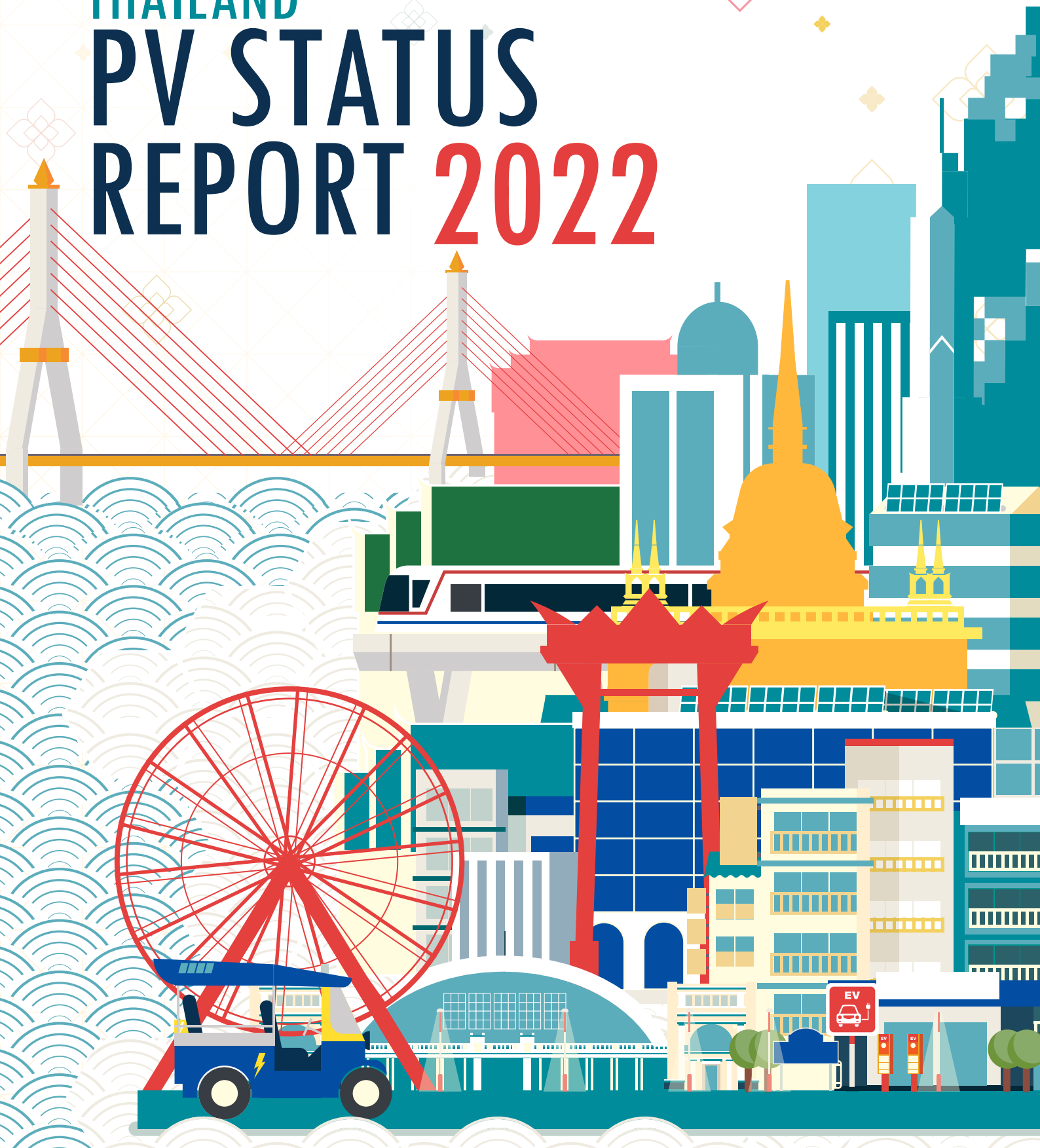
DEDE 2023

Department of Alternative
Energy Development and Efficiency
MINISTRY OF ENERGY

THAILAND PV STATUS REPORT 2022

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Thailand PV Status Report Committee 2022

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Thailand PV Status Report Committee 2022

Definitions

	Definition
Adder	Additional incentive of purchasing of electricity purchasing from renewable energy from the base electricity price for a certain support period of time.
Battery Energy Storage System : BESS	Systems or equipment that can convert electricity to chemical energy and vice versa, integrating with the electrical grid[1].
Feed-in Tariff: FiT	Incentive schemes for the purchasing electricity from renewable energy source at a rate set by the government's policy[2].
Grid-connected systems user	Approved electricity users who synchronize power generation equipment with the utility grid[3].
Independent Power Supply : IPS	Electricity generation owners who produce electricity for self-consumption or supply electricity to other direct customers and are authorized to connect to the utility grid in compliance with the requisite network connection criteria[1].
Microgrid	Small electricity system that integrates generation, transmission, and control systems. Microgrid system can operate with main grid or separate (islanding mode) from the main grid if necessary[1].
On-grid user	Electricity users who own a generator and synchronize it with the utility grid[3].
Power Purchase Agreement : PPA	The agreement for purchasing electricity between the electricity producer and the utility[5].
Small Power Producers : SPP	Electricity producers either private sector, government, or state enterprises, who sell electricity more than 10 MW but not exceeding 90 MW to EGAT, for both firm and non-firm contract[1].
Very Small Power Producers : VSPP	Electricity producers either private sector, government, or state enterprises, who sell electricity not exceeding 10 MW to PEA and MEA[1].

Sources :

1. Regulation on the operation of the electrical network system by the Electricity Generating Authority of Thailand (EGAT) was issued in December 2019.

2. Regulation on the purchase of electricity from rooftop PV systems by the Energy Regulatory Commission (ERC) was enacted in 2013.

3. Regulation on the connection requirements of the electrical network system for the Metropolitan Electricity Authority (MEA) was issued in 2015.

4. Regulations on the connection requirements of the electrical network system for the Provincial Electricity Authority (PEA) was issued in 2016.

5. Announcement inviting the purchase of electricity from renewable energy sources through Feed-in Tariffs (FiT) for the period 2022 – 2030, specifically for ground-mounted PV systems in the year 2022, issued by the Energy Regulatory Commission (ERC).

Definitions

PV technology's definitions:

High efficiency PV modules : PV modules determine the efficiency of solar cells based on the photovoltaic material used, such as PERC, TOPCon, HJT etc.

Crystalline silicon PV modules : PV modules have a crystalline silicon base.

Low efficiency PV modules : General PV modules determine the efficiency of solar cells based on the polycrystalline silicon.

Acronyms

Name	Initials-ENG
Thailand Board of Investment	BOI
Chulalongkorn University	CU
Department of Alternative Energy Development and Efficiency	DEDE
Department of Industrial Works	DIW
Electricity Generating Authority of Thailand	EGAT
Energy Policy and Planning Office	EPPO
The Federation of Thai Industries	FTI
Industrial Estate Authority of Thailand	IEAT
King Mongkut's University of Technology Thonburi	KMUTT
Metropolitan Electricity Authority	MEA
National Energy Policy Council	NEPC
National Science and Technology Development Agency	NSTDA
Naresuan University	NU
Office of Energy Regulatory Commission	OERC
Provincial Electricity Authority	PEA
Thai Industrial Standards Institute	TISI
Thai Photovoltaic Industries Association	TPVA

1 Executive Summary

PV system applications in Thailand can be divided into three groups: on-grid PV systems with PPA, on-grid PV systems without PPA, and off-grid PV systems.

Group 1 On-grid PV systems with Power Purchasing Agreement (PPA)

This group consists of PV power producers who sell electricity to the power utility (mostly under FiT contract), which can be categorized as 2,894 MWp solar ground-mounted, 156 MWp solar rooftop, and 48 MWp solar floating systems. Total installed capacity for this group was 3,098 MWp.

Group 2 On-grid PV systems without Power Purchasing Agreement (PPA)

This group consists of PV power producers who consume the electricity produced or sell electricity to other direct customers, which may sometimes be referred as IPS or private-PPA. Systems in this group can be categorized as 105 MWp solar ground-mounted, 1,673 MWp solar rooftop and 76 MWp solar floating systems, totaling 1,854 MWp.

Group 3 Off-grid PV systems

This group consists of PV power producers who do not connect their PV system with utility grid - for example, solar water pumping system, PV systems in remote area that often incorporate BESS, and solar PV system for islands that often hybridized with other renewable energy available in the area.

Over the last few years, the installation of PV systems has experienced rapid growth, attributed to the decrease in the price of PV systems, and the development of novel PV technologies. Moreover, electricity tariffs have increased due to rising fuel costs, the impact of the European Union's Carbon Border Adjustment Mechanism (CBAM), and global commitments to carbon neutrality and achieving net zero carbon emissions, as outlined in the international declarations. This has bolstered carbon credit activity as well as businesses related to PV module recycling.

Currently, Thailand is undergoing a transition to clean energy era to achieve the target of carbon neutrality by 2050. Solar PV is expected to be one of pivotal players in response to such target. Additionally, Thailand is developing the final details of the National Energy Plan (NEP) which encourages more consumption of clean and renewable energy, in which solar PV will become a dominate player in Thailand future energy market.

2

Photovoltaic Solar Power Generation

2.1 Electricity statistics of Thailand

Electricity production is an important factor that contribute the wellbeing of Thai people and Thailand economy. Therefore, electricity generation planning is necessary that must be aligned with context of energy situation of Thailand. As climate change is one of the major concerns globally, attempts had been made internationally to mitigate impacts of environment including energy transition towards clean and renewable energy.

In 2022, total power generation of Thailand was 215,824 GWh, consisting of 53% natural gas, 17% imported coal, 10% renewable energy, 3% hydropower and 1% oil. Whereas total electricity consumption was 197,224 GWh. If categorize by sector, electricity consumption was dominated in industrial sector (44.9%) followed by residential sector (27.2%) and commercial sector (23.3%). The share of renewable energy in final energy consumption was 13.38%, with solar energy accounting for 24.7% of Thailand's total renewable energy production, as shown in Figure 2.1 and Figure 2.2.

Electricity Generation and the Proportion of Electricity Production in Thailand

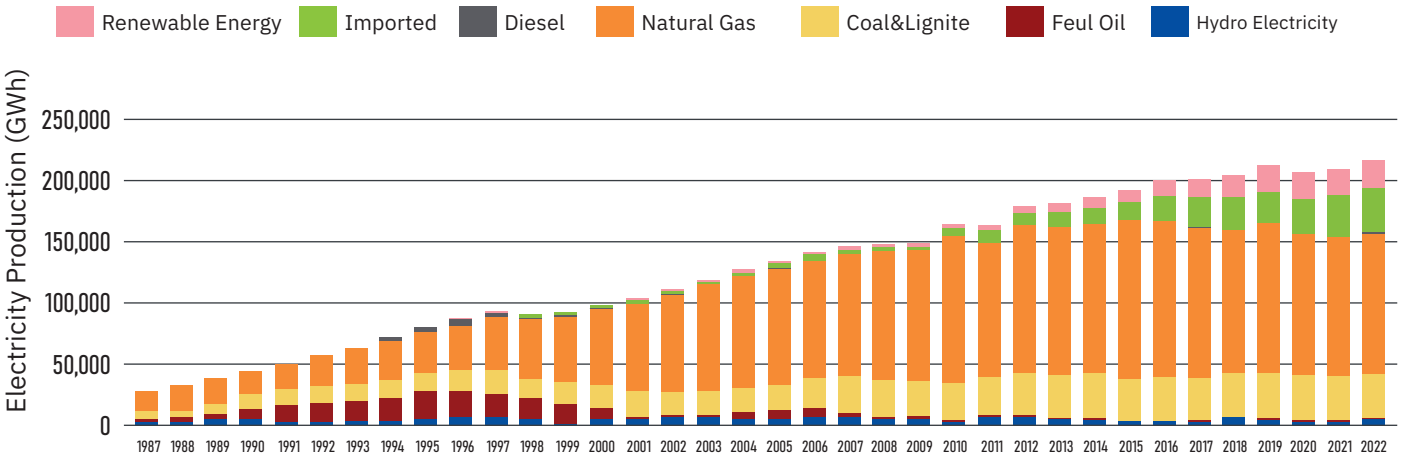


Figure 2.1 Electricity Production Capacity in Thailand by Fuel Sources and Consumption from 1987 to 2022.

Source:
Summary of energy and electricity statistic in 2022, EPPO.

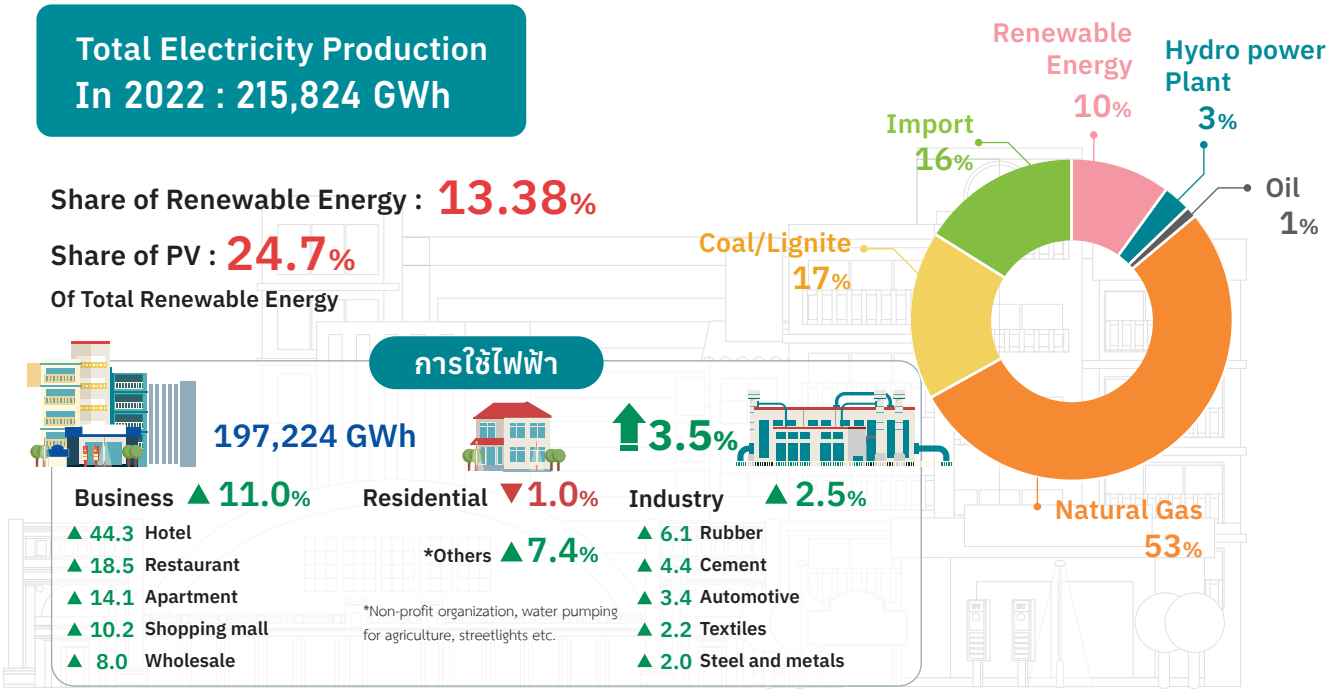


Figure 2.2 Electricity Generation and the Proportion of Electricity Production in Thailand, in 2022.

Source:
Summary of energy and electricity statistic in 2022, EPPO.

Past decade, Thailand has predominantly depended on natural gas as its primary energy source for electricity, complemented using fuel oil, and coal. In 2010, there was a significant increase in the capacity for renewable energy. Figure 2.1 illustrates the percentage of PV electricity relative to the total renewable energy output between 2020 and 2022, averaging 22%. (Table 2.1)

Table 2.1

Electricity generated from PV systems during 2020 to 2022 (as of September 2022)

Year	Total electricity generated from renewable energy (GWh)	Electricity generated from PV systems (GWh)	Ratio of electricity production from PV systems to the total renewable energy (%)
2020	20,337.52	4,763.59	23.42
2021	23,856.02	5,052.35	21.18
2022 (Sep. 2022)	15,694.31	3,250.09	20.71
Average	**19,962.62**	**4,355.34**	**21.77**

Source:
OERC annual reports for the fiscal year 2020, fiscal year 2021, and a summary of key achievements for the fiscal year 2022.

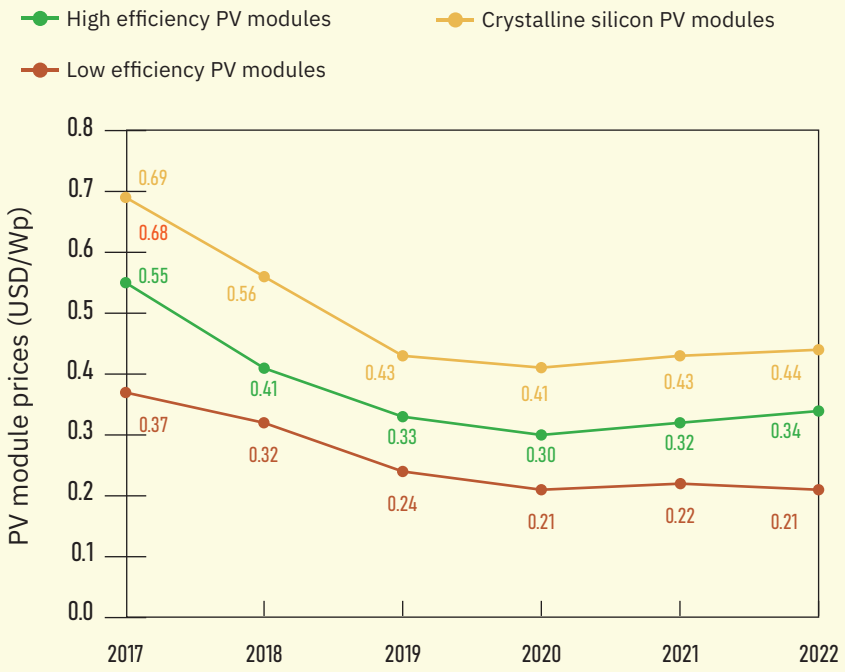


Figure 2.3 The average price of solar panels in the European Union during the years 2017–2022, categorized by solar panel technologies.

Source:
IRENA (2022), Renewable power generation costs in 2022.

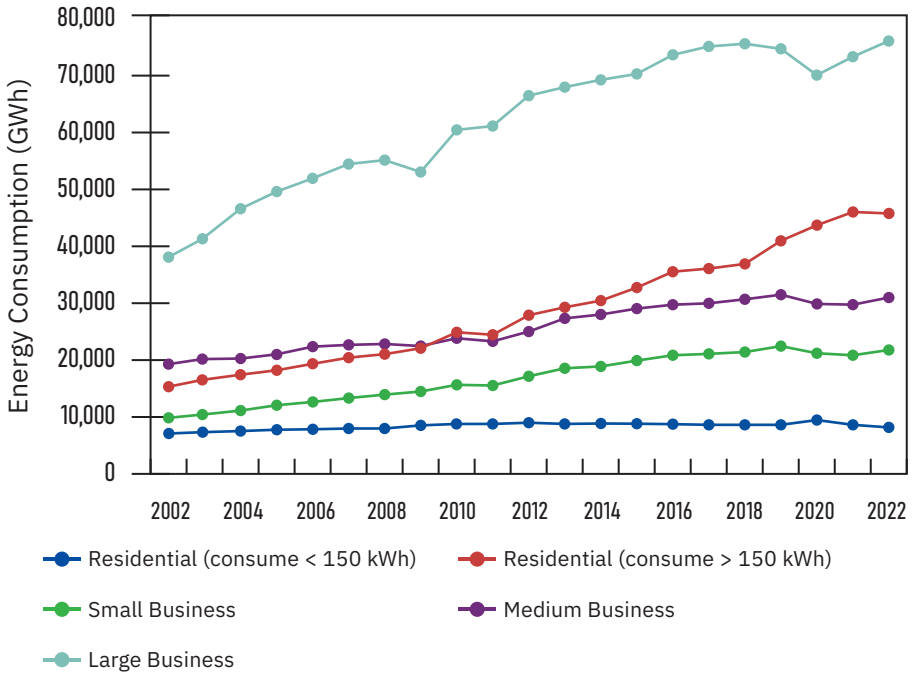


Figure 2.4 **Electricity consumption in residential and commercial sector in Thailand during 2002 to 2022.**

Source:
Summary of Energy and Electricity Statistic in Thailand, 2022, EPPO

Figure 2.4 illustrates the trend of energy consumption for residential and commercials sectors, showing continuous growth from 2002 to 2022. There was particularly notable decline in commercial sector consumption in 2019 to 2020, due to the covid-19 crisis.

Over the past 4 to 5 years, the capacity of distributed PV systems has increased, particularly for the purpose of self-consumption and direct customer supply in the private sector. This trend can be attributed from decrease in the price of PV systems and desire to reduce electricity bills.

In 2022, a significant rise in the electricity prices compared to the previous year prompted an increase in the capacity of PV systems in residential sector. Furthermore, the implementation of the Feed-in Tariff scheme further contributed to this trend.

2.2 Overview of the PV power generation in Thailand

The consecutive growth of PV system installed capacity in Thailand has been driven by energy policy and initiatives in renewable energy since 2008. The goal of the renewable energy plan, particularly in solar energy, is to reduce the fossil fuel consumption and promote environmentally friendly practices. Currently, the Alternative Development Energy Plan for 2018 to 2037 has established a target of 12,139 MW for PV power generation by 2037.

In general, solar PV system can be categorized based on grid connectivity manner into 2 groups.

(1) On-grid PV systems, which can be further categorized into 2 groups.

1.1) PV producers with power purchasing agreements.

1.2) PV producers with non-power purchasing agreements.

(2) Off-grid PV systems, which are not connected to the utility grid.

While the current AEDP target primarily covers the installed capacity of PV systems with PPA by the government, there were significant growth of solar PV system without PPA as well.

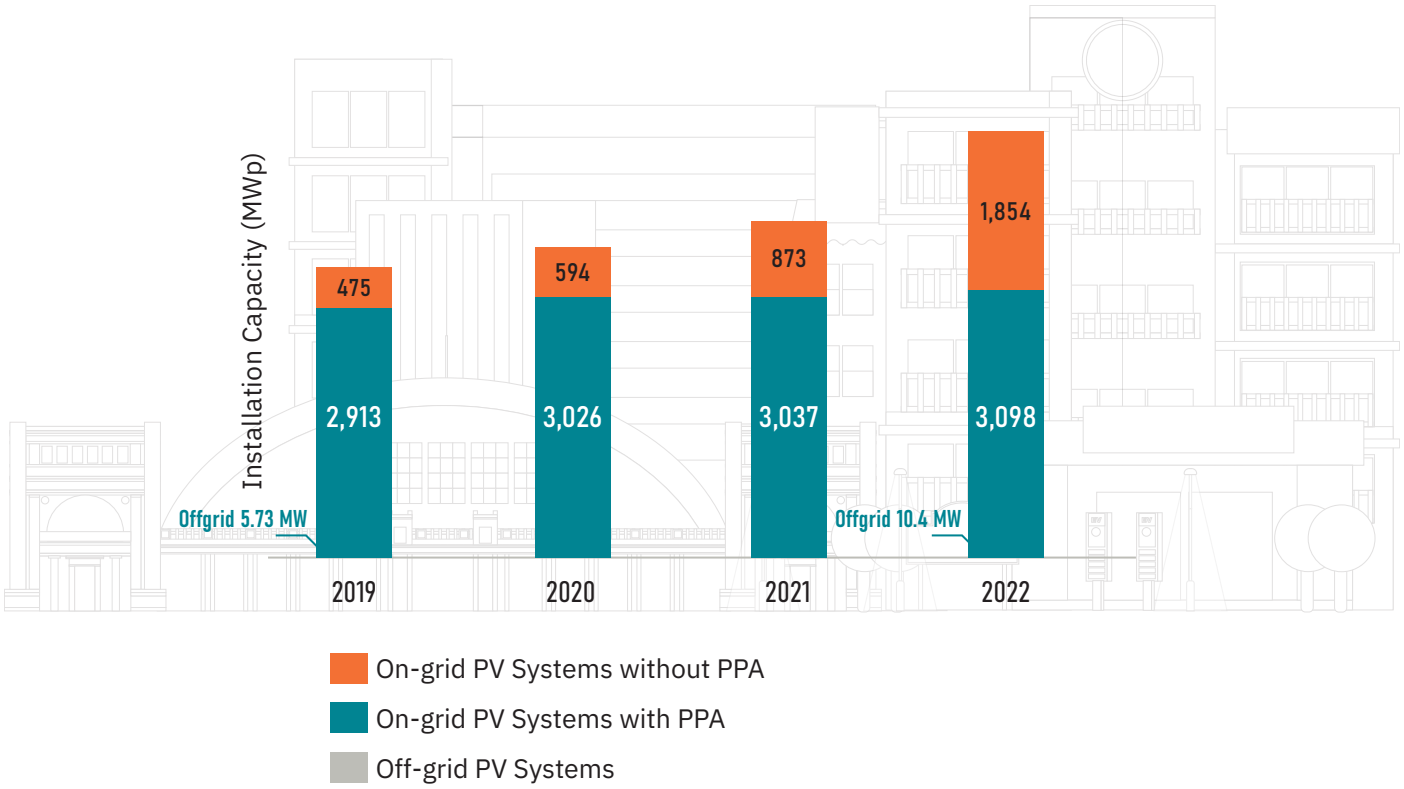


Figure 2.5 Installed capacity of PV systems in Thailand between 2019 and 2022.

Source:
EGAT, MEA, PEA, OERC and DEDE.

Table 2.2

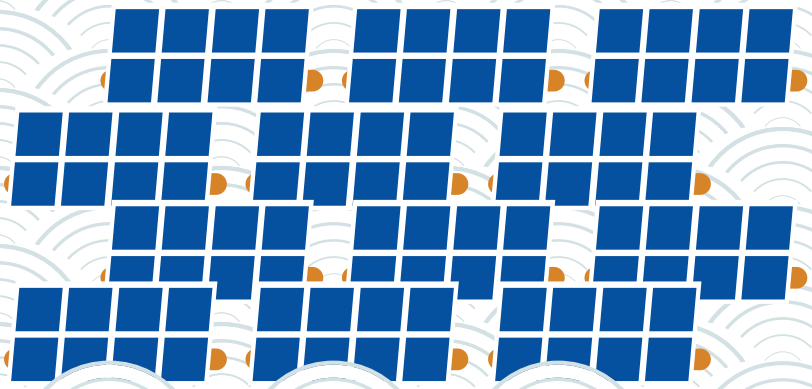
PV system capacity in Thailand between 2020 and 2022.

Year	On-grid PV systems with PPA		On-grid PV systems without PPA		Off-grid PV systems		Total	
	Number of projects (project)	Installed capacity (MWp)	Number of projects (project)	Installed capacity (MWp)	Number of projects (project)	Installed capacity (MWp)	Number of projects (project)	Installed capacity (MWp)
2019	6,697	2,913	1,011	475	3,383	5.73	11,091	3,393
2020	7,831	3,026	1,082	594	3,625	6.11	12,538	3,626
2021	8,978	3,037	1,739	873	3,637	6.33	14,354	3,916
2022	12,368	3,098	14,835	1,854	3,637	10.4	30,840	4,962

Source:
EGAT, MEA, PEA, OERC and DEDE.

Table 2.2 shows that in 2022, Thailand had a total PV system capacity of 4,962 MWp, consisting of 3,098 MWp of PV systems with power purchasing agreement by the government, 1,854 MWp of PV systems without power purchasing agreements, and 10.4 MWp of off-grid PV systems. Total solar PV system installed in 2022 was 1,046 MWp.

Moreover, if we characterized solar PV systems based on type of installation, there were cumulative 2,999 MWp of ground-mounted PV systems, 1,837 MWp of rooftop PV systems, and 114.8 MWp of floating PV systems in 2022. This increase in capacity resulted from more utilization of PV systems for self-consumption or direct supply to customers without government PPA in response to unusually high price of electricity in 2022.



2.3 On-grid PV systems with PPA by government

In the segment of on-grid PV systems with power purchase agreement (PPA) by government, the installed capacity is 3,098 MWp from 11,240 projects. These consist of 2,894 MWp of ground-mounted PV systems (93.4%) from 587 projects, 156 MWp of rooftop PV systems (5.05%) from 10,652 projects, and 48 MWp of floating PV systems (1.55%) from one project (Figure 2.6).

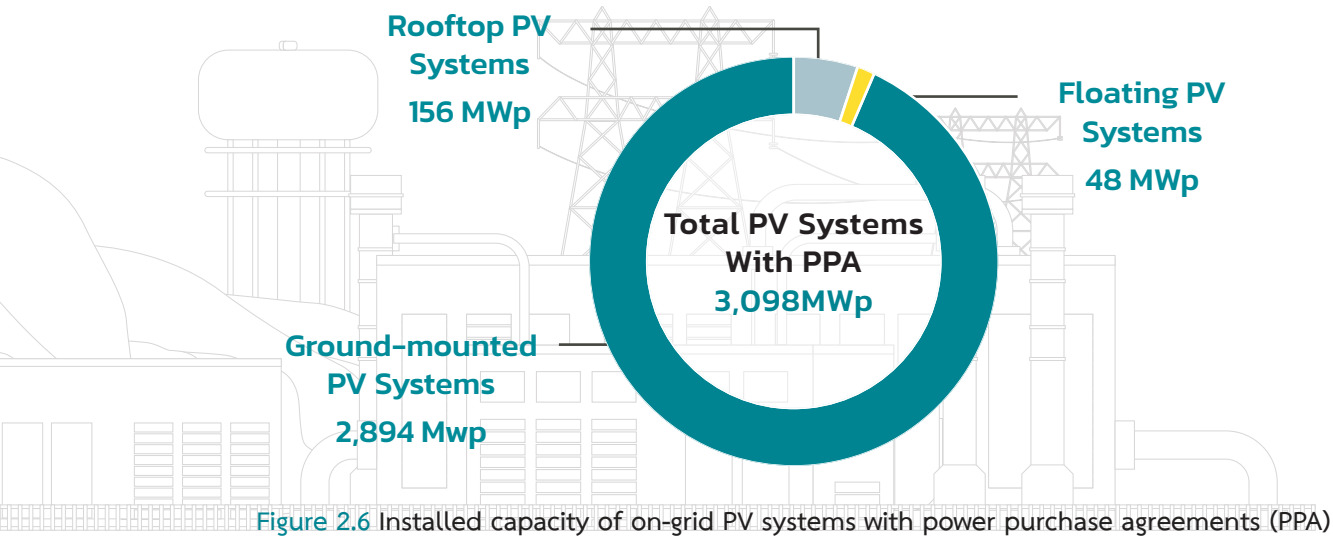


Figure 2.6 Installed capacity of on-grid PV systems with power purchase agreements (PPA) by the government, categorized by configuration type.

Source:
Summary Report of Key Operations for Fiscal Year 2022, OERC.

Table 2.3

Data on the installed capacity of on-grid PV systems with power purchase agreements (PPA) by the government, categorized by configuration type.

Installation type	Number of projects (project)	Installed capacity (MWp)	Percentage (%)
Ground mounted PV	587	2,894	93.4
Rooftop PV	10,652	156	5.05
Floating PV	1	48	1.55
Total	**11,240**	**3,098**	**100**

Source:
Summary Report of Key Operations for Fiscal Year 2022, OERC.

Solar ground-mounted in this group was consisted of 2,511 MWp solar farm and 383 MWp solar ground-mounted installation project for government agency and agricultural cooperatives. There were cumulative 131 MWp solar rooftop installation in this group with 30.85 MWp cumulative solar rooftop installation for residential program during 2019-2022.

2.4 On-grid PV systems without PPA by government

The continuously growth of installed capacity of on-grid PV systems without PPA attributed to an increased supply from China, resulting in a reduction of module prices. Consequently, electricity produced from PV systems has achieved price competitiveness with grid electricity. Additionally, the intention of power users to reduce electricity consumption cost, along with global energy market and energy price fluctuation also had impacts on energy market of Thailand as well.

The purpose of PV power producer in this group was to produce electricity for self-consumption or provide electricity to direct customers, in which sometimes referred as Independent Power Supply (IPS) that was gaining popularity in both Thailand and globally. In 2022, the cumulative installed capacity in this group reached 1,854 MWp, a 980 MWp increase from previous year. The majority of system configuration (>90%) in this group was solar rooftop systems.

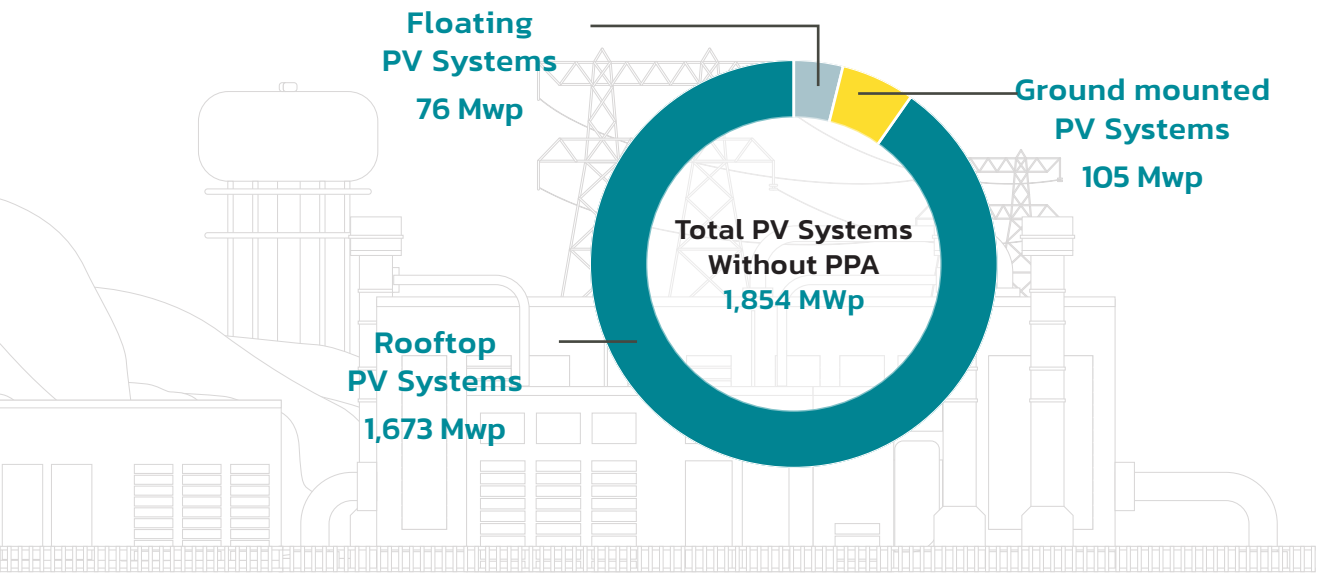


Figure 2.7 Installed capacity of on-grid PV systems without power purchase agreements (non-PPA) by the government, categorized by configuration type.

Source:
Summary Report of Key Operations for Fiscal Year 2022, OERC.

Table 2.4

Data of Installed capacity of on-grid PV systems without power purchase agreements (non-PPA) by the government, categorized by configuration type.

Installation type	self-consumption or direct supply to customers		Percentage (%)
	Number of projects (project)	Installed capacity (MWp)	
Ground-mounted PV	65	105	5.66
Rooftop PV	14,749	1,673	90.24
Floating PV	21	76	4.1
Total	**14,835**	**1,854**	**100**

Source:
Summary Report of Key Operations for Fiscal Year 2022, OERC.

PV system installations under non-PPA arrangements gained continuous increase in popularity, particularly in industrial sector, where both rooftop and floating PV systems were usually installed. These installations offer several advantages, including cost savings on electricity, increased land utilization, and aligned with country direction to reduce carbon emissions. Figure 2.8 illustrates a typical rooftop PV system in the industrial and commercial sectors. The capacity of these systems depends on related factors such as available roof area and energy demand. Moreover, floating PV systems provided additional benefits of utilizing water surfaces and reducing water evaporation.

(1) 2.0 MWp rooftop PV system in Ban Bueng, Chonburi province.

(2) 806 kWp floating PV system in khao Yoi, Phetchaburi province.

(3) 2.7 MWp rooftop PV system in Photharam, Ratchaburi province.

Figure 2.8 Typical rooftop and floating PV systems under non-power purchasing agreements (non-PPA) by government.

Source:
This data was provided by NEO Clean Energy Company Limited.

2.5 Off-grid PV systems

Off-grid PV systems have been employed for a long time, offering substantial benefits for enhancing the quality of life in rural areas. These systems play a crucial role in improving health, education, and well-being of population. Application of off-grid PV systems included electricity production in sub-district health-promoting hospitals, rural schools and the border patrol policy school, tribal community learning centers, as well as solar pumping for remote village and agricultural applications.

Table 2.5

Cumulative off-grid PV system installations in 2020 and 2022.

Number	Organization	2020		2022	
		Number of systems (system)	installed capacity (kWp)	Number of systems (system)	installed capacity (kWp)
1	TOT Public Company Limited	1	6	1	6
2	King Mongkut's University of Technology Thonburi	5	52.4	11	99.37
3	National Science and Technology Development Agency	25	207.8	32	394.4
4	Defense Energy Department	382	941	382	941
5	Department of Alternative Energy Development and Efficiency	2,589	3,974.7	2,589	3,974.7
6	System transfer from Department of Alternative Energy Development and Efficiency	622	912.2	622	912.2
7	Energy Conservation Fund from 2014 – 2017	n.a.	4,059	n.a.	4,059
8	Solar Home project in 2005*	203,100*	24,388*	-	-
Total		**3,625**	**10,153**	**3,637**	**10,386.7**

Remark * Solar Home Project in 2005 and transferred the system to the Local Administration.

Source:
System installer and owners and DEDE

Table 2.6

Off-grid PV system applications by DEDE in 2022

Activity	Year	Cumulative installed capacity (kWp)	Cumulative project number (system)
The Royal Initiative Projects	1999–2019	496.3	1,039
Rural schools	2002–2017	1,386	361
Mae Fah Luang the Tribal community learning center	2004–2017	81	54
Sub-district health promoting hospitals	2003–2016	180	81
National parks and forests	2006–2016	289	89
Solar pumping systems	2003–2015	122	61
Battery charging stations	1993–2004	1,135.2	350
Military operations base and border protection base	2002–2014	285.2	554
Total (in 2022)		**3,974.7**	**2,589**

Source:

This data was provided by DEDE.

Figure 2.9 (Left)

AIS operation base in Mae Tha, Lamphun province.

Figure 2.10 (Right)

AIS operation base in Doi Soi Ma Lai, Ban Tak, Tak province.

Source:

This data was provided by NSTDA.

Table 2.7

Off-grid PV systems applications by NSTDA in 2021 and 2022

	Activity	Solar Power Generation System (kWp)	Energy Storage System, BESS (kWh)	Remarks
1	**Microgrid-Ubon:** Consist of: (1) Colored PV solar panels, (2) Crystalline silicon solar panels, located at Wat Pa Sri Sengtham, Khong Chiam District, Ubon Ratchathani Province	**91.8** 60 31.8	**511.2**	Agrivoltaics' concept (combining PV power generation with agricultural applications), developed by NSTDA.
2	**Microgrid-NETEC:** Consist of: (1) Colored PV solar panels, and (2) Crystalline silicon solar panels, located at NETEC Pilot Plant, NSTDA, Khlong Luang District, Pathum Thani Province.	**28** 7 21	**21.3**	Agrivoltaics' concept (combining PV power generation with agricultural applications and building Integrated Photovoltaics, BIPV), developed by NSTDA.
3	**Mobil Solar PV System (Solar move)** Mobile Solar Power System (Solar move): Delivered to residents in areas. 1) Ban Moeng Gua, Amphoe Umphang, Tak 2) Ban Mae Loe, Amphoe Mae Sariang, Mae Hong Son 3) Ban Khiri Lom, Amphoe Bang Saphan Noi, Prachuap Khiri Khan 4) Ban Pilo Khikhi, Amphoe Thong Pha Phum, Kanchanaburi 5) Metropolitan Electricity Authority (MEA) Headquarters, Bangkok	**14.4**	**100.8**	Moveable PV system
4	**AIS Operation Base, Doi Soi Malai,** Ban Tak District, Tak Province	**13.6**	**76.8**	-
5	**AIS Operation Base, Khuamung,** Saraphi District, Chiang Mai Province	**17.3**	**57.6**	Hybrid system
6	**AIS Operation Base,** Mae Tha District, Lamphun Province	**10.9**	**48**	Hybrid system
7	**Schools under the Border Patrol Police** in Tak Province (2020)	**10.6**	**n/a**	5.3 kWp and 2 projects
	Total	**186.6**	**815.7**	

Source:

This data was provided by NSTDA.

Figure 2.11
Colored PV system at Wat Pa Sri Sengtham, Khong Chiam District, Ubon Ratchathani Province.

Figure 2.12 Typical microgrid system with a 28 kWp installed capacity combined with a 21.3 kWh Battery Energy Storage System (BESS), integrated with farming in Ubon Ratchathani Province, and operated by NSTDA.

Figure 2.13 PV microgrid at NECTEC pilot plant in Khlong Luang district, Pathum Thani province.

Source:
This data was provided by NSTDA.

Through the Power Development Fund, OERC supported off-grid PV system applications aimed at promoting renewable energy and technology with minimal environmental impact. Examples of those projects are as follows:

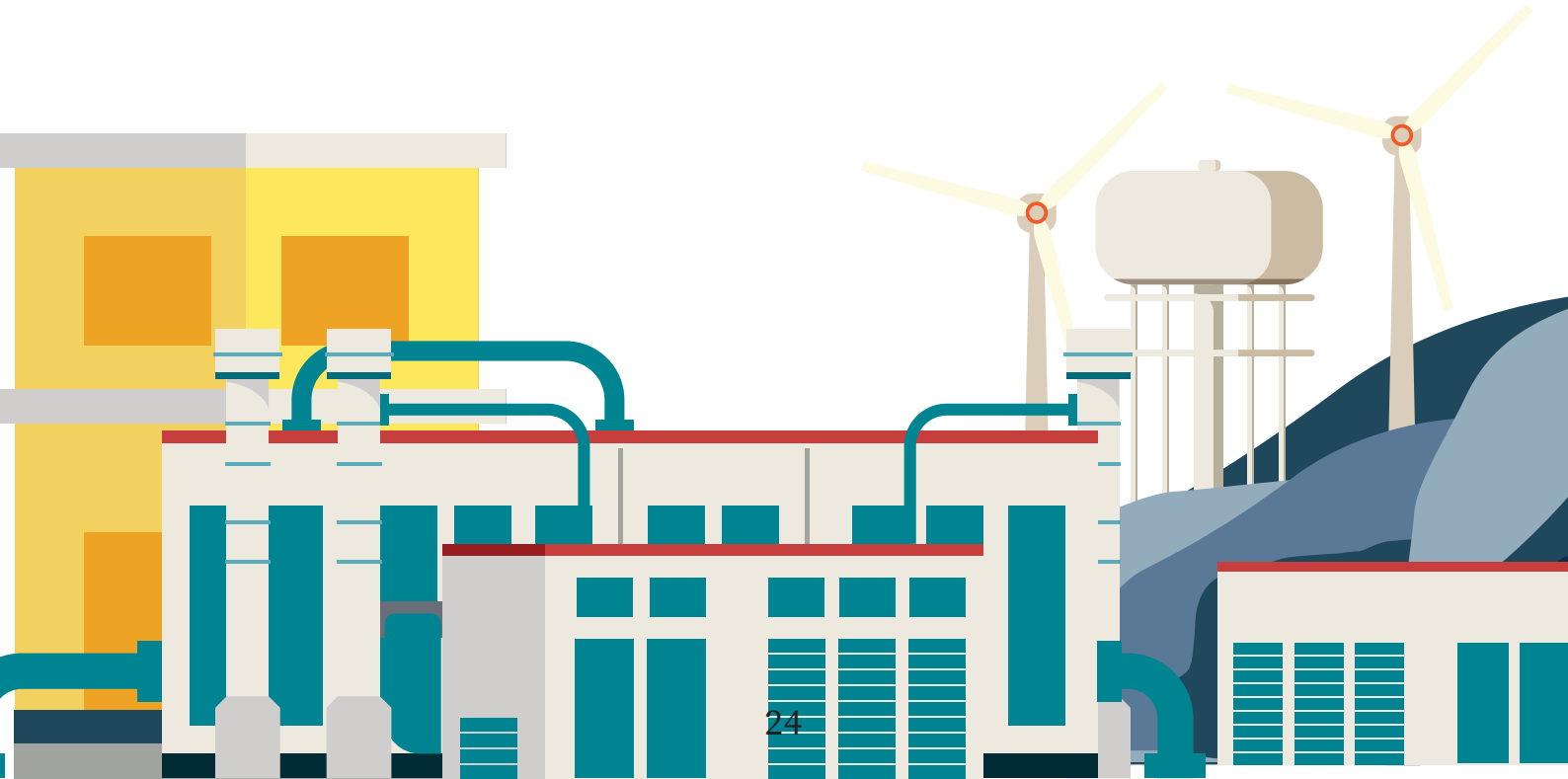
1) Prototype project for electricity generation using sustainable renewable energy for national parks and wildlife sanctuaries in Thailand. An example of this project included those implemented in Tarutao National Park, Satun Province. The project includes 46.965 kWp of PV systems and 126.43 kWh of Battery Energy Storage Systems (BESS), which were implemented by KMUTT.

2) Targeted electricity production from renewable energy promotion project to provide off-grid solar PV systems to remote academic institute located far from grid-edge network.

3

Industry and Growth

This section provides an information on solar cell technology in both global and Thailand market, covering both commercial and research aspects. Including novel and innovative PV cell technology such as perovskite, information on costs of PV modules and PV system in Thailand are provided, considering the dynamics of prices in global markets, as well as, the important role of PV electricity in the industrial sectors within the context of achieving carbon neutrality. This included policy developments and related measures such as carbon credit certification or utility green tariff.



3.1 Commercial photovoltaic technology

3.1.1 Global development of PV technology

Continuous development of PV cell and module technology to increase efficiency had been observed during the past years. IEA reported that the size of wafers and PV modules had increased and continued to grow. Initially, the size of PV module was 250 – 300 W per module, consisting of 60 cells. The wafer size was 156 mm, known as M0, and this standard persisted in the market until 2018 when wafer sizes increased, such as M2 (156.75 mm), M3 (158.75 mm), M4 (161.7 mm) and M10 (182 mm), leading to continuous improvements in PV module efficiency. New types of high-efficiency PV modules, such as the 144-cell or 120-cell half-cut PV modules, had been developed, resulting in modules capable of producing up to 500 – 600 W.

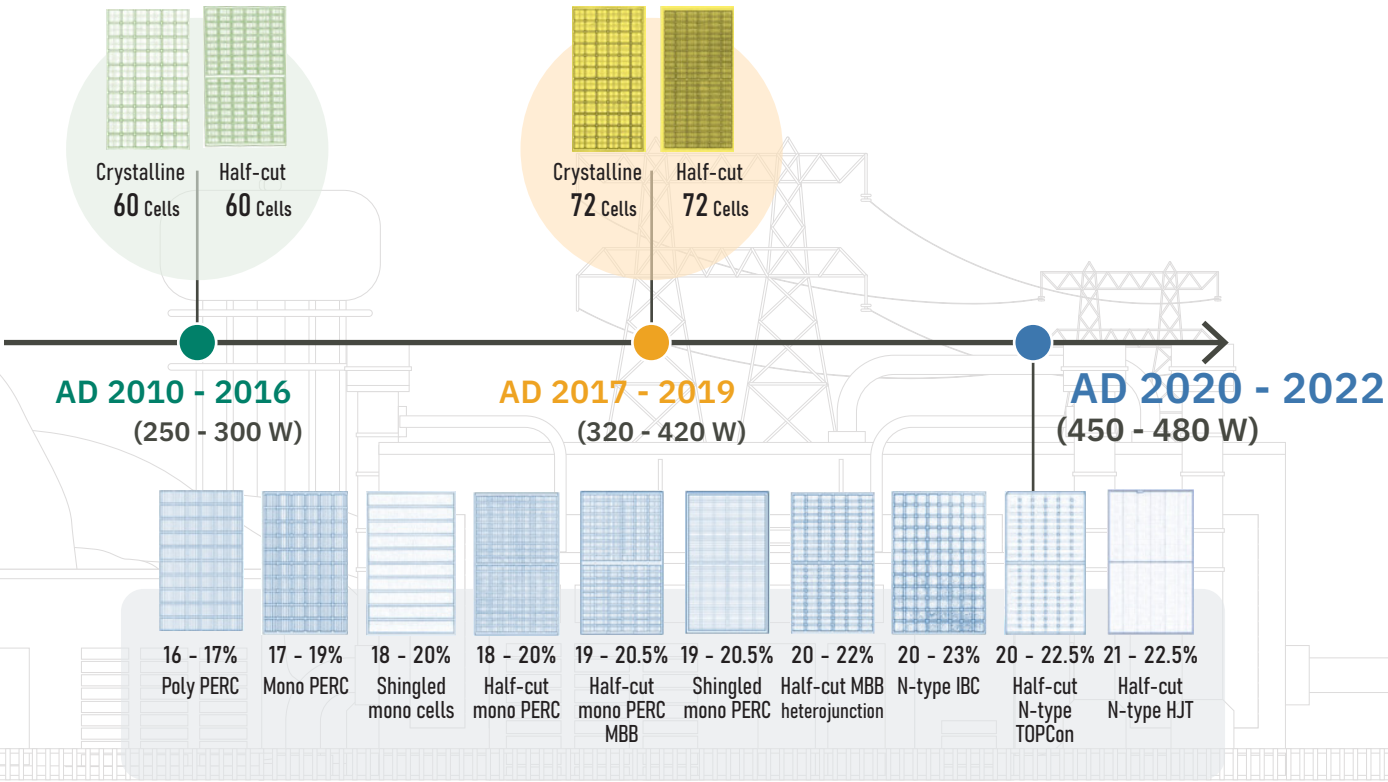


Figure 3.1 The development of PV module technology from 2010 to 2022.

[1] IEA Special Report on Solar PV Global Supply Chain 2022

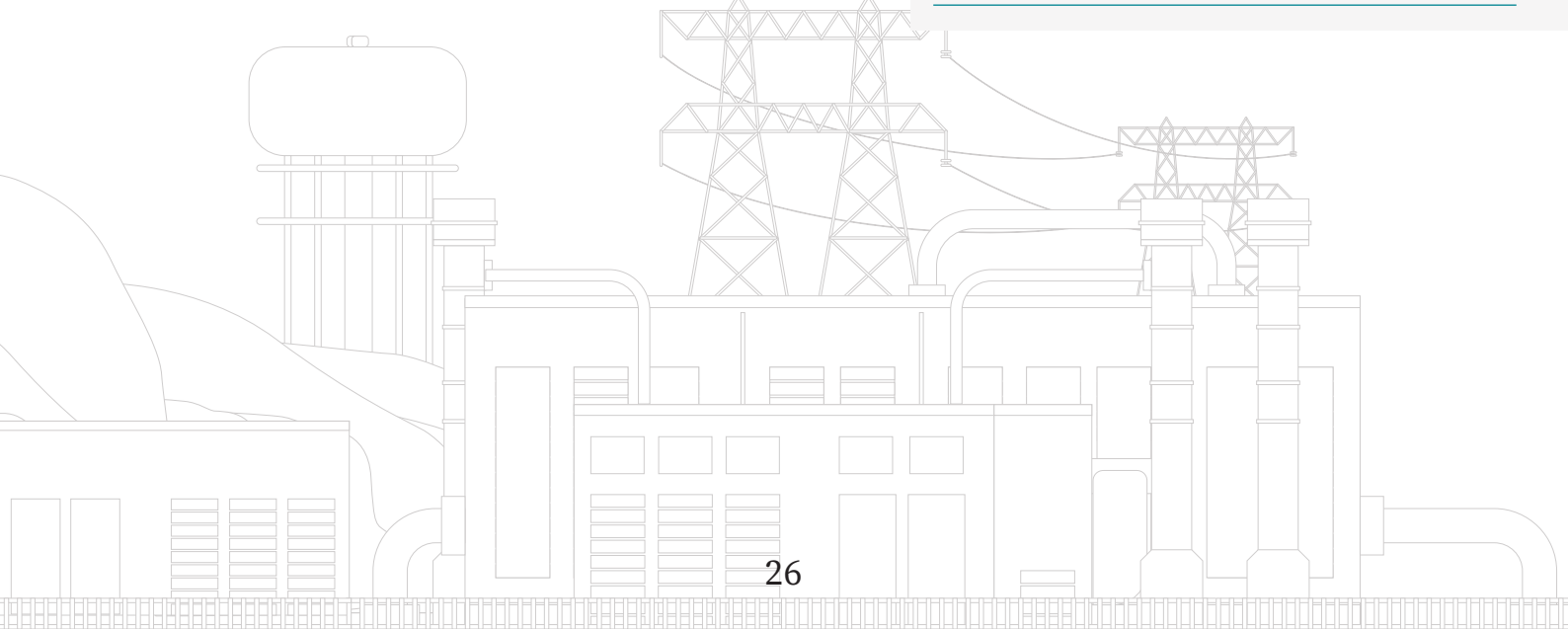
Table 3.1 shows the development of commercial PV module efficiency from 2020 to 2022. New types of PV cells such as half-cut N-type HJT can reach maximum efficiency of 21-22.5% higher than traditional PERC module which possess cell efficiency of around 16-19%.

Table 3.1

Commercial PV technology efficiency during 2020 to 2022.

No.	Technology	Efficiency (%)
1	Poly PERC	16 – 17
2	Mono PERC	17 – 19
3	Shingled mono cells	18 – 20
4	Half-cut mono PERC	
5	Half-cut mono PERC MBB	19 – 20.5
6	Shingled mono PERC	
7	Half-cut MBB heterojunction	20 – 22
8	N-type IBC	20 – 23
9	Half-cut N-type TOP con	20 – 22.5
10	Half-cut N-type HJT	21 – 22.5

Source:
Clean Energy Reviews website, www.cleanenergyreviews.info



3.1.2 Emerging PV technologies in Thailand

Currently, organizations in Thailand are interested in PV cell technology development, particularly in new types like perovskite, which align with global trends. Interested research topics included the study on the property of resistance to environmental factors and humidity, material development to replace glass with flexible materials and electrode materials made from carbon or organic materials, and hybrid PV cell technologies by combining perovskite with traditional silicon technology to create hybridized tandem cells.

National Energy Technology Center (ENTEC), in collaboration with King Mongkut's University of Technology Thonburi, Mahidol University, and Silpakorn University, had pioneered the innovation of the four-terminal perovskite/silicon heterojunction tandem solar cell (4T PSC/SHJ tandem solar cell) with a multi-layer clip-on design. This innovation used perovskite semiconductors and multi-layer silicon that were able to mitigate light attenuation at the top-bottom junction, to disassemble damaged or deteriorated cells.

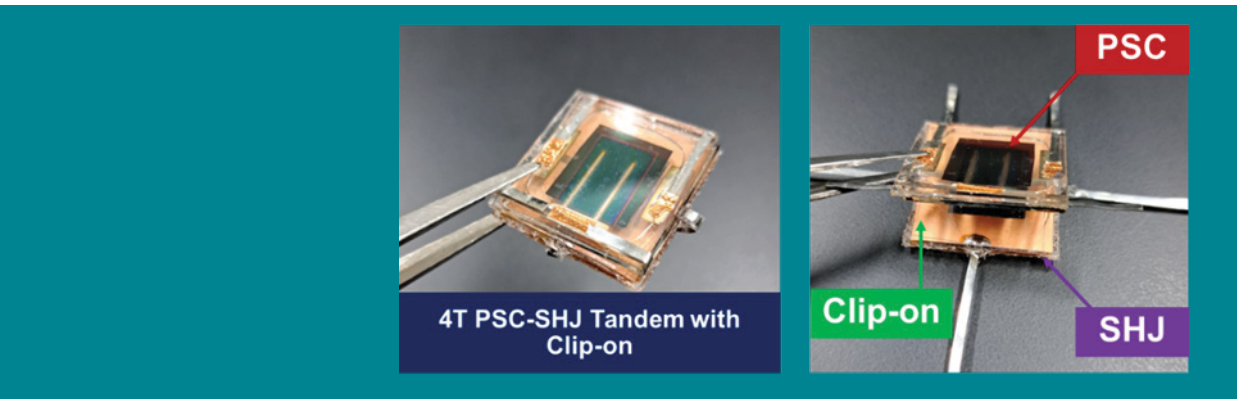


Figure 3.2 **Development of four-terminal perovskite/silicon heterojunction tandem solar cell (4T PSC/SHJ tandem solar cell) by ENTEC, NSTDA.**[2]

[2] Sanglee, K., S. Sakunkaewkasem, C. Piromjit, M. Nukunudompanich, P. Kanjanaboos, S. Chuangchote, S. Suttiruengwong, S. Sahasithiwat, A. Limmanee and T. Krajangsang (2023). "Intermediate matching layer for light-induced performance and removable clip-on applications of four-terminal perovskite/silicon heterojunction tandem solar cells." Solar Energy Materials and Solar Cells 253: 112235

Source:
The National Energy Technology Center (ENTEC) The National Science and Technology Development Agency (NSTDA).

Moreover, the advancement of PV modules for innovative applications, like lightweight PV modules for building-integrated photovoltaic (BIPV) or vehicle integrated photovoltaic (VIPV) systems, and the improvement of PV module transparency with photosynthetically active radiation (PAR) properties for agrivotatic applications, were also prominent areas of research. (Figure 3.3)

Figure 3.3 **Development of lightweight PV module and transparent PV designed to transmit photosynthetically active radiation (PAR), designed for agrivoltaics applications.**

Source:
This data was provided by ENTEC, NSTDA.

3.1.3 Other research direction

Floating PV systems received increased interest during the past few years, particularly in the private sector, aiming to increase system efficiency. Innovations included the development of materials to reduce the temperature effects and studies on rust prevention for floating PV systems.

Research on the recycling of PV modules and their components had garnered interest from various sectors due to the increasing waste from used PV modules. Recycling offered advantages in reducing consumption of natural resources and enhancing the sustainability of energy production. Furthermore, the recycling of PV modules also recovered high-quality silicon for remanufacturing, as well as other materials such as glass and aluminum frames. Additionally, research topic also focused on the development of recycling processes for collecting, sorting, selecting PV modules.

In addition, both government and private sectors were also giving interest in reusing warranty-voided or lowered-efficiency PV modules for other utilization, including businesses focused on reuse and recycling. These efforts supported the development of businesses or investments related to the Bio-Circular-Green Economy (BCG) model for sustainable development.

3.2 Manufacturing of PV module, Balance of Systems, and Battery

3.2.1 PV module manufacturing industries

PV module manufacturers from foreigner countries, including those from China, Singapore, and Taiwan, started operations in 2015, with a combined total capacity of 8,550 MW per year, as detailed in Table 3.2. Meanwhile, Table 3.3 provides information on local manufactures, who have a total capacity of 914.8 MW per year and achieved a total production of 211.8 MW in 2022.

Table 3.2

PV cells and module manufactures in Thailand in 2022 by foreign investors.

No.	Manufacture	Primary investors	Module production capacity: (MW/year)	PV module Technology	Remark
1	CANADIAN SOLAR MANUFACTURING (THAILAND) COMPANY LIMITED	Singapore, China	5,300	Bifac ial N-type TOPCon Mono-facial N-type TOPCon	In 2020
2	GINTECH (THAILAND) LIMITED	Taiwan	1,000	Mono / Poly, Half-cut	In 2018
3	JETION SOLAR (THAILAND) COMPANY LIMITED	China, Thailand	250	Monocrystalline bifacial Monocrystalline module Half-cut, multi-busbar	-
4	TALESUN TECHNOLOGIES (THAILAND) COMPANY LIMITED	China	1,500	Half-cut Mono PERC, bifacial, mono-facial	-
5	TRINA SOLAR SCIENCE & TECHNOLOGY (THAILAND) COMPANY LIMITED	China	500	N-type TOPCon	In 2015
Total			8,550		

Source:
Information from company's website.

Table 3.3

PV cells and module manufactures in Thailand in 2022 by Thai investors.

No.	Manufacture	Production capacity (MW/year)	Annual production (MW/year)	Technology
1	EKARAT SOLAR COMPANY LIMITED	15	4.8	N/A
2	FULL SOLAR COMPANY LIMITED	100	1*	Mono/Poly
3	IRRADIANCE SOLAR COMPANY LIMITED	3	1.5	N/A
4	SOLAR POWER TECHNOLOGY COMPANY LIMITED	2 – 3	1*	440 Wp
5	SOLAR PPM COMPANY LIMITED	94.8*	94.5*	450 – 600 Wp Monofacial & bifacial
6	SOLARTRON PUBLIC COMPANY LIMITED	700	100	N/A
Total		**914.8**	**211.8**	

Remark: *Estimated values

Source:
Information from the company's website and investors.

Inverter manufactures, investors, and battery manufactures in Thailand are illustrated in Tables 3.4 and 3.5, respectively.

Table 3.4 Inverter manufactures in Thailand.

No.	Manufacture	Technology
1	CHUPHOTIC COMPANY LIMITED	Solar Pump Inverter, Stand-alone Inverter, Grid connected Inverter, Hybrid Inverter, Charge Controller
2	DELTA ELECTRONICS (THAILAND) PUBLIC COMPANY LIMITED	Grid connected Inverter, Hybrid Inverter
3	DADDEE POWER GROUP COMPANY LIMITED	Solar Pump Inverter
4	THAI DIAMOND&ZEBRA ELECTRIC COMPANY LIMITED	Stand-alone Inverter, Grid connected Inverter
5	LEONICS COMPANY LIMITED	Solar Pump Inverter, Stand-alone Inverter, Grid connected Inverter, Grid Interactive Inverter, Hybrid Inverter, Charge Controller
6	A.P.Y. ENGINEERING COMPANY LIMITED	Solar Pump Inverter, grid-connected inverter

Source:
Information from the company's website and investors.

Table 3.5

Battery manufactures in Thailand for EV and BESS in 2022.

No.	Manufacture	Location	Production capacity (GWh)	Technology / Annual production (GWh)
1	Amita Technology Thailand (ATT) Affiliated of Energy Absolute Public Company Limited (EA)	Bang Pakong, Chachoengsao	50	Lithium ion Polymer (Taiwan) /1 GWh
2	Global Power Synergy Public Company Limited (GPSC) PTT Group's	Map Ta Phut, Mueang District, Rayong	50	Lithium ion Polymer (Taiwan) /1 GWh
3	Rojana Industrial Park Public Company Limited (55%) and EVLOMO Technologies Company Limited (45%)	EEC Nong Yai District, Chonburi	8	Lithium ion (Korea) /1 GWh

Remark: * Eastern Economic Corridor: EEC, EV = Electric vehicle, BESS = Battery Energy Storage System

Source:
Information from the company's website and investors.

3.2.2 The import and export of PV modules in Thailand.

Figure 3.4 illustrates the import and export trends of PV modules from 2007 to 2021. During the period of government electricity purchasing from 2007 to 2017, the average annual import value was 43.54 million THB. In subsequent period from 2018 to 2021, the average annual import value ranged from 81.95 million THB to 150.49 million THB, due to the increasing installation of PV systems by the industrial sector aiming to reduce electricity costs and support the green electricity consumption scheme.

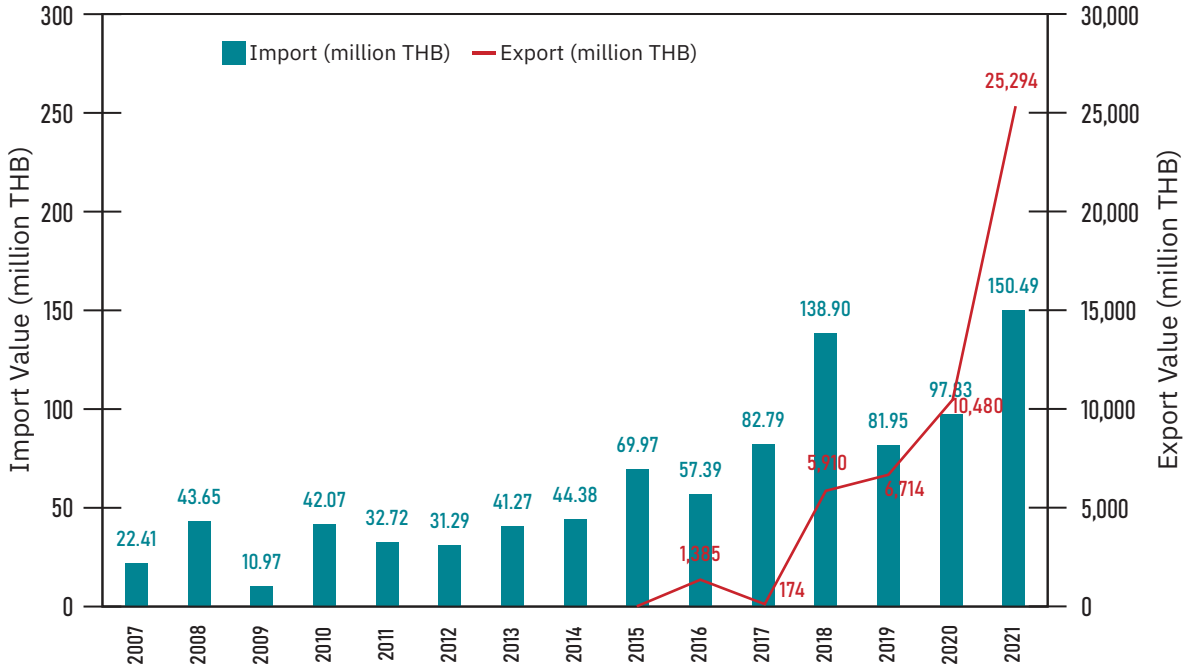


Figure 3.4 Import and Export Trends of PV modules in Thailand. 2007 – 2021.

Source:
Import and export statistic report, 2007 - 2021, Department of Customs.

Since 2015, Thailand has attracted foreigner investments to export PV modules. By 2021, the export value reached 25,294 million THB, reflecting a 58.57% increase compared to the export values in 2020.

Furthermore, after 2010, the price of PV modules was 3-4 USD/W or 95.2 – 126.9 THB/W (exchange rate of 31.73 THB/USD in 2007) and decreased to 0.2 – 0.44 USD/W or 7.3 – 16.04 THB/W in 2022 (exchange rate is 36.46 THB/USD on November 1, 2023), as shown in Figure 2.3, which led to increase installation of PV system globally.

3.2.3 PV modules and photovoltaic system prices

Table 3.6 illustrates the changes in PV module prices in Thailand from 1997 to 2022. Table 3.7 shows PV system prices in Thailand from 1997 to 2022, and Table 3.8. displays the inverter prices in Thailand in 2022.

Table 3.6 The evolution of solar panel prices in Thailand from the year 1997 to 2022.

Year	1997 – 2003	2011	2012	2013	2014	2015	2016	2017	2018	2019 – 2020	2022
Scale of Installation capacity-kW (THB/Wp)	180-200	110*	70-80	50-60	35-50	25-40	16-22	16-20	16-20	13-19	11-14
Scale of Installation capacity-MW (THB/Wp)	-		50-60	35-45	20-25	20-25	15-20	15-17	14-16	8-11	9-10

Remark: * For the system which scale size more than 30 MWp
Mono PERC Half-cut >350 Wp: 9.5 – 11.5 THB/Wp,
Polycrystalline 200 Wp – 350 Wp: 10.6 – 14 THB/Wp

Source:
Manufactures and Investors.

Table 3.7 Trend of PV systems prices for different applications from 1997 to 2022 (Unit: THB/Wp)

Year	1997 – 2003	2011	2012	2013	2014	2015	2016	2017	2018	2019 – 2020	2022
Residential House (≤ 10 kWp)	210-250	200-220	n/a	90-150	65-100	60-100	52-73	51-64	50-55	35-45	33-45
Industry (>10 – 1,000 kWp)	-	-	n/a	90-150	60-65	50-55	43-57	45-54	35-45	25-30	25-27
Solar Farm (> 1,000 kWp)	-	-	110*	60-100	40-60	30-50	42-57	41-48	30-40	20-25	23-24**

Remark: PV System prices exclude land costs.
*For systems larger than 30 MW.
**For floating systems with a capacity of 5–10 MW.

Source:
Manufactures and Investors.

In 2022, the average price of PV modules for residential rooftop applications decreased to 12.5 THB/Wp from 16 THB/Wp in 2019 – 2020, marking a 21.8% decrease, while the price of PV systems was 39 THB/Wp in 2022.

In the commercial and industrial sector, the price of solar PV rooftop system decreased from 27.5 THB/Wp in 2020 to 26 THB/Wp in 2022. For larger PV system exceeding 1,000 kWp, mostly in floating types of 5-10 MWp had an average price of 23.5 THB/Wp of PV system prices.

Commercial inverters in Thailand can be categorized into two types: on-grid inverters and off-grid inverters. On-grid inverter for PV system only had an average costs 3.28 THB/W, whereas a hybrid PV system with other renewable energy sources costs had an average 13.52 THB/W. Price of off-grid inverters also varied upon applications, for example, power generation and water pumping which had average costs of 8.12 THB/W and 10.97 THB/W, respectively.

Table 3.8 Inverter prices in Thailand, 2022

Type of system	Type of inverter	Average Price (THB/W)	Type of system	Type of inverter	Average Price (THB/W)
On-Grid	Grid-connected inverter (PV)	3.28	Off-Grid	Stand-alone inverter	8.12
On-Grid	Grid-connected inverter (Hybrid)	13.52	Off-Grid	Solar pumping inverter	10.97

Source:
Investors

Moreover, additional information about inverters in PV systems registered with the Provincial Electricity Authority (PEA) and the Metropolitan Electricity Authority (MEA) can be obtained by scanning the QR code provided below.

List of Inverters Meeting PEA Criteria

List of Inverters Meeting MEA Testing Requirements

3.2.4 Comparison of PV module price in global market

The main manufactures of PV modules globally were China, Japan, and Germany, who produced silicon-based PV manufacturers during 2010 and 2013, the price of crystalline silicon PV modules decreased from 4.0 USD/Wp to 1.4 USD/Wp for modules from Germany and Japan, and from 3.2 USD/Wp to 0.9 USD/Wp for modules from China. Between 2014 and 2017, modules from China decreased further to 1.0 USD/Wp, while modules from Germany and Japan remained at 1.2 – 1.3 USD/Wp. This trend led to comparable price of module from Germany and China at around 0.6 USD/Wp in 2017.

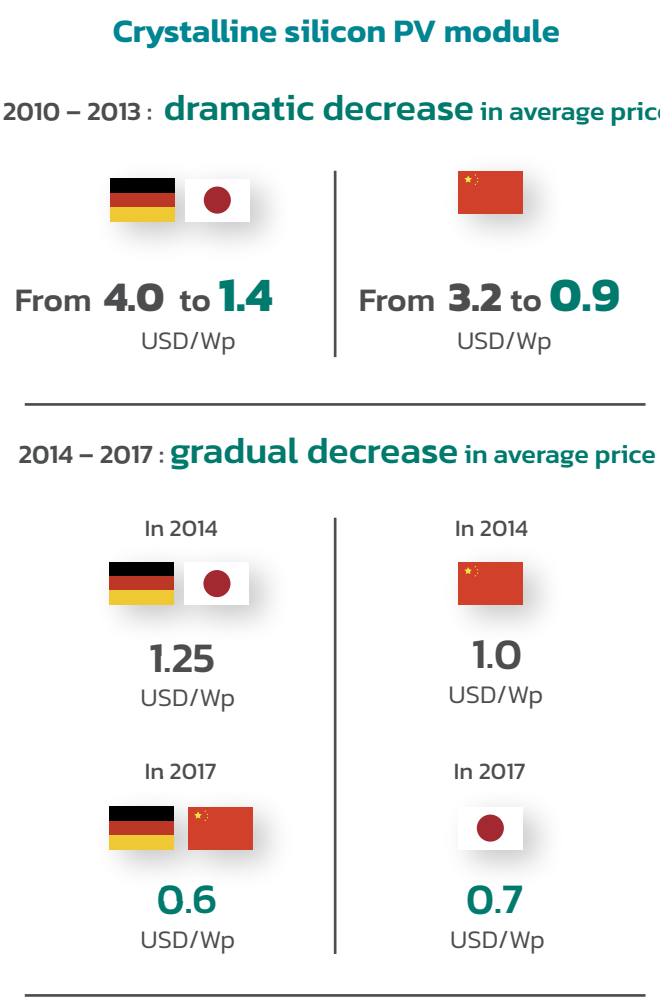


Figure 3.5 PV module price in global market from 2010 to 2022.

Generally, the price of a certain solar PV systems comprises three components:

(1) Equipment, including the module, inverter, battery, and battery controller, supporting structures, wiring, safety devices, and monitoring systems. (2) installation costs, and (3) Operation costs, such as system design costs, license fees, and customer service.

As a result, different countries exhibited varying system prices due to differences in the cost of these components. For example, the high cost of PV systems in Japan was 1.905 USD/Wp, particularly due to the cost of safety components under potential of different natural disasters. In India, the cost of PV systems was 0.64 USD/Wp, with high equipment cost accounting for 50%, of total cost.

In Thailand, the equipment price for PV systems accounts for 16.7% of total system cost of around 0.7 USD/Wp in 2022, which is comparable to China, Australia, and Turkey.

Source:
IRENA (2022), Renewable power generation costs in 2022

3.2.5 Standards and regulations regarding PV market

While the installation of PV system in Thailand was growing, TISI - who was responsible for setting the standard for industrial products had announced and implemented PV-related standards and regulations, to ensure good quality and product safety. Additionally, other agencies also provided standards for PV systems, such as the requirements for grid connected by PEA and MEA and the standards for the installation of rooftop PV systems by the Engineering Institute of Thailand under H.M. The King's Patronage (EIT) to ensure the safety of related personnel.

Table 3.9 Industrial Product Standards of PV modules, inverters, batteries (TIS standard)

Product	TIS	Description
PV module	TIS 2580 - 1-2562	Safety qualification of PV modules for testing codes Part 1: Requirements for construction, according to IEC 61730-1:2016 Ed.2.0
	TIS 2580 - 2-2562	Safety qualification of PV modules for testing codes Part 2: Requirements for testing, according to IEC 61730-2:2016 Ed.2.0
	TIS 61215 - 1-2561	Ground-mounted photovoltaic (PV) modules – Design qualification and type approval - Part 1, testing requirements in compliance with IEC 61215-1:2016 Ed.1.0.
	TIS 61215 - 1(1)-2561	Ground-mounted photovoltaic (PV) modules – Design qualification and type approval - Part 1-1: Specific requirements for testing crystalline silicon photovoltaic (PV) modules in accordance with IEC 61215-1-1:2016 Ed.1.0.
	TIS 61215 - 1(2)-2561	Ground-mounted photovoltaic (PV) modules – design qualification and type approval - Part 1-2: Specific requirements for testing thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules in accordance with IEC 61215-1-2:2016 Ed.1.0.
	TIS 61215 - 1(3)-2561	Ground-mounted photovoltaic (PV) modules – Design qualification and type approval - Part 1-3: Specific requirements for testing thin-film amorphous silicon based photovoltaic (PV) modules in accordance with IEC 61215-1-3:2016 Ed.1.0.
	TIS 61215 - 1(4)-2561	Ground-mounted photovoltaic (PV) modules – design qualification and type approval - Part 1-4: Specific requirements for testing thin-film Copper Indium Gallium Selenide Cu(In,Ga)(S,Se)2 based photovoltaic (PV) modules in accordance with IEC 61215-1-4:2016 Ed.1.0.
	TIS 61215 - 2-2561	Ground-mounted photovoltaic (PV) modules – design specifications and certification - Part 2, testing procedures in compliance with IEC 61215-2:2016 Ed.1.0.

Table 3.9 Industrial Product Standards of PV modules, inverters, batteries (TIS standard)

Product	TIS	Description
Grid-connected Inverter	TIS 2603 - 1-2556	Safety of power converters for use in photovoltaic power systems, Part 1 General requirements, in accordance with IEC 62109-1 Ed.1.0 2010-04: Part 1.
	TIS 2603 - 2-2556	Safety of power converters for use in photovoltaic power systems, Part 2 Particular requirements for inverters, in accordance with IEC 62109-1 Ed.1.0 2010-04: Part 2.
	TIS 2606-2557	Photovoltaic (PV) systems – Characteristics of the utility interface in accordance with IEC 61727 Ed.2.0 2004-12.
	TIS 2607-2557	Utility-interconnected photovoltaic inverters – Test procedure of islanding prevention measures in accordance with IEC 62116 Ed.1.0 2008-09.
Battery	TIS 2218-2548	- Cells and secondary batteries with alkaline electrolyte or non-acidic electrolytes - Cells and secondary batteries based on lithium for portable applications.
	TIS 718-2530	Stationary lead-acid storage batteries.
	TIS 61427 - 1-2566, effective date: August 9, 2023.	Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid application. Conformity testing in accordance with IEC 61427-1:2013-04.
	TIS 61427 - 2-2566, effective date: August 9, 2023.	Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 2: On-grid applications. Conformity testing in accordance with IEC 61427-2:2015-08.
PV systems	TIS 2572-2555	Electrical installations – Photovoltaic (PV) power supply systems in accordance with IEC 60364-7-712:2017.
	TIS 62124-2566, effective date: May 29, 2023.	Stand-alone photovoltaic (PV) systems – Design verification in accordance with IEC 62124:2004.
	TIS 61724 Part 1-2563	Photovoltaic system performance – Part 1: Monitoring in accordance with IEC 61724-1:2017
	TIS 61724 Part 2-2565	Photovoltaic system performance – Part 2: Capacity evaluation method in accordance with IEC TS 61724-2:2016
	TIS 61724 Part 3-2565	Photovoltaic system performance – Part 3: Energy evaluation method in accordance with IEC TS 61724-3:2016

Source:
Buyer Guide, on TISI website

Table 3.10 Regulation of grid-connected PV systems

Product	Regulations	Harmonization Standard
Grid-connected inverter	MEA regulation of grid connection 2015	IEEE1547.1-2005, IEC62116-2008, IEC61000-3-3, IEC61000-3-5, IEC61000-3-11
	PEA regulation of grid connection 2016	IEEE1547.1, IEC62116, IEC61000-3- 3, IEC61000-3-5, IEC61000-3-11, IEC TS 62910

Source:
MEA and PEA

Table 3.11 Standard by the Committee on Electrical Installation Standards for Thailand, Engineering Institute of Thailand under Royal Patronage (EIT).

Product	Standard	Code of Standard
PV system installation	Standard for the installation of solar power generation systems installed on rooftops, B.E. 2559.	EE 022013-59
	Electrical installation standard for Thailand: Solar power generation systems installed on rooftops, B.E. 2565.	EIT Standard 022013-22

Source:
Engineering Institute of Thailand under Royal Patronage (EIT).

3.3 PV and circular economy

It is possible to categorize PV system utilization into those who use power produced from the system directly, such as to sell to utility via PPA or to sell to the customer directly, who usually required high efficient PV modules for better investment returns and those who use power produced from the system to support their activities, such as for agricultures and rural lighting, who may not requires such high efficient PV modules.

Currently, many countries offer the option of using PV modules for sale in the secondary PV market. Thailand is interested in the business model of used PV modules because of several benefits, such as supporting the circular economy, adding value to used PV modules, reducing costs, and minimizing the environmental impact of waste from used PV modules. Moreover, damaged PV modules and end-of-life PV modules can be processed in recycling facilities to recover useful materials, providing raw materials for other manufacturers.

In addition, due to continuous promotion of solar power generation, Thailand had the potential of Thailand circular economy of PV modules. Many agencies interested in this business model began to implement prototype management processes for PV modules, such as the National Energy Technology Center (ENTEC) of NSTDA. (Figure 3.6)

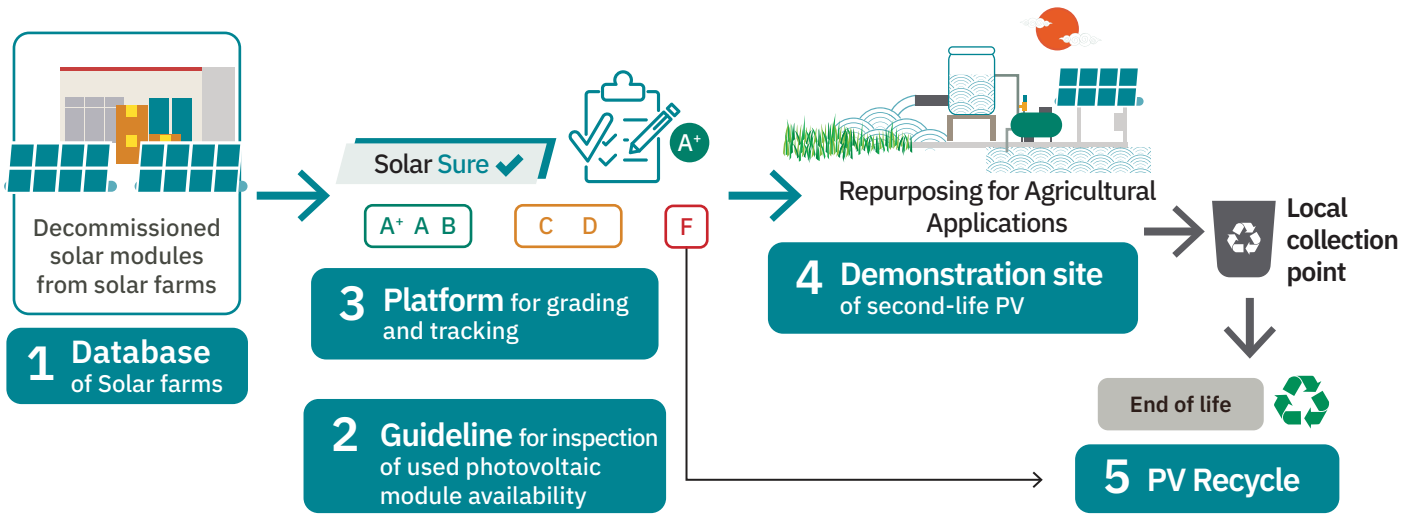


Figure 3.6 Prototype management processes for PV modules by the National Energy Technology Center (ENTEC) of NSTDA.

Source:
This data provided by ENTEC, NSTDA

3.3.1 Management guidelines for second-life of PV modules

ENTEC, under NSTDA, had implemented management guidelines for used PV modules as followed:

1) Development of solar power plant database for example of required data included licensee name, business name, location (province, district, sub-district, postal code, latitude, and longitude), Commercial Operation Date (COD), generating capacity (MW), PV module technology, manufacturer, power output (W), number of PV modules, COD year, and lifetime, etc. This was to forecast the amount and timeframe for decommissioning during various periods.

2) Development of guidelines for assessing the readiness for reuse of PV modules. This was intended to serve as a practical framework for sorting the proper PV module for reuse and for disposal processes.

3) Development of an application and data management system for used PV modules, namely SolarSure. This system was capable of processing and recording decommissioned modules, including features for generating inspection labels to facilitate tracking of modules. This system was useful in the collection process when modules reach the end of their lifetime, requiring either disposal or future recycling.

4) Demonstration of the second life application of PV modules in agriculture by NSTDA in collaboration with the Department of Industrial Works, Ministry of Industry. The project involved decommissioned PV modules from solar farms, selecting those with a performance capacity of no less than 70%. These selected PV modules were repurposed for use in small-scale off-grid systems, such as solar water pumps and electric charging stations. The pilot system was installed at Valaya Alongkorn Rajabhat University under royal patronage, Pathum Thani Province, with an overall capacity of approximately 10 kWp. PV module with low performance or those that did not pass safety tests are utilized for demonstration. Moreover, upcycled products from recycle PV material were studied to understand the advantages, disadvantages, cost-effectiveness, and various impacts resulting from the second life approach.

Moreover, Department of Primary Industries and Mines (DPIM) had developed a complete recycling process for waste PV modules project using mineral and metal dressing method, which was in Pra Phadaeng. The product of recycling process included glass, mixed silicon silver copper aluminum. The project focused on implementing the equipment and machines for sorting PV module waste which included broken glass, conductive wire, and pieces of silicon. The plant was expected to be operational by the end of 2022.

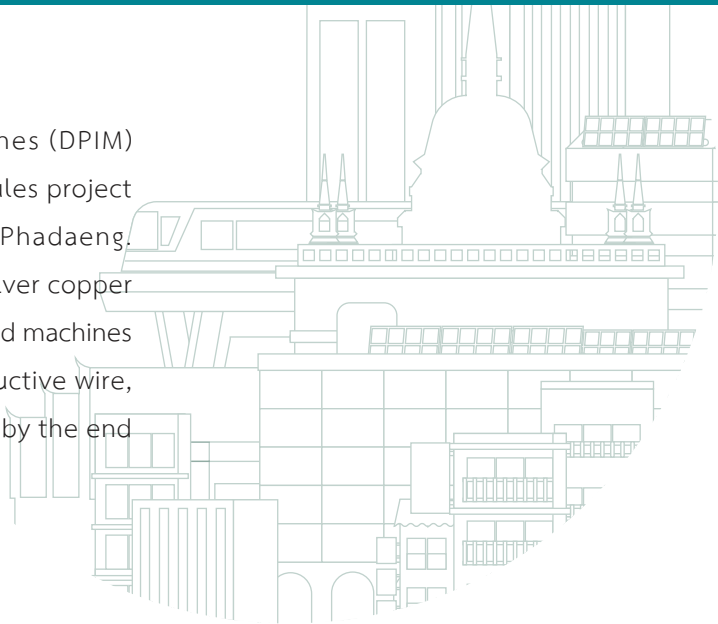


Figure 3.7
Full-service recycling process for waste PV modules by Department of Primary Industries and Mines (DPIM).

Source:
This data provided by ENTEC, NSTDA

3.3.2 Carbon market and carbon credit certification mechanism

Carbon credit verification and certification are essential tools that help the management of CO_2 emission. This was operated by Thailand Greenhous Gas Management Organization (TGO) which is an agency that certifies and controls the registry system in Thailand.

Carbon credit represents a reduction in greenhouse gas emissions (measured in units of carbon dioxide equivalent) achieved through projects that reduce emissions, using various mechanisms both domestically and internationally.

Figure 3.8 Mechanisms for managing carbon credits operations by the Thailand Greenhouse Gas Management Organization (TGO).

Source:
The Federation of Thai Industries (FTI)

Guidelines and operational mechanisms for carbon credit management was approved by the National Climate Change Policy Committee, Office of Natural Resources and Environmental Policy and Planning, with two primary objectives for the purchase and utilization of carbon credits.

1) Domestic objectives involve, which utilized carbon credit to verify or receive benefits from certain government projects that have specific conditions or criteria related to greenhouse gas management.

2) International objectives, which involve using carbon credits from projects located in Thailand to demonstrate project progress or achievement of greenhouse gas reduction targets for the country or other entities under international agreements or agreements by which Thailand is a party or activities that were carried out according to Thailand's national practices and were subjected to authorization in accordance with the provisions of the Paris Agreement, Article 6.3.

Carbon credits in Thailand are voluntary carbon market, which differed from the mandatory carbon markets in Europe, China, and Korea. Purchases of carbon credits must be certified according to the Thailand Voluntary Emissions Reduction (T-VER), which was Thai standard for green house gas emissions, facilitating over the counter (OTC) or direct negotiations between buyers and sellers. Applicants were needed to register with the Thailand Greenhouse Gas Management Organization (TGO) to use carbon credit to offset greenhouse gas emissions. Moreover, the renewable energy and carbon credit exchange platform (Figure 3.9), named FTIX, was developed by the Federation of Thai Industries (FTI) and Alliance. This platform served as an exchange center for carbon credits and Renewable Energy Certificate (REC).

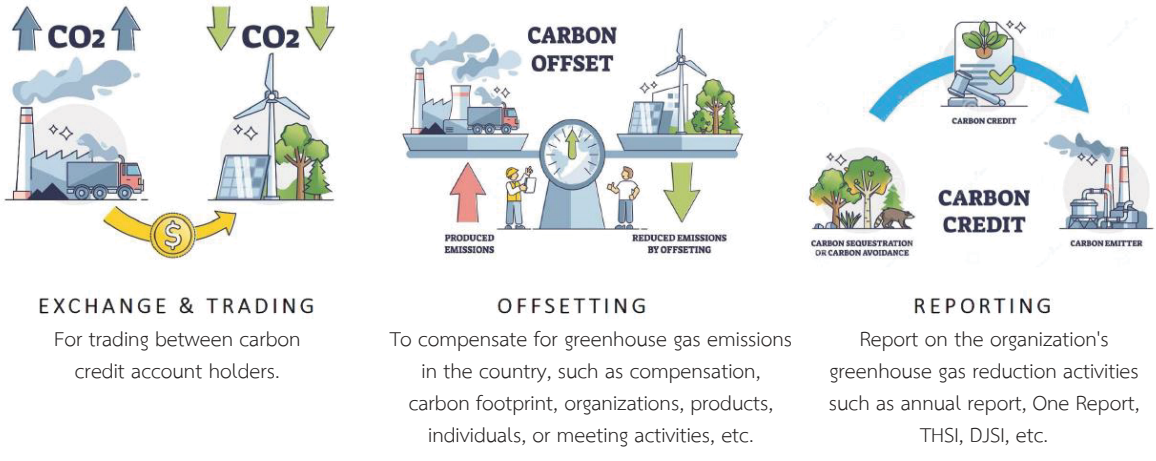


Figure 3.9 Renewable Energy & Carbon Credit Exchange Platform

Source:
https://www.fti-cc.com/market, FTI

In addition to T-VER and the carbon trading platform, the trading of Renewable Energy Certificates (REC) had been developed to verify electricity generated from reliable renewable energy sources. One REC is equivalent to 1 megawatt-hour (MWh). The trading of REC must complied with global standards for energy attribute certification (EAC), which has 3 types in the present as follows:

1. US Renewable Energy Certificate Schemes (US RECs)
2. European Energy Certificate System – Guarantee of Origin (EECS-GO)
3. International REC Standard (I-REC) which is currently using in which EGAT provided certification of REC under I-REC authorization.

REC can be traded in Thailand via different channels:

1) The Carbon Markets Club (CMC), which is a network that supports the trading of carbon credits and REC through an over the counter (OTC) system. For generation of electricity from renewable source for injecting to the utility grid. There was planning to transform into a digital platform to register and provide certification services in the near future.
2) ReAcc, which is a platform developed by PTT to facilitate clean energy trading, including the trading of REC and electricity purchases through corporate power purchase agreements (CPPA).GreenLink
3) GreenLink Marketplace, which is a platform developed by EGAT to serve as a centralized marketplace for trading Renewable Energy Certificates (REC). Power producers from various renewable energy projects can exhibited their projects on the online marketplace, allowing potential buyers to browse, purchase, and negotiate REC transactions independently.
4) Gideon, which is a platform developed by Blockfint Co. Ltd. for the exchange of carbon credits for Thai Carbon Neutral Network (TCNN), which aims to support REC trading in the near future.

3.3.3 Carbon emissions from electricity generation

Emission Factor[2] is the rate of greenhouse gas emissions per unit of activity or output/input of a system or considered boundary. For instance, a specific fossil power plant has a CO_2 emission factor of 0.7650 kg/kWh, indicating that for every 1 kWh of electricity generated, 0.765 kg of CO_2 is emitted. Moreover, it is essential to define that a captive power plants were those who produce electricity for their own consumption without injecting electricity to the utility grid.

The calculation of greenhouse gas emissions from electrical energy production can be classified as follows:

1. Categorized by electricity generation type.

1.1 Generation of electricity from renewable sources for injecting to the utility grid (to replace electricity production from conventional sources).

[2] Source: Calculation for Emission Factor of Electricity Generation and Electricity Consumption Issued No. 3, Thailand Greenhouse Gas Management Organization (Public Organization)

1.2 Generation of electricity from renewable sources for self-consumption, which can be as follows:

(1.2.1) Electricity purchasing from utilities grid.

(1.2.2) Electricity purchasing from other power producer or other captive power plant but not through the utility grid, for example power plant in industrial estates.

(1.2.3) Use of fossil fuels in machinery/equipment, such as the use of diesel in water pumping systems.

(1.2.4) Solar lighting

Furthermore, calculations of greenhouse gas emissions depend on electricity generation types. For generation of electricity from renewable sources for injecting to the utility grid, greenhouse gas emission can be calculated as follows[3]:

Quantity of greenhouse gas emissions (kgCO2eq) = A – B

Where:

A refers to the amount of greenhouse gas emissions from the base case ($kgCO_2eq$) from EG x EFgrid

Or in the case of generating electricity from PV systems =
(Maximum power of PV module / 1,000) x Number of PV module x Hour of solar radiation for electricity generation x EF_{grid}

B refers to the amount of greenhouse gas emissions from the project ($kgCO_2eq$) from
(EC x EFelec) + (FC x NCV x EF_{fuel})

However, for generation of electricity from renewable sources for self-consumption would be similar in principle with the aforementioned method but differed in activities details.

Factor	Description	Unit	Value	Measured Source
EG	Electricity generation	kWh	Record	Meter, Bills, Monitoring data, Name plate
EC	Electricity consumption from utility grid	kWh	Record	Meter, Bills, Monitoring data, Name plate
FC	Fuel consumption	Liter or Ton	Record	Meter, Bill of fuel
EF_{grid}	Greenhouse gas emission value from electricity generation	$kgCO_2eq/kWh$	0.5251	Greenhouse gas emission report, latest edition by TGO
EF_{elec}	Greenhouse gas emission value from electricity consumption from utility grid	$kgCO_2eq/kWh$	0.4857	Greenhouse gas emission report, latest edition by TGO
h	Average hour of solar radiation for electricity generation per day	Hour/day	4.00	DEDE

[3] Source: https://ghgreduction.tgo.or.th/th/calculation/less-calculate-document/less-energy.html

Fuel properties for electricity generation.

Fuel type	NCV	EF_{fuel}	$= NCV*EF_{fuel}$
	Net Calorific Value	Greenhouse Gas Emission Factor	
Unit	MJ/Unit	$kgCO_2eq/MJ$	$kgCO_2eq/kWh$
Natural gas (cubic foot)	1.02	0.0561	0.0572
Liquid petroleum (liter)	26.62	0.0631	1.6797
Gasoline (liter)	31.48	0.0693	2.1816
Diesel fuel (liter)	36.42	0.0741	2.6987
Gasohol 91 (liter)	31.48	0.0624	1.9634
Gasohol 95 (liter)	31.48	0.0624	1.9634
E20 (liter)	31.48	0.0554	1.7453
E85 (liter)	31.48	0.0104	0.3272
Diesel B7 (liter)	36.42	0.0689	2.5098
Diesel B10 (liter)	36.42	0.0667	2.4288

2. Categorized by the electricity consumption type.

1) Self-consumption power plant or captive power plant: the greenhouse gas emissions of power consumption were equal to the value of greenhouse gas emissions from captive power generation. If there were power purchase from utility grid, it would be needed to consider additional greenhouse gas emissions from transmission line, heat generated for the project and activities, according to TGO announcement.

2) Electricity consumer of captive power plant: greenhouse gas emission from this consumption was needed to the power losses from transmission and distribution lines, caused by distance between generation and users. Those who purchase electricity from both captive power plant and utility grid were needed to calculate the greenhouse gas emissions by energy consumption, transmission losses, and heat generation for projects and activities according to the TGO announcement, which can be divided into three groups.

Case 2.1: Electricity consumption data can be categorized by source of electricity generation.

Case 2.2: Electricity consumption data cannot be identified by the source of electricity generation. Greenhouse gas emissions will be calculated using the ratio of releases gas.

Case 2.3: Unable to provide information from Case 2.1 and Case 2.2. Therefore, the conservative-based would be used by choosing minimal EF from the similar type of registered power plant in T-VER.

The emission factor[4] for electricity generation in the industrial sector, as specified by the TGO, is 0.5986 kgCO_2eq/kWh.

QR code for the Emission Factor refers categorized by industries according to the publication on the TGO website, as of July 2022.

3.3.4 CBAM and the provision of green electricity

Due to global climate variation Carbon Border Adjustment Mechanism (CBAM), which was a concept of managing taxes on greenhouse gas emissions from certain products imported into Europe, was enacted to discourage production that causes greenhouse gas emissions in accordance with international commitments to reduce global warming. As a result, the demand for electricity production from renewable sources were expected to be significantly increased, especially in industrial export and foreign investors. This was particularly due to some products with high greenhouse gas emissions contents or from their industrial processes that consume large amounts of fossil fuels, leading to high CO_2 emissions.

Updated version of CBAM that will be enacted in 2027 includes a list of products such as cement, iron, and steel, aluminum, fertilizer, electricity (including hydrogen-chemical products), and plastic. And will be expanded to cover every product under the European Union Trading Scheme (EU ETS), including glass, ceramics, and paper. This implied that manufacturers in Europe as well as EU product importers will share equivalent contribution in carbon emissions cost.

For Thailand export situation to EU, it was found that Thailand contributed around 0.41% of products listed in EU ETS. Effects of CBAM was forecasted to pose around 0.07% and 0.27% effect, respectively. Additionally, the taxes imposed by CBAM will be calculated based on direct carbon emissions (Scope 1 emissions) and indirect emissions from electricity generation sources (Scope 2 emissions).

[4] Source: https://thaicarbonlabel.tgo.or.th/admin/uploadfiles/emission/

Draft CBAM in 2027

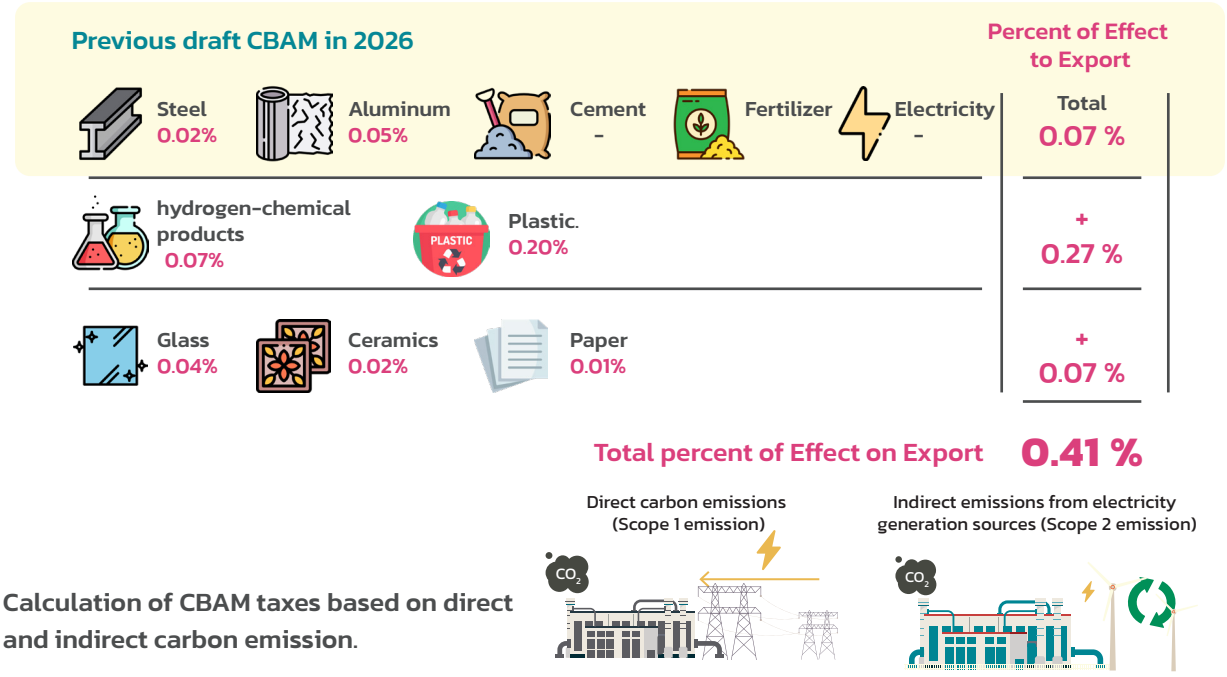
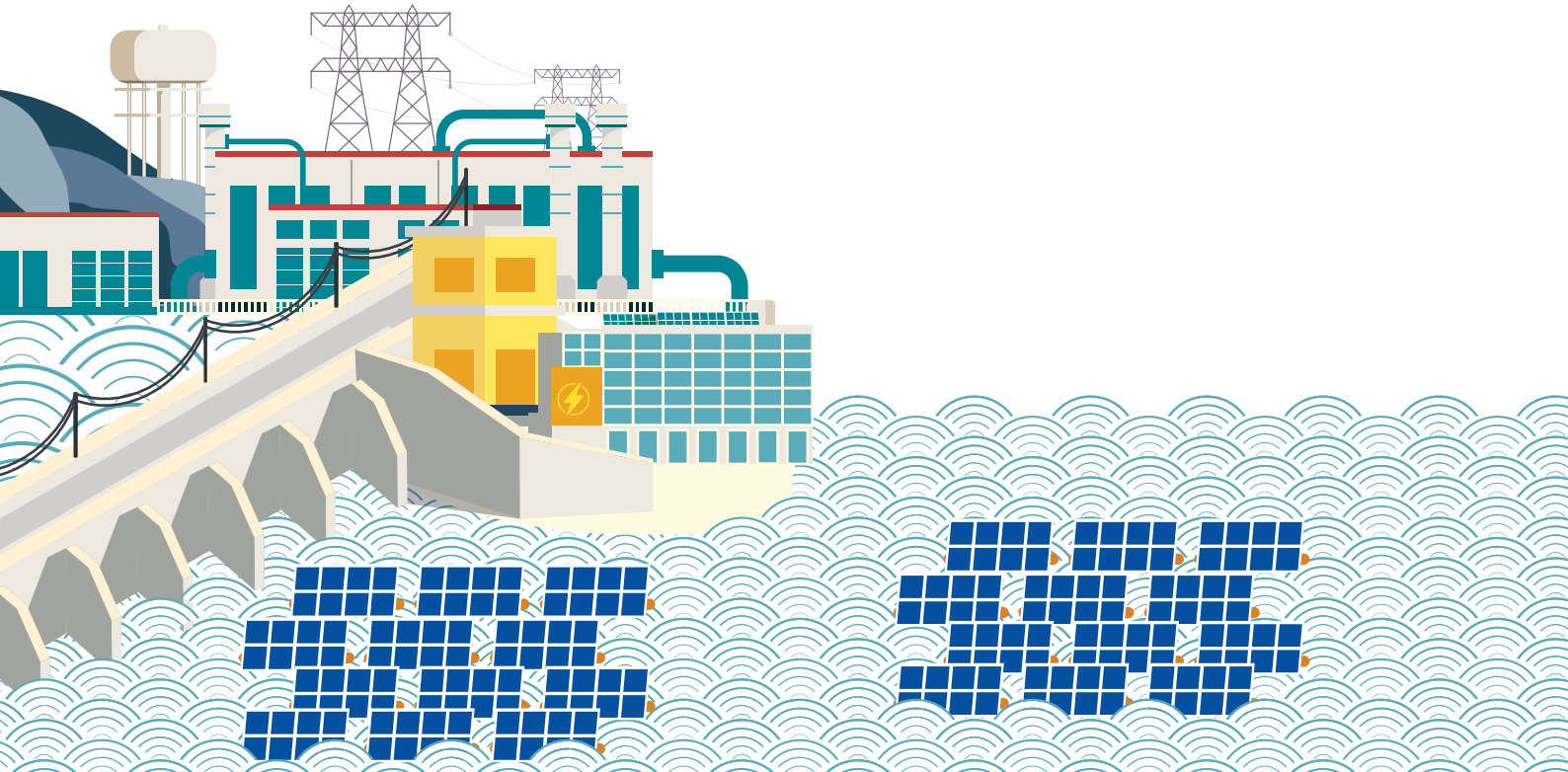


Figure 3.10 Draft CBAM expected to be enforced in 2027.

Source:

Pitchayut Rerksupasompon, "An important step for CBAM, the EU's weapon in solving global warming problems with its impacts," Column "Jang Si Bia," bangkokbiznews, Issue 17/2022, 13 September 2022, Bank of Thailand

Additionally, the National Energy Policy Council had approved the Utility Green Tariff approach for retail electricity tariff structure to provide concrete support for clean energy consumption. More details are provided in Chapter 5.



PV Energy Policy, Promotion, and Support Measures

4

According to continuous increase of greenhouse gas emissions and climate change situation, Thailand had pledged the intention to become carbon neutral by 2050 and net zero emission by 2065 in COP26 meeting in Glasglow in 2021.

All countries, including Thailand, emphasized the need to support more consumption of renewable energy, particularly solar PV systems, to replace fossil fuel consumption for electricity generation and achieve such committed targets.

4.1 National Energy Plan: NEP

The National Energy Policy Council (NEPC) approved the framework of the National Energy Plan (NEP) to support Thailand's transition to clean energy and reduce CO_2 emissions, to enhance the competitiveness of Thai businesses and attract investments, and to leverage investments in new innovations to enhance economic value. The policy directions to promote these operations are as follows:

- Increase the share of new electricity production with a renewable energy proportion of not less than 50%, considering integration with long-term energy storage systems.
- Transition from conventional transportation energy to green electricity through Electric Vehicles (EV) promotion and enhancing energy efficiency in the transportation sector.
- Improve energy efficiency by more than 30% through the implementation of new energy management technologies and innovations.
- Adjust the energy business structure to align with the trends of energy transition following the 4D1E approach. (Digitalization, Decarbonization, Decentralization, De-regulation, and Electrification)

To ensure energy transition according to 4D1E policy direction, Ministry of Energy, through the Energy Policy and Planning Office (EPPO), is currently in the process of finalizing the details of NEP which will drive country toward net zero emission in different aspects as follows:

Electricity:

Increase the proportion of renewable and clean energy from new power plants, with a minimum share of renewable energy not less than 50%, reduce the use of fossil fuels, develop technologies for carbon capture, promote the use of electric vehicles, enhance the infrastructure for grid modernization to support decentralized power generation. This would be implemented along with the development of a flexible energy management system and promote market competition and future trade opportunity.

Natural Gas:

Efficiently manage domestic natural gas supply and imports, promote LNG consumption in the industrial sector, develop infrastructure, and liberalize natural gas market to enhance market competition and increase overall efficiency of the system.

Oil:

Upgrade oil refinery standards to meet Euro 5 and Euro 6 equivalence, promote the use of biofuels in transportation in an appropriate proportion, develop monitoring and data collection systems for fuel, and encourage the transition from conventional fuel to electricity.

Renewable Energy and Energy Conservation:

Promote the production and consumption of renewable energy and enhance energy efficiency across all sectors.

4.2 Implementation of Alternative Energy Development Plan

Thailand had implemented renewable energy development policy according to the Alternative Energy Development Plan (AEDP) along with Energy Efficiency Plan (EEP) and Power Development Plan (PDP). These plans aim to develop and apply technologies for secure and sustainable energy generation, enhance energy reliability and in accordance with Thailand's economic and social growth.

Alternative Energy Development Plan 2018 (AEDP2018), from 2018 to 2037, aimed to increase the share of renewable and alternative energy in the final energy consumption to 30% by 2037. The targets include integrating renewable energy into electricity generation, heat energy production, and fuels usage in the transportation sector.

The AEDP2018 plan has set a target of total renewable energy generation of 29,411 MW by 2037, which accounted for approximately 34.23% of the overall electricity consumption. For solar power generation, the target was to achieve 12,139 MW of total electricity generation from solar PV by 2037. It should be noted that the target according to AEDP target were the on-grid with PPA solar power plant that already COD. As of 2022, the cumulative installed capacity was 3,135 MW, with 45 MW generated from floating solar systems (Table 4.1).

Table 4.1 AEDP2018 plan targets renewable and alternative energy for the years 2018 to 2037, with performance results for 2019 to 2022.

Renewable energy	Target of AEDP2018 in 2037* (MW)	Project results (MW)			
		2020	2021	2022	Progress Percentage
1. Solar PV	12,139	2,982	3,015	3,135	25.83
2. Biomass	5,790	3,517	3,646	3,765	65.03
3. Wind energy	2,989	1,506	1,545	1,545	51.69
4. Hydropower	2,920	2,919	2,918	2,918	99.93
5. Floating PV system and hydropower	2,725	-	45	45	1.65
6. Biogas (wastewater/solid waste/energy crop)	1,565	382	635	652	41.66
7. Community solid waste	900	333**	389	371	41.22
8. Small hydropower	308	239	192	192	62.34
9. Industrial solid waste	75	-	-	34	45.33
Total	**29,411**	**11,878**	**12,385**	**12,657**	**43.03**

Remark: * From AEDP2018, the figures represent contracted capacity that already COD only and do not include Independent Power Supply (IPS).

** In 2020, electricity production from waste energy included both community waste and industrial waste.

Source:
DEDE, the proportion of renewable energy consumption in May 2023, AEDP2018.

In 2022, the NEPC resolution had approved the plan to increase electricity production from renewable energy under PDP2018 Rev.1 for 2021-2030. As a result, ERC has invited bids for the purchase of electricity from various renewable energy sources in the Feed-in Tariff (FiT) scheme, including the ground-mounted solar energy (solar farms) installations for the years 2022-2030. The target of 2,368 MW for purchasing electricity from solar farms was targeted at first. Furthermore, follow the NEPC resolution in March 2023, the ERC had approved additional 2,362 MWp of solar farm installation for 2021-2030, bringing the total installation target to 5,000 MW (Figure 4.1).

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Solar PV	45	10	34	300	400	898	800	1,300	1,600	1,700	7,087
Solar Rooftop (Residential)		10	10	10	10	10	10	10	10	10	90
Solar Floating	45		24			298	50		280	300	997
Solar Farm + BESS				100	100	100	100	200	200	200	1,000
Solar Farm				190	290	490	640	1,090	1,110	1,190	5,000
Wind					250	250	250	450	650	650	2,500
Biogas						106.5	100				206.5
Biomass						150	150	90			390
MSW					200	200					400
Industrial waste						130	70				200
Import						469				1,400	1,869
Small Hydro		10.81	4.14	1.27	9.84	5.25	5.05	6.51	3.45	5.18	51.5
Total	45	20.81	38.14	301.27	859.84	2,208.75	1,375.05	1,846.51	2,253.45	3,755.18	12,704

Figure 4.1 Clean Electricity Generation Increment Plan under the PDP2018 Revision 1.

Source:
National Energy Policy Council (NEPC) resolution on May 6, 2022, and the NEPC resolution on March 9, 2023, announced the purchase of electricity from renewable energy sources, including non-fuel and industrial waste, through the Feed-in Tariff scheme for 2022 - 2030.

Additionally, the plan also included the installation target of 90 MWp solar rooftop for residential sector, 997 MW of floating solar, and 1,000 MWp of solar ground-mounted with BESS. The evolution of solar energy promotion goals in Thailand, as outlined in the Alternative Energy Development Plan (AEDP) since 2008, was illustrated in Figure 4.2.

REDP	AEDP	AEDP2015	AEDP2018	AEDP
15-year the Renewable Energy Development Plan	Alternative Energy Development Plan targets 25% of final consumption in a 10-year period.	Alternative Energy Development Plan	Alternative Energy Development Plan	Alternative Energy Development Plan
From 2008 to 2022	From 2012 to 2021	from 2015 to 2036	from 2018 to 2037	from 2023 to 2037 (tentative).
Target of renewable energy consumption to final energy consumption:				
20%	25%	30%	30%	In progress
Target of solar energy				
2008: 500 MW	2012: 2,000 MW 2013: 3,000 MW	2015: 6,000 MW	2018: 12,139 MW	In progress

Figure 4.2
Evolution of the Alternative Energy Development Plan (AEDP) in the period from 2008 to 2022.

Source:
Alternative Energy Development Plan (AEDP), AEDP2015 and AEDP2018, DEDE.

Remark: REDP refers to the Renewable Energy Development Plan, which was replaced by AEDP in 2012.

4.3 Government policy to promote electricity generation from solar PV

Currently, the government put strong effort in transitioning from conventional to cleaner energy policies and measures to promote PV systems applications. These include rooftop PV systems for residential use, targeted electricity production from renewable energy promotion project, floating PV systems, business models for PV systems on islands, a utility green tariff scheme, PV generation with energy storage systems (including battery energy storage systems), and the recycling of PV modules. Additionally, there are interests in developing businesses regarding Thailand's environmental considerations, as outlined in the Thailand Taxonomy, which will be discussed in Chapter 5.

4.4 Measures to promote investment in PV industry by BOI

The Board of Investment of Thailand (BOI), who was responsible for promoting investment from both domestic and international aspect, had implemented measures to promote investment in the PV system industry, which can be categorized into three groups:

- **Group 1** Manufacturing parts or equipment for solar PV systems.
- **Group 2** Generation of electricity from solar energy.
- **Group 3** Improvement of efficiency of renewable energy utilization.

Different incentive schemes under BOI can be categorized as follows:

A1: Knowledge-based industries focus on design, research, and development to enhance the country's competitiveness.
Corporate income tax exemptions for 8 years without specifying the proportion of corporate income tax exemptions.

A2: Infrastructure development businesses for the country and high-tech businesses that generate added value with minimal or no investment in the country.
Corporate income tax exemption for 8 years with a specified exemption rate of 100% of the investment, excluding land and working capital, increased to 200% for SMEs.

A3: Businesses that utilize advanced technology and are important to the development of Thailand, with minimal production bases.
Corporate income tax exemption for 5 years with a specified exemption rate of 100% of the investment, excluding land and working capital, increased to 200% for SMEs.

A4: Businesses with technology levels below A1-A3 but contribute to adding value to raw materials in the country and enhancing the supply chain.
Corporate income tax exemption for 5 years with a specified exemption rate of 100% of the investment, excluding land and working capital, increased to 200% for SMEs.

Groups A1-A4 are entitled to the following benefits:

- Exemption of import duties on new machinery throughout the promoted period.
- Exemption of import duties on raw materials used in R&D or essential materials used in the production for export.
- Non-tax incentives: Permit to own land. Permit to bring into the Kingdom skilled workers and exports to work in investments promoted activities, Pemit for foreign nationals to enter the Kingdom for the purpose of studying investment opportunities, permit to take out or remit money abroad in foreign currency.

Table 4.2 Promotion of investments in the solar energy industry by the Board of Investment (BOI).

Activities	Group 1	Group 2	Group 3
1.1) Manufacture of parts or equipment for solar-powered products			
Conditions	• Investment of not less than 1 million THB, excluding land and working capital. • For small and medium enterprise (SMEs) investors, the investment must be at least 500,000 THB, excluding land and working capital. • The project must have approved production methods and energy yield as determined by the BOI board.	• Investment of not less than • 1 million THB, excluding land and working capital. • For small and medium enterprise (SMEs) investors, the investment must be at least 500,000 THB, excluding land and working capital. • Solar power generation project must have an installed capacity of solar panels of not less than 200 kW at each electricity distribution point. • Submission of a Power Purchase Agreement (PPA) with the utility or a private company as the contracting party.	• The business must be of a type that the BOI has announced to promote at the time of application for promotion, except for types of businesses with specific policies that do not grant rights and benefits as specified by the office. • There must be an investment in upgrading of not less than 1 million THB, excluding land and working capital. • In the case of investment projects for medium and small enterprises (SMEs), the investment must be at least 500,000 THB, excluding land and working capital. • There must be an investment in machinery modification to utilize alternative energy in the business, in proportion to the criteria set by the office, compared to the total energy consumption.
Incentives	**A2**	**A2** • The period of exemption from import duties for new machinery shall not exceed 30 months from the date of the promotion certificate issuance. • Additional special rights and benefits are granted when located in the investment promotion zone, such as the Southern Border Provinces, the Eastern Economic Corridor (EEC), or the 20 provinces with low per capita income.	• The period of exemption from import duties for new machinery shall not exceed 36 months from the date of receiving the promotion certificate. • Exemption from corporate income tax for 3 years at a rate of 50% of the investment, excluding land and working capital, for improvement purposes.

Source:
Investment Promotion Guide 2023, BOI

Table 4.3 Promotion of investments in the electronic equipment in solar energy industry by BOI.

Activities	Conditions	Incentives
1.2) Manufacturing electronic equipment that is used in conjunction with solar panels, such as inverters and batteries		
1.2.1 Inverter		
4.2.18.1 Manufacture of power supply, converter, inverter or charger which has operation control software.	Project must have following production processes: 1. Designing of circuit layout for the circuit board (PCB Design) 2. Loading of control software within the same project	**A3**
4.2.18.2 Manufacture of power supply, converter, inverter, or charger.	Project must have production process as approved by the Board	**A4**
1.2.2) Batteries or Energy Storage Devices		
4.2.8.1 Manufacturer of high-density batteries with the cell production process.	Project must manufacture high-density batteries with the properties as approved by the Board as followings: 1) Specific energy density not less than 150 Wh/kg 2) Charging cycle not less than 500 cycles	**A1** • The project will be eligible for a 90 percent reduction in import duties on non-locally produced raw materials and essential materials for five years under Section 30. The benefit will be approved for one year at a time, starting from the date of the first import of raw materials.
4.2.8.2 Manufacturing of high-density batteries, in case of using cells in the production of modules or battery packs.	Project must manufacture high-density batteries with the properties as approved by the Board as followings: 1) Specific energy density not less than 150 Wh/kg 2) Charging cycle not less than 500 cycles	**A2** • The project is eligible for a 90 percent reduction in import duties on non-locally produced raw materials and essential materials for five years under Section 30. The benefit will be approved for one year at a time, starting from the date of the first import of raw materials.
4.2.8.3 Manufacture of high-density batteries in the case of using modules in the production of battery packs.	Project must meet the following properties as approved by the Board: 1) Specific energy density not less than 150 Wh/kg 2) Charging cycles not less than 500 cycles	**A3**
4.2.8.4 Manufacture of supercapacitors	Project must meet the following properties as approved by the Board: 1) Specific energy density not less than 10,000 Wh/kg. 2) Charging cycle not less than 10,000 cycles.	**A2**

Source:
Investment Promotion Guide 2023, BOI

4.5 Support measures from financial institutions

Currently, there was increased interest in installing solar PV system, either in residential, commercial, and industrial sector, which was driven by intention to reduce electricity consumption costs and by government promotion policies. However, the high investment cost of Solar PV installation posed another important challenge to those who may not possess financial fluidity to install PV system. To address this issue, major financial institutions had implemented soft loan programs to aid those who desire to install PV systems. Examples of loan programs of major financial institutions of Thailand was summarized in Table 4.4.

Table 4.4 Typical soft loans from financial institutions for solar PV rooftop installation.

Bank	Loan	Maximum credit limit	Repayment period.
Kasikorn	Solar rooftop	100% of the investment cost	8 years maximum
Krungsri Ayutthaya	Solar rooftop for business	100% of the investment cost	6 years maximum
Bangkok	Bualuang Phoon Phon green		
	Bualuang Phoon Phon	1. For home improvement, maximum is not exceeding 10 million THB. 2. loan-to-value ratio is a maximum of 90% of the appraisal value.	10 years or the remaining period of the home loan (total loan term not exceeding 65 years of age of loaner)
	Home for cash Bualuang Phoon Phon	1. For home improvement, maximum is not exceeding 10 million THB. 2. loan-to-value ratio is a maximum of 80% of the appraisal value.	10 years or the remaining period of the home loan (total loan term not exceeding 60 years of age of loaner)
Krung Thai	Energy conservation and environment for business	1. Case of no collateral required the maximum is 3 million THB. This applies to small business with sales not exceeding 100 million THB. 2. Case of no collateral required maximum is 5 million THB. This applies to medium and large-sized business owners with sales exceeding 100 million THB.	7 years maximum
TMBThanachart	ttb solar rooftop PV	Maximum at 100% of PV system	Contact the bank
Siam Commercial	Solar rooftop	100% of the investment	Up to 10 years, including a principal-free year.
Government Savings	GSB go green	Absence loan collateral: maximum to 10 times the total income and not exceeding 500,000 THB.	Maximum not more than 7 years
		Loan collateral: For long-term loans, maximum not exceeding 5,000,000 THB or a maximum of 90% of the appraised loan collateral.	Not exceeding 30 years, including loaner's age and the loan repayment period, must not exceed 70 years.
	GSB for BCG economy	• For legal entity, no limit on the loan. • Individual, starting from 1 million THB and above.	10 years maximum
Export-Import bank of Thailand	Solar orchestra phase 3	100 million THB	Maximum of not more than 7 years

Remake: Programs and their conditions may change, contact the bank directly for the up-to-date information.

Source:
Bank web site

5 Implementation and related activities in solar PV

5.1 Floating PV systems

According to the Power Development Plan 2018 Revision 1, a target of 2,725 MW of floating PV systems installation by 2037 was set, which will be operated as hybrid PV systems with large hydropower plants operated by the Electricity Generating Authority of Thailand (EGAT), to enhance the stability and reliability of Thailand's electricity generation.

EGAT had completed a 45 MW floating PV system hybrid hydropower project at the Sirindhorn Dam in Ubon Ratchathani province, which had been in commercial operation since October 2018. Furthermore, a 24 MW floating PV system hybrid hydropower project, along with a 3 MWh battery energy storage system (BESS), at the Ubonrat Dam in Khon Kaen province was being developed, which was expected to be online by 2023 (Figure 5.1).

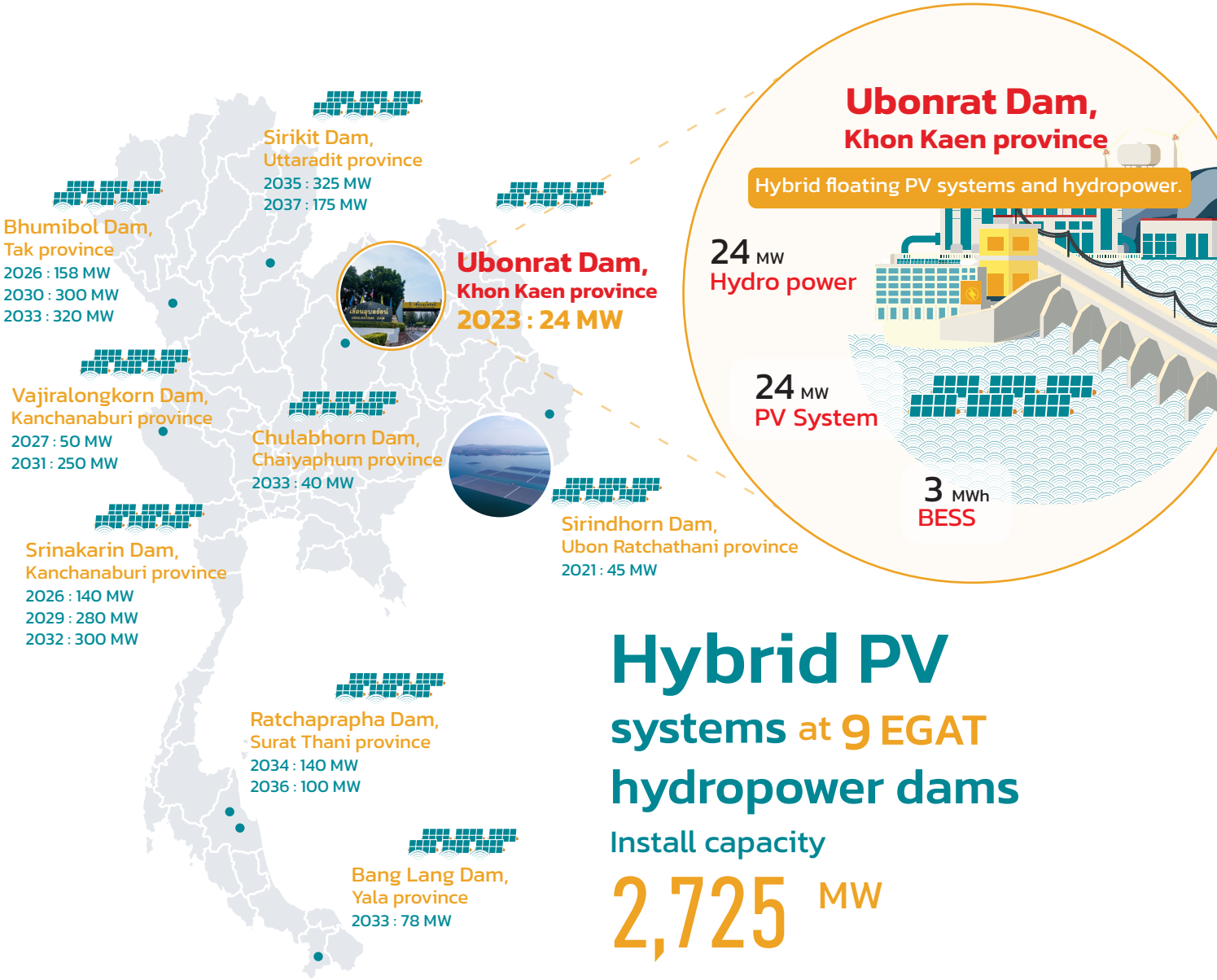


Figure 5.1 Floating PV system hybrid hydropower project by EGAT in the Power Development Plan (PDP) of Thailand for 2018 to 2037, revised 1 (PDP2018 Revision 1).

Source:
Annual report 2022, EGAT

Moreover, Floating PV systems (FPV) without power purchasing agreement with the government were experiencing rapid growth, especially in the industrial sector. These FPV systems aim to reduce cost of electricity bills and carbon emission from factories. An example is the 60 MW FPV phase 1 at the 304 industrial estate in Prachinburi province, along with other systems was shown in Figure 5.2.

Figure 5.2

Typical Floating PV systems (FPV)

(1) 45 MW FPV hybrid hydropower project at the Sirindhorn Dam in Ubon Ratchathani province,

(2) 978 kWp FPV at Rayong Olefin Co., Ltd. Rayong province,

(3) 806 kWp FPV at Khao Yoi, Phetchaburi province.

Source:

EGAT, SCG, and NEO clean energy Co., Ltd.

5.2 Rooftop PV system for residential sector

The solar rooftop installation for residential sector (commonly known as solar for Thai people project) had the objective to support household to install solar rooftop for self-consumption purpose to reduce electricity expenses, while the excess electricity produced can be sold back to the utility grid under a certain Feed-in Tariff (FiT) rate. FiT scheme, helping to reduce electricity bill

According to the Clean Electricity Generation Increment Plan (2nd revision) under PDP 2018 rev.1, there was a target of 90 MWp for the solar rooftop installation in residential sector. FiT rate was set at 2.20 THB/kWh for a period of 10 years. Since 2019, cumulative installed capacity was 30.8 MWP as shown in Figure 5.3 and Table 5.1.

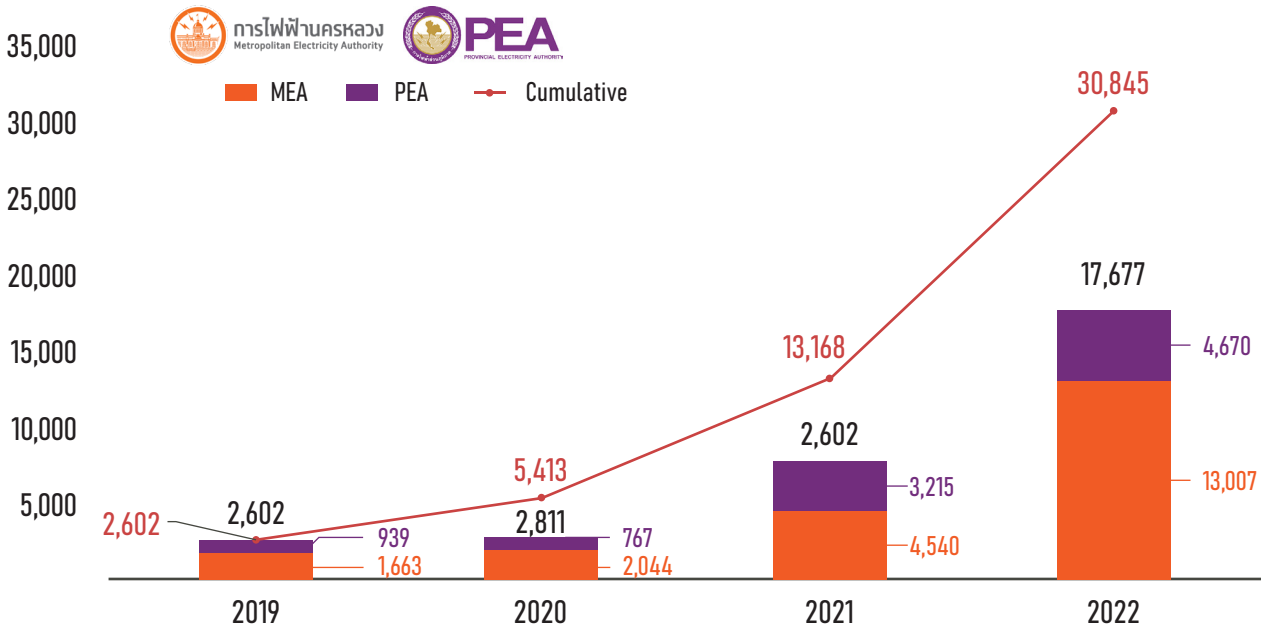


Figure 5.3 Installed capacity (kWp) for Solar PV Rooftop systems in residential public sector, 2019 – 2022.

Source

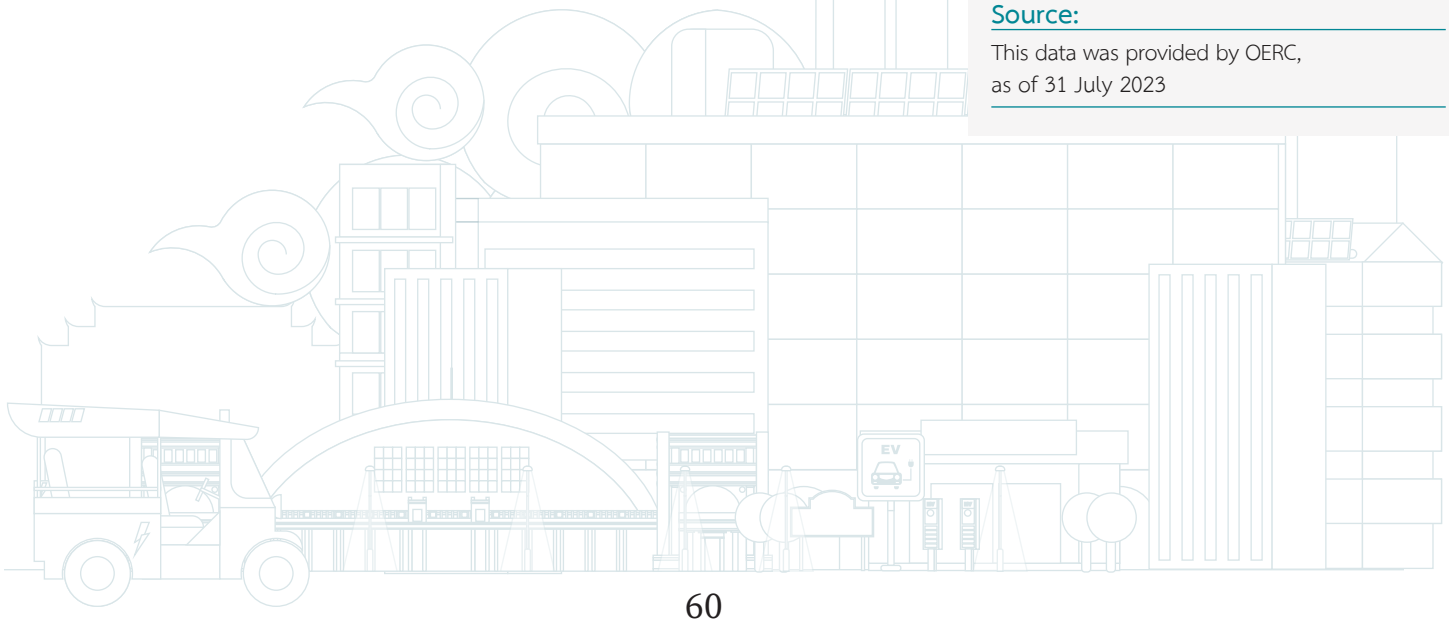
This data was provided by OERC, as of 31 July 2023

Table 5.1 Installed capacity of rooftops PV systems in residential public sector: 2019 – 2022.

Year	Target (MWp)	FiT (THB/kWh)	Number of projects (project)	Installed capacity (kWp)	Number of projects (project)	Installed capacity (kWp)
2019	100	1.68	484	2,602	484	2,602
MEA	30		303	1,663	303	1,663
PEA	70		181	939	181	939
2020	100	1.68	507	2,811	991	5,413
MEA	30		364	2,044	667	3,707
PEA	70		143	767	324	1,706
2012	50	2.2	1,414	7,755	2,405	13,168
MEA	15		787	4,540	1,454	8,247
PEA	35		627	3,215	951	4,921
2022	10	2.2	3,204*	17,677*	5,609	30,845
MEA	5		2,334	13,007	3,788	21,254
PEA	5		870	4,670	1,821	9,591

Remark: *Including the remaining portion for the year 2021.

Source:
This data was provided by OERC, as of 31 July 2023



5.3 Integration of BESS with solar PV system

Recently, there has been a growing interest in grid-connected PV systems with energy storage systems, particularly battery energy storage. These systems aim to maintain the stability and security of power generation.

Figure 5.4 illustrates an example of integrating BESS with solar PV generation at the Sa Kaeo Hybrid Super Plant project, which had total 48.91 MWp solar PV, along with 0.99 MW biogas power generation system, and a 45 MW/136.24 MWh Battery Energy Storage System (PCS/BESS). The plant was expected to be online January 2023 under the renewable energy hybrid small power producer (SPP) firm scheme. Additionally, this system represents the largest PV generation with a battery energy storage system in Southeast Asia.

Figure 5. 4 **Typical PV system with a battery energy storage system (BESS) and biogas power generation system installed capacity of 48.91 MWp, located in Han Sai, Aranyaprathet district, Sa Kaeo province.**

Source:
This data was provided by Super Energy Corporation Public Company Limited.

5.4 Targeted electricity production from renewable energy promotion project

OERC had allocated funds from the Power Development Fund to promote renewable energy and environmentally friendly technology, as stipulated in section 97(4) of the Energy Business Act B.E. 2550. In fiscal year 2022, there were installations of PV systems, including on-grid and off-grid systems, for school in rural areas to enhance the quality of education and in hospitals, to improve the healthcare service and raise the overall quality of life. This initiative is aligned with the Sustainable Development Goals: 4, 7 and 13.

5.5 ERC Sandbox program

OERC had announced the addition of ERC Sandbox to implement innovative technology to support energy services, aiming to promote the piloting and development of innovative energy and technology during Thailand's transition to renewable energy. The criteria of ERC Sandbox project as follows.

1) Projects under ERC Sandbox that announced by OERC on May 2, 2019.
2) Project involves testing platforms or innovations for electricity trading from renewable energy, carbon credits, or Renewable Energy Certificate (REC).
3) Project involves testing innovations related to smart grid systems or enhancing the flexibility of the electricity grid to increase electricity generation from renewable energy. Additionally, including support for new business models in electricity trading, such as testing standards for connecting electricity grid systems for third parties and establishing rates for related services, such as Wheeling Charge.
4) Project involves testing new formats of Power Purchase Agreements (PPA) for procuring electricity from renewable energy sources.
5) Project involves testing formats or guidelines beneficial for supervising energy innovations in the Green Innovation and Green Regulation.

Source:

Energy Regulatory Commission Sandbox: Addition of ERC Sandbox, 21 September 2023, OERC.

5.6 Utility Green Tariff: UGT

According to CBAM introduction and enactment by EU as a measure to reduce greenhouse gas emissions, by adjusting the costs of specific imported products to reflect their carbon emissions during production process. Export industry and foreign investors in Thailand were needed to procure electricity from renewable energy sources that can be reported in GHG emission account in accordance with CBAM requirement. This would benefit in increasing the competitiveness of Thai manufactures and avoid of cross-border carbon penalties.

ERC resolution on November 7, 2022, approved the guidelines for defining the Utility Green Tariff (UGT) in the retail electricity rate structure to provide an alternative for electricity consumers who need to declare carbon emission reports, to enhance Thailand's competitiveness, and to attract foreign investors, and to supports the goal of reducing carbon emission in Thailand. Currently, the UGT services will be operated by Thailand utilities, which can be divided into two types.

1. Non-specific Utility Green Tariff rate. (UGT-1)

UGT-1 offered provision and claiming REC from existing power plants. UGT-1 will be calculated as premium of base electricity price in a uniform tariff manner. The utilities will provide the collection purchase order (1 REC is equal to 1,000 kWh). Interested applicant can order an amount less than 1 REC under a short-term contract for 0 to 1 year (Figure 5.5).

UGT-1 = Regular electricity rate including Ft + Premium

Where Premium is the market price of REC plus the management fee and operational compensation for electricity entity associated with REC.

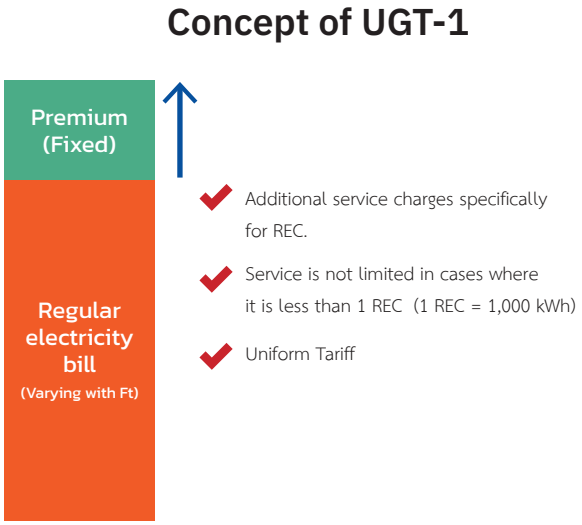


Figure 5.5 Concept of the non-specific Utility Green Tariff rate (UGT-1).

Source:
ERC announcement, criteria of energy services and utility green tariff rate, B.E. 2566, Royal Gazette, 8 January 2024.

2. Specified Utility Green Tariff rate (UGT-2)

UGT-2 offered provision and claiming of REC for renewable power user with high electricity demand. There are three types of portfolios: Portfolio A for solar energy and wind energy, which can be categorized as Energy and REC A. Portfolio B for solar and hydropower, which would be Energy B and REC B. Finally, Portfolio C for wind and biomass energy, which would be Energy C and REC C. UGT-2 is offered in sleeved PPA contract – direct power generation and transmission to customer via utility grid renting. UGT-2 does not apply time-of-use rates because of intermittent manner of renewable energy sources, and does not possess a uniform tariff like UGT-1.

UGT-2 is an alternative for large electricity consumers (Type-4 of utility definition) or special businesses (Type-5 of utility definition). The period of UGT-2 services ranges from 10 to 25 years. Additionally, the UGT-2 service rate has two levels: wholesale and retail.

UGT-2 (Wholesale) = Fixed rate for wholesale + Variable rate for wholesale

UGT-2 (Retail) = Fixed rate for retail + Variable rate for retail

		Components		
UGT-2 (Wholesale)	**Fixed rate for wholesale**	Electrical energy rate	Electricity transmission system service rates	Management expense rate (wholesale level)
	Variable rate for wholesale	Cost of government policy (wholesale level)	The adjustment of the electric energy tariff of portfolios	
UGT-2 (Retail)	**Fixed rate for retail**	Cost of procurement for wholesale (fixed rate)	Distribution system service rates	Cost of distribution and management
	Variable rate for retail	Cost of procurement for retail (variable rate)	Cost of government policy (retail level)	Cost of portfolio adjustment (retail level)

Remark: Penalty for power factor is included in both wholesale and retail.

Source:

ERC announcement, criteria of energy services and utility green tariff rate, B.E. 2566, Royal Gazette, 8 January 2024.

In summary, UGT-1 is suitable for users with low electricity consumption needs who do not require long-term commitments or specific electricity generation sources. In contrast, UGT-2 is designed for large-scale electricity that support the development of new power plants with specified power generation sources under long-term contracts. Figure 5.6 illustrates the UGT scheme with electricity generation structure in Thailand, including various renewable energy sources.

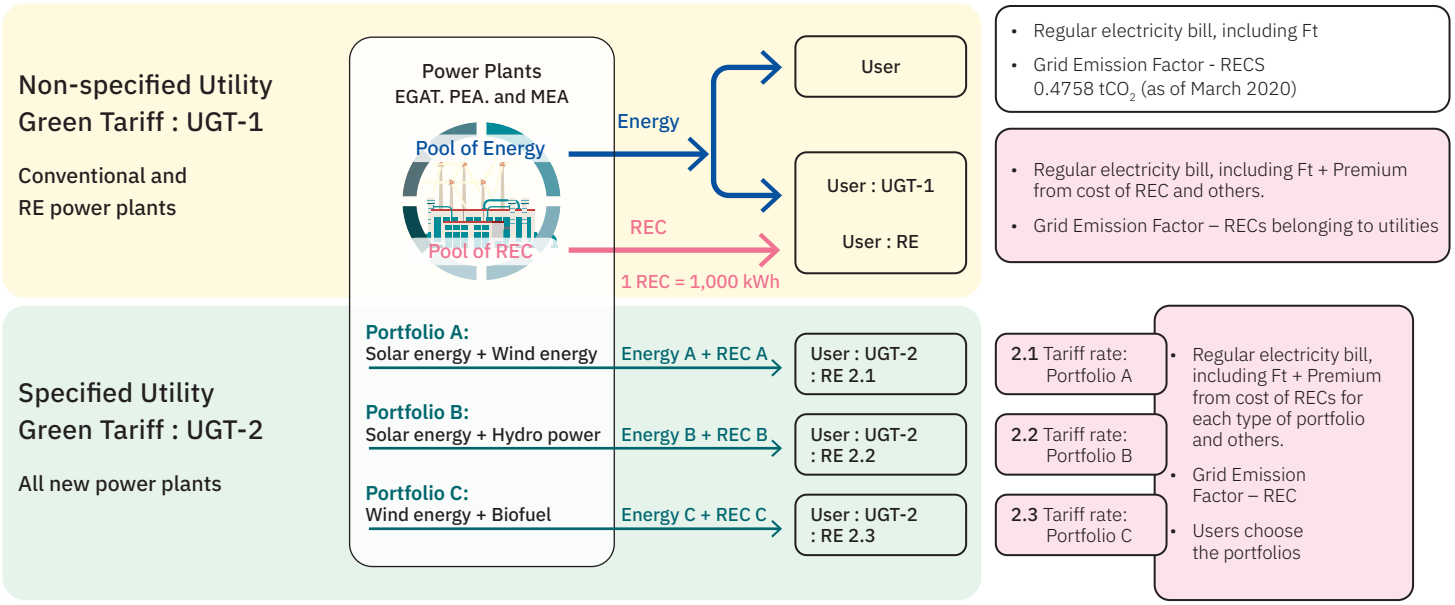


Figure 5.6 UGT scheme with electricity generation structure in Thailand.

Source:
Draft of Utility Green Tariff: UGT, OERC

5.7 DEDE supported projects

5.7.1 Energy efficiency and renewable energy support project in response for Royal Initiative Project

Department of Alternative Energy Development and Efficiency (DEDE) has implemented this project to support installation of energy conservation and renewable energy technologies to the Royal Initiative Projects in block grant projects 2021. The objective of this project was to achieve tangible and sustainable implementation of renewable energy and energy efficiency. Most project was implemented in the Royal Initiative Project area such as Chiang Mai, Lamphun, Mae Hong Son, Tak, Chiang Rai, Lampang, Phrae, Nan, Saraburi, and Loei.

Figure 5.7

(1) Greenhouse solar drying system, dimension 6m X 8.2m (DEDE 1R model), at Thung Roeng Royal Projects Development Center, Hang Dong district, Chiang Mai province.

(2) Centralized mini-grid system, installed capacity of 15 kWp, power system backup 90 kWh, at the Royal Projects Development area, Area 2, Omkoi district, Chiang Mai province.

(3) Solar pumping for submerge/surface water, at the Royal Projects Development area, Area 1, Phu Ruea district, Loei province.

Source:
This data was provided by DEDE.

Examples of solar energy technologies provided under this project included:

1) Greenhouse solar drying systems:

To increase the drying efficiency of agricultural products, create jobs, and contribute added value to agricultural products, thereby increase income for people and stimulate economic growth in community.

2) Solar pumping systems:

Apply solar PV system to water pumps to decrease dependency of fossil fuels, to provide water for agricultural use. This increase production cycles and generates income for farmers.

3) Solar PV systems for refrigerated rooms

Apply solar PV system for the cooling system of the refrigerated room, thereby reducing the cost of electricity to preserve agricultural product, decrease post-harvest losses, and generate income for farmers.

(1)

(2)

Figure 5.8

(1) Moveable solar pumping system, capacity 0.6 kW at Mae Hae Royal Projects Development Center, Mae Chaem district, Chiang Mai province.

(2) Solar Street light at the Royal Projects Development area, Area 1, Kanlayani Vadhana district, Chiang Mai province.

Source:

This data was provided by DEDE.

In addition to agriculture, the project also supported the installation of technologies to improve well-being and quality of life for people. For instance, the centralized mini-grid PV system, which comprises PV modules and battery energy storage systems (BESS) to store energy for use during nighttime or periods without sunlight, and solar street lighting, which consists of LED streetlights, PV modules, and batteries to storage energy to provide lighting during the night. Both technologies were supported to the area without electricity access to improve better quality of life to the area.

Implementation of these projects was expected to create 1.52 ktoe saving per year, reducing energy expenses by around 62 million THB per year, to reduce CO2 emissions of approximately 4,700 tons per year, contribute an additional income for agriculture of about 78 million THB per year, and enhances the quality of life and the local economy by generating employment opportunities, reducing investment costs and energy expenses for people. The project also aims to create awareness of the benefits of conserving energy and using renewable energy in local communities, enhance the competency of people in general and in agriculture, and support the security and sustainability of energy in Thailand.

5.7.2 Solar Rooftop Knowledge and Skill Development Project

Solar Rooftop Knowledge and Skill Development Project was supported by the Energy Conservation Promotion Fund (ENCON Fund) in the fiscal year 2022. The objective of this project was to develop the knowledge and understanding of educational and public health personnel regarding the solar energy promotion policy, solar PV, solar rooftop installation techniques, principles. Target organization was processed to achieve at least 450 individuals across at least 9 generations, from various regions nationwide. It was expected that, upon the completion of project, participants would be able to apply the knowledge gained during the training to further develop themselves and their respective organizations.

5.8 PV system project implemented in remote areas

5.8.1 Electricity pricing scheme in remote areas scheme

According to the Energy Business Operation Act of 2007, the electricity rates were set uniform nationwide, except in certain cases such as electricity trading in island areas. ERC has approved draft criteria for energy service rates of projects expanding electricity coverage to island areas, where the electricity price should reflect true generation cost and transmission expansion. The new electricity price on island includes a special rate for added capital cost. However, for islands that already have electricity access, normal rate of electricity should be applied until the new pricing structure that reflect transmission expansion and distribution is enacted.

Figure 5.9 Typical PV systems on Tarutao island, Satun province.

Source:
This data was provided by KMUTT.

5.8.2 Business model for PV systems on island areas

In some islands, there was development of solar PV businesses to promote more use of solar PV application, to develop participation of community, to create jobs and income, and to improve better life quality. Examples are as follows:

1) Hybrid PV System in the clean energy village on Koh Jik Island, Khlung district, Chanthaburi province, under Koh Jik Recharge project. Solar PV installation on this island covers 97% of the energy consumption that can reduces carbon emissions by 4 tonnes of CO_2. Koh Jik represent a demonstration of sustainable clean energy community from community participation. Moreover, the project was awarded with ASEAN Energy Award in 2023. This success demonstrates strong community under self-sufficient philosophy that can contribute to better quality of life to the community – in both health and education aspects.

2) Solar home systems installed on Bulon Don Island, Pak Nam subdistrict, La-ngu district, Satun province. There systems were also managed by community participation and supported by the Australian Agency for International Development (AusAid), the GIZ Thai-German Climate Programme-Energy Component (TGCP-Energy), the Ministry of Energy and Recharge Project-which represented sustainable development of clean energy on islands. The PV systems are coupled with battery energy storage and were operated on a pay-as-you-go business model, which was also known as prepaid solar homes. Participants were able to choose the appropriate package for their needs. The project's key success lies in its sustainability through community participation, job creation and increased income for people and communities. As a result, the project received the Thailand Energy Award in 2022 for renewable energy for off-grid projects.

Figure 5.10
Prepaid solar home systems on Bulon Don Island, Satun province.

Figure 5.11 Microgrid PV system for sustainable community on Koh Jik Island, Chanthaburi province.

Source:
facebook.com/KohJiKReCharge, and
facebook.com/ReChargeTH

5.9 Solar PV recycling business

Several agencies are currently interested in PV recycle business. An example is RE-PV, a PV recycling service offered by Eridian Solar Co., Ltd. This service included collection of PV modules waste from solar farms to processing through crushing, compressing, separating, and returning the materials for reuse. The goal is to reduce waste from solar PV systems.

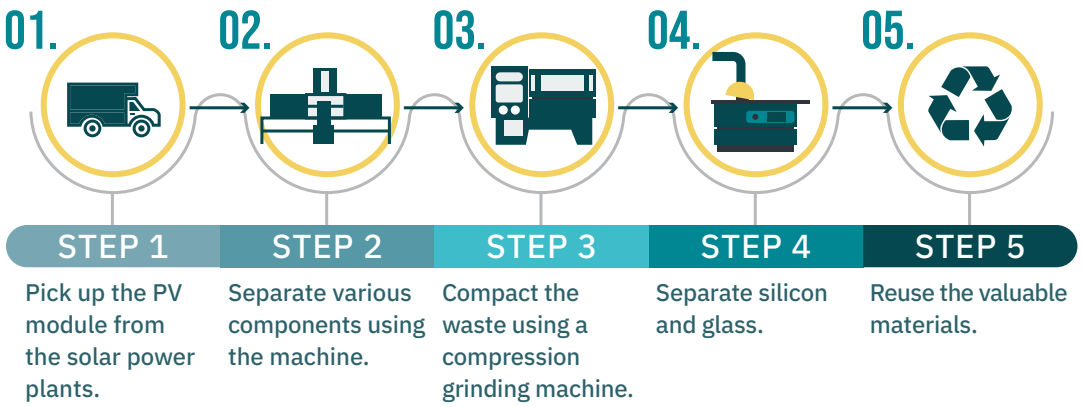


Figure 5.12 **PV recycling service provided by Eridian Solar Co., Ltd.**

Source:
This data was provided by Eridian Solar Co., Ltd.

In addition, the National Science and Technology Development Agency (NSTDA), in collaboration with the Department of Industrial Works under the Ministry of Industry, has piloted the second-life use of PV modules in the agricultural sector. This involves selecting PV module with an output of not less than 70% of power capacity and introducing them to a 10 kWp off-grid PV system. This pilot system was demonstrated at Walaya Alongkorn University in Pathum Thani province. Simultaneously, a recycling pilot plant has been established in Phra Pradaeng district, Samut Prakan province, under the jurisdiction of the Ministry of Industry. This initiative is part of a development project for machinery and equipment used in the physical/mechanical separation of PV module waste, in collaboration with EGAT. The pilot plant aims to separate glass, lead wires, and silicon sheets from PV modules waste for reuse as raw materials in subsequent recycling processes.

5.10 Thailand voluntary emission reduction program (T-VER) project

According to Thailand target in carbon neutrality and net zero emission, there were increased in activities that support growth of green energy and carbon mitigation measures, such as carbon credits and Thailand Voluntary Emission Reduction Program (T-VER).

The Thailand Greenhouse Gas Management Organization (TGO), a public organization, who is responsible for registering projects and certifying them under T-VER, as well as the amount of verified greenhouse gas mitigated or sequestered from T-VER projects, which can be used for GHG compensation report. Projects that can apply for T-VER can be illustrated in Figure 5.13.

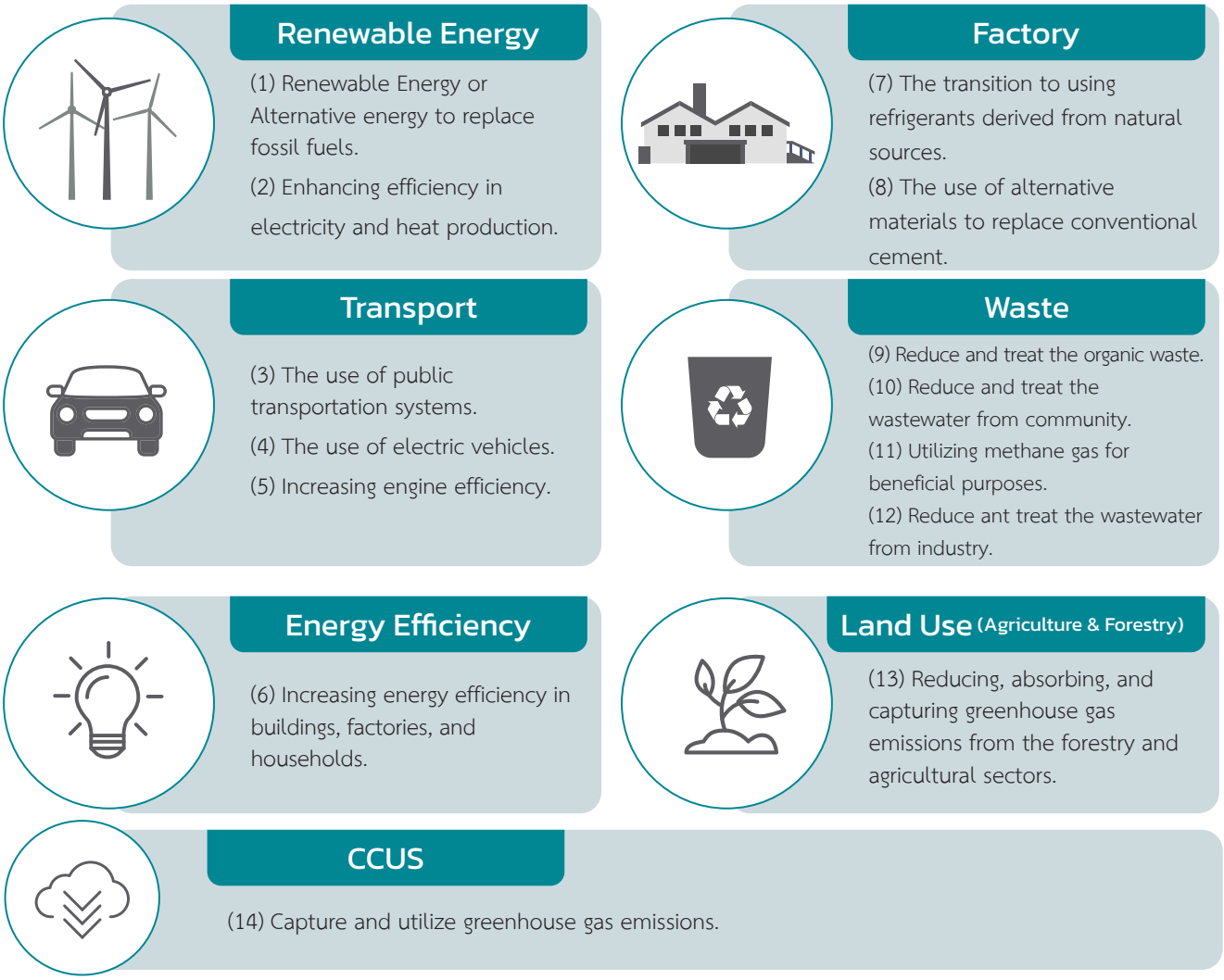


Figure 5.13 Various developed projects in a T-VER project.

Source:

Voluntary greenhouse gas reduction project according to Thailand standards. The data is from TGO website.

5.11 Thailand taxonomy

Thailand Taxonomy is a central standard used for the classification and grouping of economic activities that are environmentally friendly in Thailand, based on voluntary participation. The standard relies on principles grounded in environmental science and aligns with globally accepted standards, such as the EU Taxonomy and Climate Bond Taxonomy. The goal is to achieve net-zero greenhouse gas emissions, preventing global temperatures from rising beyond 1.5 degrees Celsius, as outlined in the Paris Agreement.

By categorizing activities, they can be divided into three levels, similar to the traffic light signals used in traffic signaling systems.

Green

refers to activities that are environmentally friendly and align with the goals of the Paris Agreement, such as solar energy and wind energy.

Yellow

represents activities where net greenhouse gas emissions are not yet close to zero or can be improved and developed to be more environmentally friendly. Additionally, they may be categorized as green in the future, such as electricity from biological sources.

Red

represents activities that are not environmentally friendly and require a gradual reduction in operation. These activities need to be phased out progressively, such as electricity from coal.

The principle of Thailand Taxonomy needs to comply with condition and environmental indicators and must comply with the principles of Do No Significant Harm (DNSH) and Minimum Social Safeguards (MSS).

The scope of developing the Thailand Taxonomy can be divided into two phases. Phase 1 covers the energy and transportation sectors because they are significant contributors to climate change and greenhouse gas emissions. Phase 2 includes the industrial production sector, agriculture sector, construction and real estate sector, and waste management sector. These standards are currently under development and are expected to publish in the near future.

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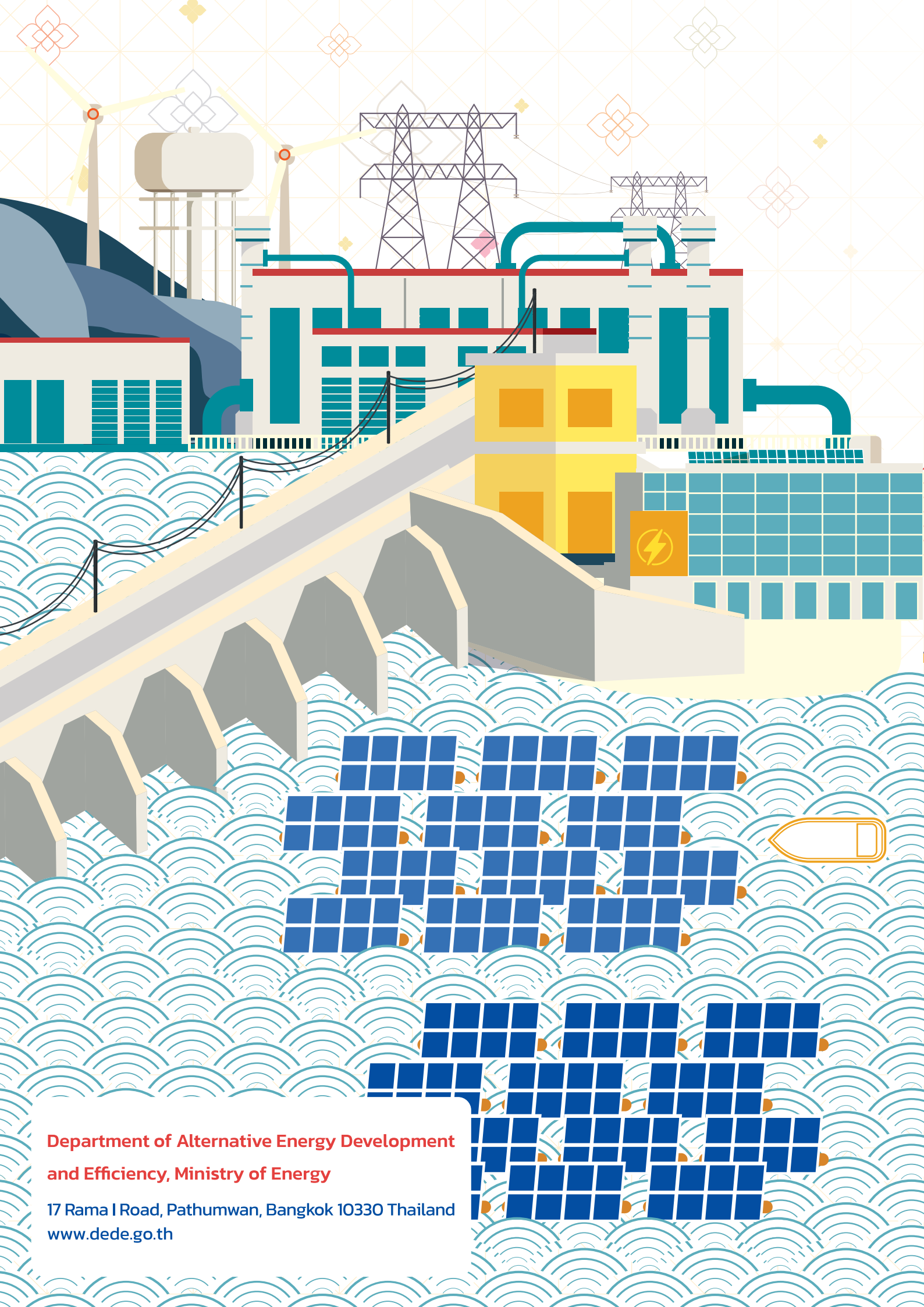

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