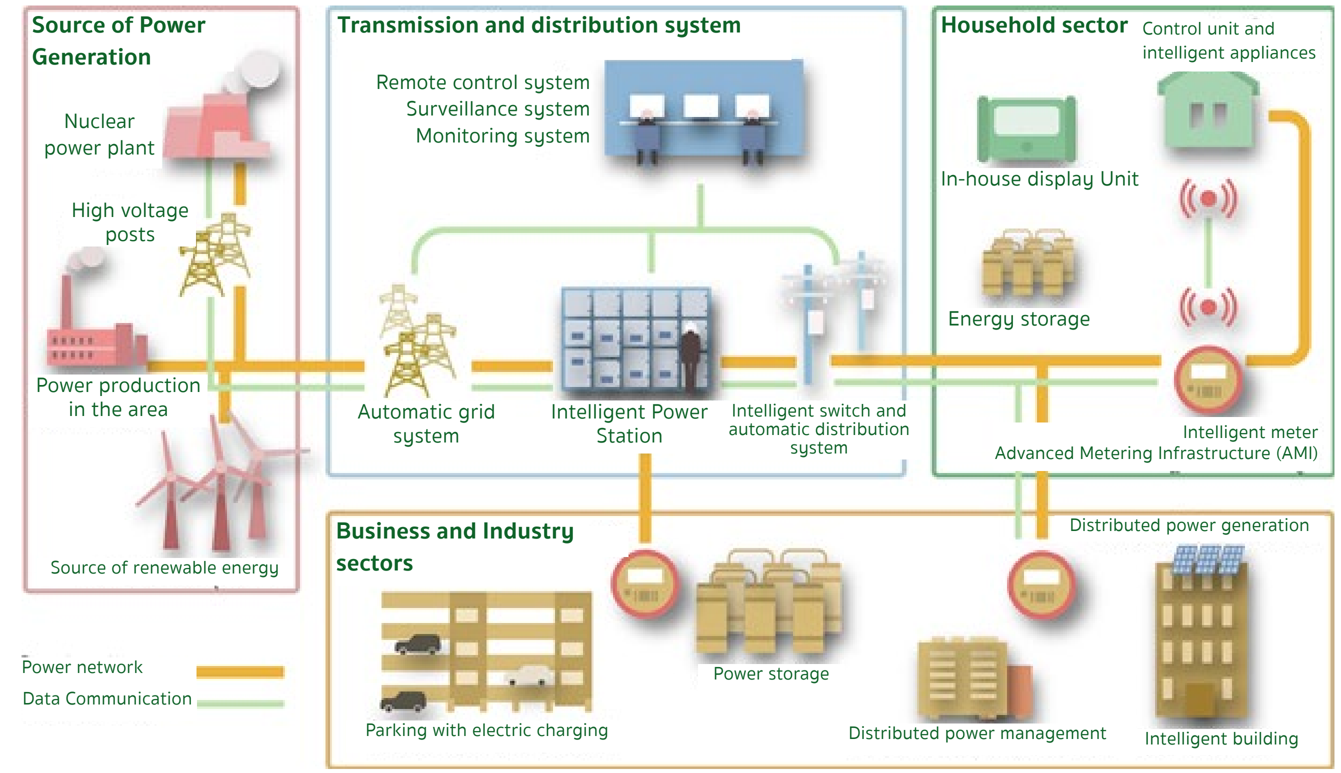
To support the sufficient and sustainable energy development of Krabi and other provinces in the entire country, the energy policy concerned with assigning electricity needs to be adjusted to facilitate the uplink of renewable energy electricity to the transmission systems before those generated from fossils or large dams. There also needs to be a clear and systematic pricing mechanism for the purchase of electricity from each of the renewable energy industries. The prices need to be economically justifiable to help promote continuous renewable energy development. At the same time, purchasing prices need to be revised each year in accordance to the reduction in the cost of producing renewable energy electricity.

Policies on purchasing power from renewable energy industries and pricing mechanism should not be determined by the unilateral decision of government's politicians like in the past. It should follow the renewable energy law as a continued system in the long run.

For change in policy enactment of the renewable energy legislation to take place, there needs to be structural adjustments or reforms in institutions and organisations related to the national energy policy and planning. The composition of the National Energy Policy Council (NEPC) needs to be revised to include representatives from the direct selection of the public as committee members. For the senior officials of the Ministry of Energy, it is necessary to prevent potential conflicts of interest that may arise from the



▲ Figure 6.2-1 Shows the difference between the current (left) and future (right) power systems



▲ Figure 6.2-2 Diagram showing the connection in an intelligent electrical network

implementation of the project policy. Different measures including changing the business model and restructuring of the three electricity authorities (the EGAT, the PEA, and the MEA) should be carried out so as not to pose undue hindrances, but be supportive to the development of renewable energy and energy efficiency initiatives.

6.2 Smart grids

The key to switching to renewable energy is the efficient management of production and demand for electricity. There are several challenges:

1. The sources of power are varied (and spread out in different areas), use different fuel types, and has a wide range of production capacities. See Figure 6.2-1

2. Some power sources, such as wind, have limitations with production fluctuations and hence, hourly production forecasts must be anticipated. With solar, there is no sun after sunset and hence, will need power support from other sources.

3. Since the consumers can become power producers (Prosumers) and can supply electricity back to the system, its infrastructure, design and management needs to be adapted accordingly to this modality.

4. There is a need to communicate data on electricity production and usage in all areas for hourly evaluation and planning of production using mathematical models and weather forecasts.

5. A Home Energy Management system is needed that communicates with the centre, enabling measurement and prediction of the use of electricity in each home and delivering real-time data through intelligent meters.

Intelligent Power Management requires management in both the security and efficiency dimensions. With that said,

1. Efforts must be made to ensure that the power supply is adequate.

2. Demand management is flexible. In particular, reducing or delaying the use of electricity during periods of low electricity consumption.

3. Increase the proportion of electricity from wind and solar to reduce the system's cost of electricity production cost per unit.

4. Quick assessment of the production capacity and adjustments accordingly. In assessing the efficiency of the plant production capacity, the 'capacity factor' which will help reduce the problem of building a new power plant unnecessarily should be used. Currently, capacity factor is not used to measure the efficiency of the Thai power generation system.

Item	Quantity	Unit
Cost of electricity from natural gas	3.09	THB/ unit
Cost of electricity from fuel oil at 100 MW	3.30	THB/unit
Cost of electricity from mixture of fuel oil and crude palm oil (55:18 tonnes per hour formula)	3.47	THB/unit
Number of units of electricity produced per month (at full capacity)	244.8	million units
Increased cost of electricity compared to the electricity generated by fuel oil	41.6	THB million/ month
Increased cost of electricity compared to the electricity generated by natural gas	93.0	THB million/ month
The amount of palm oil that can be absorbed from the market.	12,960*	tonnes/month

** Representing at least 18% of the crude palm oil production in Krabi Province or 6.7% of the country's crude palm oil production

Table 6.3 A comparison study of using crude palm oil for electricity generation per electricity cost

Photo 6.3 Aerial photograph of the Krabi power plant in Nua Khlong District, Krabi Province

Capacity factor is calculated from the number of units actually produced in one year in the whole system, divided by the number of units to be produced in case that all power plants operate at full capacity throughout the year.

There are several ways to increase the flexibility of the power system:

1. Developing power plants to be more flexible by improving existing power plants and the efficiency in use of fuels.

2. Develop transmission lines to be more flexible such that the grid connections have the ability to purchase and distribute power in various directions, thus increasing the robustness and reliability of the system. Using grid-level power storage systems at appropriate points and in right situations for cost-effectiveness.

3. Demand-side management (DSM) to reduce power demand during the peak times.

6.3 Development of transmission line and secondary power plant

Krabi has a regional electricity distribution network whose original design emphasized the expansion of transmission lines along the zones of economic development and where electricity demands are high.

The expansion of transmission lines in Krabi in the future should consider the following:

1. Supporting a wide range of renewable energies, such as uplink and distribution of electricity to the areas with renewable energy sources. This should be done in parallel with predicting the different demands for electricity in different areas in order to reduce power losses in transmission lines and to maintain transmission efficiency.
2. The development of grids and grid security, i.e. connecting the feeder terminals of several sub-power stations together in a 'ring loop' to enable sending of backup power across power stations when there are problems in the normal transmission lines or imbalances between electricity generation and demand.

Figure 6.3 shows an aerial view of the Krabi power plant. Once a coal-fired power plant, it was transformed into a fuel-oil-fired power plant when the coal supplies from the local mines ran out. Since the cost of generating electricity from fuel oil is more expensive than natural gas, the plant is only used occasionally when necessary. According to some studies, Krabi power plant has the potential to improve its operation for a specific use such as during high power consumption or when the price of palm oil is below 25 baht per litre, using a fuel oil formula of 18:55 tons of crude palm oil and fuel oil, respectively, per hour. The feasibility study found that when in running in full power at 100 MW, the price of electricity produced from the mixture of crude palm oil and fuel oil is about 0.17 baht per unit or about 41.6 million baht per month. This rate is higher than the production of electricity from fuel oil alone at Ft = 0.0026 baht per unit if running a 340 MW operation for 30 days.

Considering many benefits of mixing crude palm oil including stabilising the price or managing the excess output of crude palm oil in the market, slowing down the construction of new power plants and the numerous long-term socio-economic benefits as well as minimisation of environmental impacts of using renewable energy sources, the difference in cost difference is minimal and hence presents itself as a pragmatic choice for Krabi and the nation as a whole to transition towards an electricity system based on renewable energy sources.

©Niwat Wattanayamanaporn

REFERENCES

[1] https://www.ramsar.org/wetland/thailand

[2] http://www.dmcr.go.th/upload/dt/file/file-1812560139973.pdf

[3] Marine and Coastal Resources Survey and Assessment Report: Coral and Seagulls, 2015, Department of Marine and Coastal Resources, Ministry of Natural Resources and Environment

[4] Wetlands of International Importance, Office of Natural Resources and Environmental Policy and Planning, http://wetland.onep.go.th/KrabiEstuary_n.html

[5] 'Krabi Vision 2020 – Standpoint and Directions to prepare for future development'

[6] Presentation on Integration of Alternative Energy in Southern Thailand, Payom Rattanamanee, National Research Council of Thailand(NRCT) Academic Conference on Alternative Conference, January 26-27, 2010

[7] Analysis Report Alternatives of Power Development Plan To reduce the emission of greenhouse gases from the power branches, Suphakit Nuntavorakarn and others, Research Fund, 2014.

[8] Renewable Energy Scenarios for the Thai Provinces Phuket, Rayong, and Nan,
Fraunhofer ISE, GIZ, 2015, HTTP: // www.thai-german-cooperation.info/admin/uploads/publication/3155324998f206e29cfe74d9b51721caen.pdf

[9] Renewable Energy Outlook: Thailand, International Renewable Energy Agency, 2017, https://www.irena.org/-/media/Files/Irenewable energyNA/Agency/Publication/2017/Nov/IRENA_Outlook_Thailand_2017.pdf

[10] Renewable Energy Market Analysis: Southeast Asia, International Renewable Energy Agency, 2018,https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_Market_Southeast_Asia_2018.pdf

[11] Renewable Energy Job Creation in Thailand Report, Decharut Sukkumnoed et al, Greenpeace Thailand Office, 2018.

©Niwat Wattanayamanaporn

©Raweewat Tuntisavee