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Innovative Approaches for Scaling-up Renewable Energy Deployment in APEC Region

APEC Energy Working Group

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Innovative Approaches for Scaling-up Renewable Energy Deployment in APEC Region (EWG 04 2020S)

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Executive Summary

Achieving the goal of doubling renewable energy in the energy mix by 2030 is one of the main targets of the Asia-Pacific Economic Cooperation (APEC) region. APEC is the most dynamic and potential region globally, including 21 economies, with about 38% of the world's population, about 2.9 billion in total. As the main driving force and engine of global growth, the economy and the trade volume of the region stand for 61% and 47% of global total respectively. APEC region is also one of the most important regions for the development of renewable energy in the world. The region includes four of the five major energy markets in the world, namely China, the United States, Russia, and Japan. The region’s primary energy supply, final energy consumption and power generation account for 57%, 50% and 63% of the world total respectively, and the regional renewable installed capacity and power generation account for 57% and 58% of the global total respectively.

In the past decade, the world and the APEC region have made great progress in the development of renewable energy power. From 1226.9 GW to 2536.9 GW, the installed capacity of renewable energy in the world increased by 2.1 times from 2010 to 2019, while in the same period in the APEC region, it increased from 610.5 GW to 1444.3 GW, an increase of 2.4 times, with a growth rate higher than the global average. From 2010 to 2019, eight of the top twenty economies in terms of cumulative renewable energy investment are in the APEC region. The APEC area has emerged as the world's most powerful force in promoting the growth of clean energy and energy transition.

Renewable energy development has been one of the critical issues in energy work in the APEC region. In 2014, the APEC leaders have set a goal of doubling the share of renewable energy in power generation by 2030 in the region’s energy structure compared with 2010. As for 2018, the share of renewable energy in primary energy supply and final energy consumption in the APEC region has reached the targets of 41.8% and 44.5%, respectively. However, it is necessary to accelerate and further promote the large-scale development of renewable energy in the region to achieve the regional goal, particularly with more economies in the region have pledged to cut carbon emission vigorously and set the goal for carbon neutrality over longer terms.

In this report, the current situation of renewable energy development in the APEC region and the gap of the development among different economies are comprehensively analyzed and evaluated by using the indicators of power generation, sustainability and energy accessibility. Despite substantial variations in development levels among the economies, the APEC’s annual electricity consumption per capita was greater than the global average. Developed economies like Canada, the United States, Australia, Japan, and Korea use over 10,000 kWh per capita, whereas the developing economies like Thailand, Mexico, Viet Nam, Peru, Indonesia, the Philippines, and Papua New Guinea use less than the world average, 2,845 kWh per capita. According to the 2018 statistics, there are still 4 economies in the APEC region, namely Papua New Guinea, the Philippines, Peru, and Indonesia, which have not yet reached 100% electricity access, and the total number of populations without electricity access reached 14.5 million.

Regarding alternative energy, hydropower, solar photovoltaic (PV) and onshore wind power are the main components of renewable energy resources in the APEC. Hydropower, solar and onshore wind were the main dominants in renewable energy supply. Hydropower, solar, and onshore wind power made up 45.5 %, 26.7 %, and 24.3 % of installed renewable electricity generation capacity respectively by the end of 2019. In the last decade, solar and onshore wind power has grown remarkably, with installed capacity increasing by 39.5 and 4.4 times respectively. As for offshore wind, although it has only 6.3 GW of installed capacity, yet it has grown by 50.6 times in the last decade, making it the fastest-growing renewable energy with enormous development potential. Renewable energy investment in the APEC has seen a slower pace of growth since 2017; however, over 65% of the renewable energy investment in the world still comes from the APEC region. In order to achieve the renewable energy doubling goal by 2030 in the region, increasing investment in renewable energy still be a crucial issue.

The report discusses the availability of renewable energy resources in the APEC region and the composition of technological development and costs. It also examines the regulatory system and energy development policies and plans, and the investment environment and relevant infrastructure for renewable energy development.

In order to promote renewable energy in the region, investment and financing of renewable energy projects are further addressed. The report also analyzes the development and deployment of renewable energy technologies, and provides case studies as references. The main factors that influence the development of renewable energy are analyzed systematically, the experience of renewable energy development is summarized, and roadmaps toward a large-scale innovation and development of renewable energy are studied.

To support scaling-up renewable energy in the APEC region, the report presents the following policy recommendations:

- **Strengthen policy support:** strengthen market supervision policies and achieve a balance between macro policymaking, market operation, and effective regulation. Based on the specific conditions, improve policy framework, and set appropriate strategies and goals apocopate to enable more businesses in renewable energy sectors.
- **Promote technological progress and cost reduction:** continuous expansion of government investment in R&D, support scientific and technological research, demonstration and application, and enhance renewable energy industry development. Support technological breakthrough to eliminate the barriers toward safe and affordable renewable energy. Through market competition, giving a full play to the key role of enterprise research and development innovation is a key driver to achieve technological progress and cost reduction as well as affordable energy access.
- **Strengthen financial support:** to minimize renewable energy project cost in the process of project development, project license and permit applications and project grid connection application, government's related management costs in the process of project development should be suitably reduced, which will contribute to the reduction of renewable energy projects. Supporting private enterprises and renewable energy generation businesses through renewable energy development funds would be an option. The introduction of new fund scheme can go along with directing social funds toward renewable energy investment. This will not only effectively promote the development scale of renewable energy but will also improve social welfare through the creation of more job vacancies.
- **Innovate financing and business models:** establish effective financial mechanisms to ensure low-cost financing for renewable energy projects and encourage innovation in business and financing models. Subsidy policies should be appropriately utilized to lower financing expenses. As the primary source of funding, green finance can help businesses lower their financing costs and extend business models. Building up the capacity of local banks and practitioners to finance sustainable energy projects should be considered.
- **Improve the business environment**: update relevant policies in a timely manner according to market development and the needs, further simplify, standardize, and accelerate the approval procedures of renewable energy projects. The relevant competent authority shall continuously conduct land space inventory and support renewable energy development, encourage wind power, solar and other projects to use land in a compact way, minimize land use and reduce land cost of renewable energy projects. Innovation of renewable energy project development mechanism and bidding method shall be adapted to select project investment when the conditions are appropriate. Strengthen the implementation and supervision of policies and eliminate the potential investment risks caused by policy uncertainty, which will lift up investors' confidence in renewable energy project.

- **Improve the flexibility of power system:** on the power supply side, improving the flexible adjustment ability of coal power units is recommended in economies where coal power generating units account for a large share of total electricity generation capacity while existing units must be continuously upgraded to be more flexible, and new units must have deep regulation capacity. It is suggested that economies with suitable conditions accelerate the development of pumped storage power plants and other storage capacity. Concerning the power grid, it is recommended that measures be undertaken to increase the security, dependability, and stability of the power supply as well as to ensure the absorption of electricity from renewable energy resources.

- **Accelerate the development of distributed energy resources**: the key to developing distributed energy is policy support. It is advised that policy support for distributed energy be strengthened, different policy toolkits are improved, and technical standards are better aligned. Also, assessing development potential of distributed energy and investigating economic viability and technical routes and development modes for distributed energy systems help accelerate the development.

- **Promote energy access through renewable energy:** this includes economies with rural areas that are sparsely populated and have poor geographic conditions with less electricity access. Based on renewable energy resources, relying on distributed energy technology, including micro grid, with right support policy can be a better solution to improve energy access. Also, adjustment of relevant regulation and electricity pricing policy, provision of corresponding technical support for stakeholders through capacity building, exploring the suitable business model, and making such projects profitable and financially sustainable are among the critical.

- **Learn from advanced experience**: implementing domestic strategies is an important prerequisite for the rapid development of new energy and renewable energy. APEC economies, especially developing economies, should learn the best practice and experiences from other economies. Taking the solar PV project as an example, the development experience of China and Thailand can be drawn upon, formulating and implementing the development own strategies and plans.

- **Strengthen international cooperation:** developing renewable energy has become one of the prior policies of all economies in energy sector, facing the pressing challenges of climate change and emission reduction, also in the light of the COVID-19 pandemic and economic slow-down. Green economic recovery should be powered by renewable energy. While renewable energy is still in the early stages of the broader market, economies with different advantages and requirements in the field of renewable energy can achieve benefits by strengthening international cooperation, making full use of renewable energy development; this will enhance the economy's manufacturing capacity, advancement in technology, and resulting in market development. One of the major ways for the large-scale growth of renewable energy in APEC is to encourage demonstration projects, increase personnel capacity building, and optimize resource allocation through international exchanges and collaboration.

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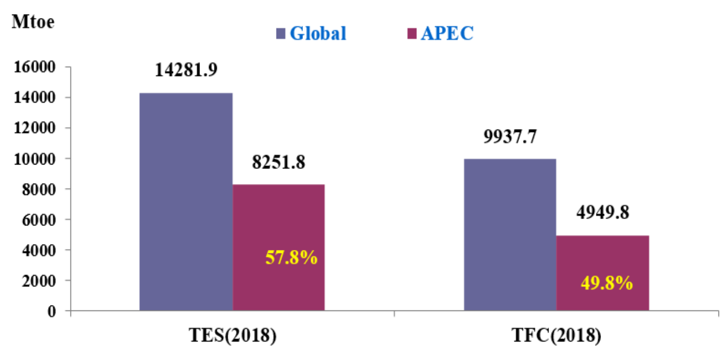
Chapter 1: Introduction

The 21 economies of the Asia-Pacific Economic Cooperation (APEC) account for 38% of the world's population (2.9 billion), 61% of global economic output, and 47% of global trade volume. As one of the key drivers of global expansion, the annual GDP in the APEC region grew at an annual average rate of 3.3%, compared to 2.3% for non-APEC regions. According to the International Energy Agency (IEA) statistics, global primary energy supply and final energy consumption in 2018 reached 14,281 Mtoe and 9,937 Mtoe, respectively. While APEC's primary energy supply and consumption totalled 8252 Mtoe and 4950 Mtoe respectively, globally accounting for 57.8 % and 49.8% over the same period as Figure 1.1 depicts.[1, 2, 3]



Source: IEA, APEC Energy Database

Figure 1.1 World and APEC Primary Energy Supply and Consumption (2018)

1.1 Energy Development Overview

1.1.1 Current Status of Energy Development

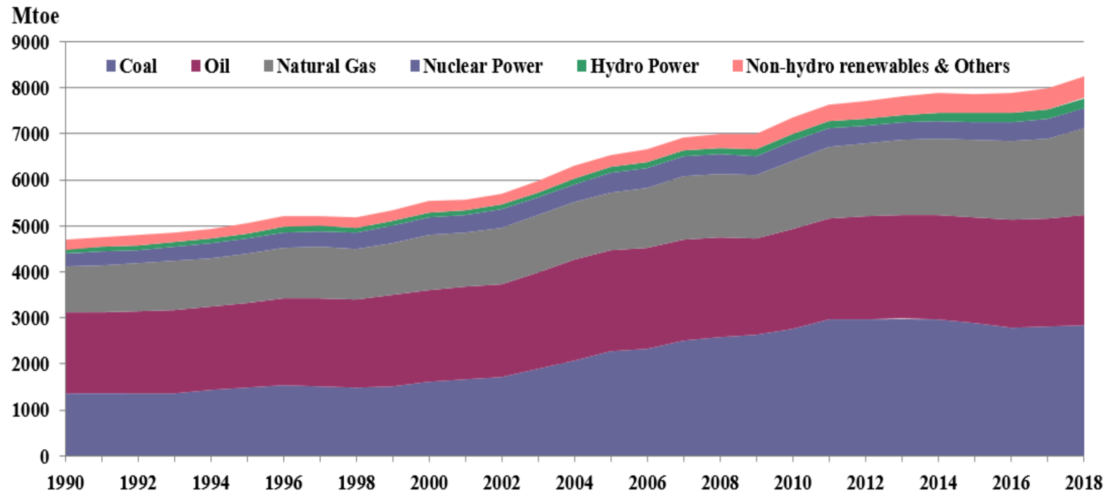
(1) Primary Energy Supply and Final Energy Consumption

The primary energy supply in the APEC region has seen a rapid growth between 1990 and 2018, having an annual average growth of around 3.3%, which is higher than the global one, which stands for 3%. APEC's energy supply structure is still highly carbon-intensive, dominated by coal, oil, and natural gas, accounting for 35.1%, 29.4%, and 21.9%, respectively, with coal accounting significantly for more than the global average.

Since 2000, most of the increase in primary energy supply was dominated by coal resources. However, after peaking in 2011, the coal supply steadily declined due to environmental protection and carbon emission reduction measures, as Figure 1.2 depicts.

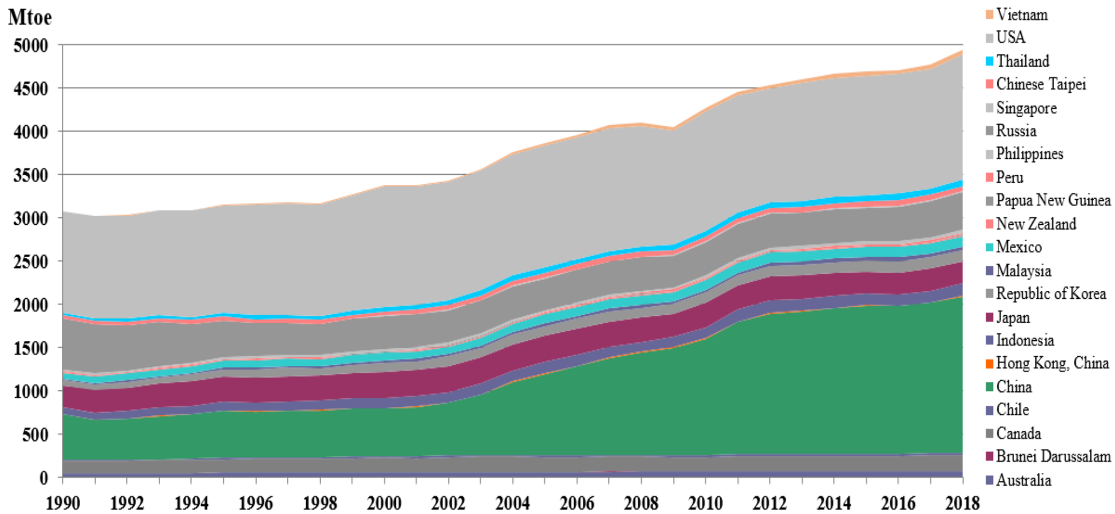
The APEC region includes four of the world's top five energy users: China, the United States, Russia and Japan, and any decisions made in the region will have a significant impact on global energy development. From a geographical perspective, demand for energy in the APEC region is mainly concentrated in China, the United States, Russia, Japan, Korea, and other economies. The United States and Japan are among the developed economies that have seen a decline in their total primary energy demand. The newly increased energy demand has been primary from China, Korea, Indonesia, Thailand, and Viet Nam.

[1] APEC Secretariat (2019), APEC at a Glance 2019, Available via https://www.apec.org/Publications/2019/02/APEC-at-a-Glance-2019
[2] APEC Energy Database (2020) APEC Energy Working Group EGEDA. https://www.egeda.ewg.apec.org
[3] Key World Energy Statistics (2020) IEA. https://www.iea.org/statistics/kwes/supply



Source: APEC Energy Database

Figure 1.2 Total Primary Energy Supply for the APEC (1990-2018)

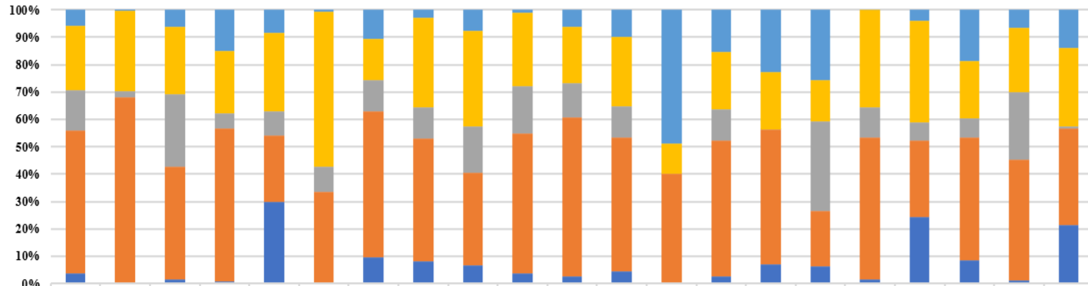


Source: APEC Energy Database

Figure 1.3 Final Energy Consumption for the APEC Economies (1990-2018)

Due to the different natural resource endowments in across the region, the final energy consumption pattern of the APEC economies varies substantially. Fossil fuels have dominated energy resources in the APEC region, with coal driving recent economic expansion, but in general, the use of coal has dropped since 2014. In 2018, coal accounted for more than 15% of the three economies, namely China (29.8%), Chinese Taipei (24.5%) and Viet Nam (21.6 %). As shown in Figure 1.4, economies in the region such as Australia, Brunei, Chile, Indonesia, and Mexico also have a relatively high share of coal.

Renewable energy (RE) currently plays an important part in the APEC economies' low-carbon and emission-reduction development. Renewable energy resources include hydropower, solar and wind power generation, biomass energy, and geothermal energy, which have been developing rapidly in response to local conditions and requirements. The utilization of renewable energy is profoundly linked to the availability of resources. Furthermore, due to technology and policy disparities, the share of renewable energy generation in industrialized APEC economies is yet larger than in emerging economies.



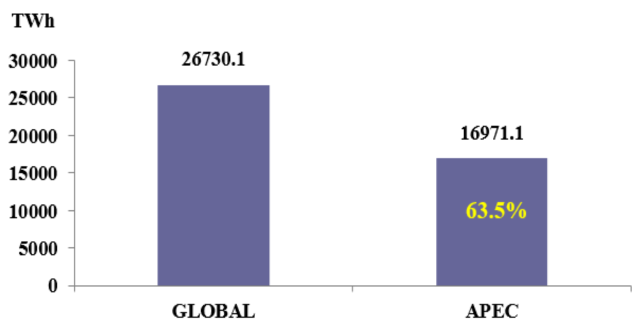
	Australia	Brunei Darussalam	Canada	Chile	China	Hong Kong, China	Indonesia	Japan	Korea	Malaysia	Mexico	New Zealand	Papua New Guinea	Peru	Philippines	Russia	Singapore	Chinese Taipei	Thailand	United States	Vietnam
others	5.7%	0.1%	6.3%	14.8%	8.3%	0.8%	10.4%	2.9%	7.7%	0.9%	6.3%	9.7%	48.8%	15.3%	22.8%	25.6%	0.0%	3.8%	18.7%	6.7%	13.9%
Electricity	23.6%	29.7%	24.5%	22.9%	28.7%	56.3%	15.2%	32.7%	34.8%	26.9%	20.3%	25.6%	11.0%	20.9%	20.7%	15.0%	35.6%	37.2%	20.8%	23.2%	28.8%
Gas	14.7%	2.2%	26.3%	5.6%	9.1%	9.2%	11.4%	11.6%	17.1%	17.2%	12.8%	11.3%	0.0%	11.6%	0.2%	32.7%	10.9%	6.8%	7.2%	24.7%	0.7%
oil	52.0%	68.0%	41.5%	55.7%	24.2%	33.6%	53.3%	44.7%	33.7%	51.3%	57.9%	49.1%	40.1%	49.4%	49.3%	20.4%	52.0%	27.8%	44.8%	44.3%	34.9%
coal	4.0%	0.0%	1.4%	0.8%	29.7%	0.0%	9.7%	8.2%	6.8%	3.7%	2.7%	4.4%	0.0%	2.8%	7.0%	6.3%	1.5%	24.4%	8.5%	1.2%	21.6%

Source: APEC Energy Database

Figure 1.4 Final Energy Consumption Mix by Source for The APEC Economies (2018)

(2) Power Supply and Consumption

The APEC region is a significant global power market. According to the International Energy Agency (IEA), global power generation capacity was 26 730 TWh in 2018, with the APEC accounting for 16 971 TWh (see Figure 1.5), making 63.5% of global power generation capacity. Electricity is an essential sector for the APEC in terms of energy and the environment [4] [5]; In 2018, electricity generation accounted for nearly 40% of primary energy supply and energy-related CO_2 emissions.



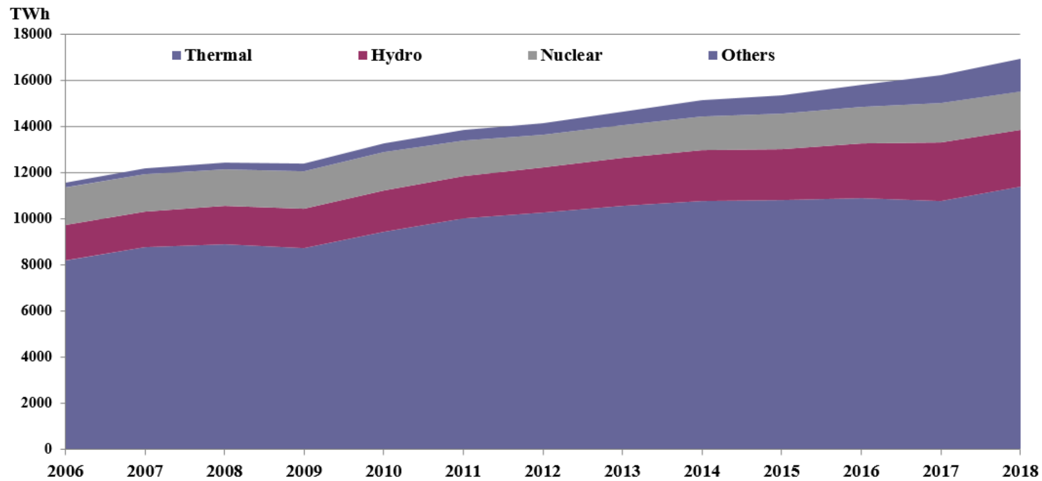
Source: IEA, APEC Energy Database

Figure 1.5 Global and the APEC Electricity Generation (2018)

The APEC region's electricity consumption has grown at a rapid pace over the last two decades, with an average annual growth rate of around 3%. China, the Republic of Korea, Indonesia, Chinese Taipei, Mexico, and Viet Nam account for the majority of the increased electricity demand. Over the last decade, demand for electricity in developed economies such as Canada and Japan have been relatively stable. The use of fossil fuels for power generation in the APEC region has expanded dramatically to fulfill the fast-expanding power demand of the developing economies. Coal, gas, and hydropower dominated the APEC power supply mix in 2018, accounting for 43.1%, 20.6%,

[4] APEC Energy Database (2020) APEC Energy Working Group EGEDA. https://www.egeda.ewg.apec.org
[5] Key World Energy Statistics (2020) IEA. https://www.iea.org/statistics/kwes/supply

and 15.7%, respectively. It has been noted that coal-fired power generation has remained steady in recent years, while oil power generation has gradually decreased, and renewable energy power output has increased significantly.

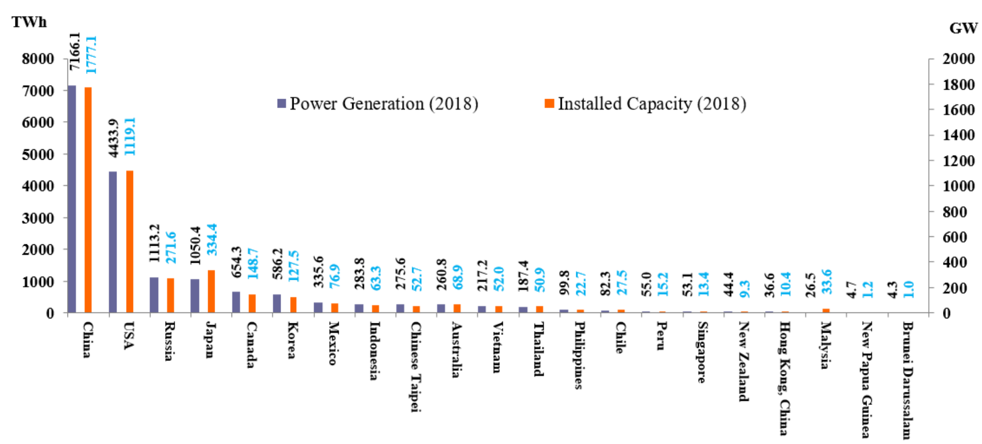


Source: APEC Energy Database

Figure 1.6 Total Electricity Consumption for the APEC Region (2006-2018)

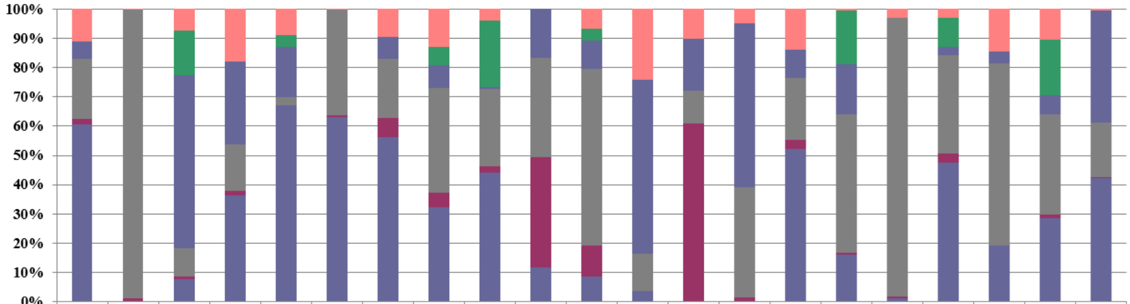
The power generation and installed capacity for the APEC economies are represented in Figure 1.7. China and the United States are among the top economies in terms of power generation and installed capacity, followed by Russia, Japan, and Canada, accounting for more than 85% of the APEC's total installed capacity. China is the largest economy in the APEC region concerning power generation and installed capacity, accounting for around 42% of the APEC region, with 7166.1 TWh and 1777.1GW in 2018, respectively. The second one is the United States, which accounts for 26% of APEC with 4433.9 TWh of power generation and 1119.1 GW of installed capacity in 2018.

Figure 1.8 represents the power generation in the APEC economies in 2018. China; Hong Kong, China; Australia; Indonesia; the Philippines; Chinese Taipei; Republic of Korea; Viet Nam; Chile; and Japan are among the ten economies that still depend on coal to generate for more than 15% of their electricity need.



Source: APEC Energy Database

Figure 1.7 Power Generation and Installed Capacity for the APEC Economies



	Australia	Brunei Darussalam	Canada	Chile	China	Hong Kong, China	Indonesia	Japan	Republic of Korea	Malaysia	Mexico
Others	11.0%	0.1%	7.3%	17.9%	8.9%	0.3%	9.4%	12.9%	3.8%	0.0%	6.7%
Nuclear	0.0%	0.0%	15.4%	0.0%	4.1%	0.0%	0.0%	6.2%	22.8%	0.0%	4.1%
Hydro	6.1%	0.0%	59.0%	28.4%	17.2%	0.0%	7.6%	7.7%	0.6%	16.6%	9.7%
Gas	20.6%	98.8%	9.6%	15.9%	2.6%	36.0%	20.2%	36.0%	26.5%	33.9%	60.3%
Oil	1.9%	1.1%	0.9%	1.6%	0.2%	0.7%	6.3%	4.9%	2.2%	37.7%	10.5%
Coal	60.5%	0.0%	7.7%	36.3%	67.1%	63.0%	56.4%	32.3%	44.1%	11.8%	8.7%

	New Zealand	Papua New Guinea	Peru	Philippines	Russia	Singapore	Chinese Taipei	Thailand	United States of America	Vietnam
Others	24.3%	10.0%	4.9%	14.0%	0.4%	3.1%	3.0%	14.5%	10.4%	0.5%
Nuclear	0.0%	0.0%	0.0%	0.0%	18.4%	0.0%	10.0%	0.0%	19.0%	0.0%
Hydro	59.2%	17.8%	55.9%	9.4%	17.2%	0.0%	2.8%	4.2%	6.7%	38.3%
Gas	12.9%	11.3%	37.6%	21.4%	47.4%	95.0%	33.5%	62.1%	34.3%	18.7%
Oil	0.0%	60.9%	1.4%	3.2%	0.7%	0.6%	3.0%	0.1%	1.0%	0.3%
Coal	3.6%	0.0%	0.2%	52.1%	16.0%	1.3%	47.6%	19.1%	28.7%	42.2%

Source: APEC Energy Database

Figure 1.8 Power Generation by Source for the APEC Economies (2018)

1.1.2 Overview of Renewable Energy in the APEC Region

Renewable energy development has been one of the APEC's most critical issues. Renewable energy deployment has seen an increasing pace in the last few decades, given its important role in reaching energy transition and sustainable development goals in the APEC economies. The 11th APEC Energy Ministerial Meeting in September 2014 explicitly declared that, by 2030, the share of renewables in the APEC's energy mix, including power generation, will double from the 2010 levels. Moreover, the APEC Energy Working Group was urged to prepare a roadmap for achieving the targets, in cooperation with the Experts Group on New and Renewable Energy Technologies (EGNRET). All the APEC economies have agreed on the goals included in the 2014 APEC Leaders' Declaration and reaffirmed by APEC leaders in 2015 and 2016.[6, 7, 8]

- According to the declaration of the 22nd APEC Economic Leaders' Meeting in 2014, the Energy Ministerial Meeting has launched an ambitious goal of doubling the share of renewable energy and electricity generation in the APEC's energy mix by 2030, from 2010 levels;
- The 23rd APEC Economic Leaders' Meeting was announced in 2015, and the goals of reducing total energy intensity by 45% by 2035 and doubling the share of renewable energy in the APEC's energy mix by 2030 were reaffirmed to achieve sustainable and resilient energy development in the Asia-Pacific region;
- According to the declaration of the 24th APEC Economic Leaders' Meeting in 2016, the ambitious goals of reducing overall energy intensity by 45% by 2035 and doubling the share of renewable energy in the region's energy mix by 2030 were reaffirmed.

According to APEC Energy Statistics, the share of renewable energy in the total primary energy supply increased from 4.9% in 2010 to 6.9% in 2018, achieving 41.8% of the target. In the APEC region, the share of renewable energy in final energy consumption increased from 6.0 % to 8.7 %, bringing it closer to the target of 44.5%. To that purpose, the APEC Energy Working Group recommended additional research and cooperation with relevant international organizations in the critical areas to bridging the gap for renewable energy development targets.

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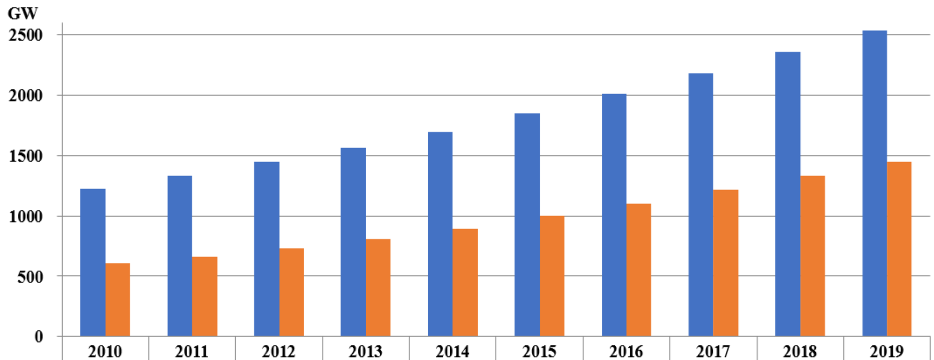
6 2014 APEC Leader's Declaration, https://www.apec.org/Meeting-Papers/Leaders-Declarations/2014/2014_aelm.aspx.
7 2015 APEC Leader's Declaration, https://www.apec.org/Meeting-Papers/Leaders-Declarations/2015/2015_aelm.aspx.
8 2016 APEC Leader's Declaration, https://www.apec.org/Meeting-Papers/Leaders-Declarations/2016/2016_aelm.aspx.

According to the International Renewable Energy Agency (IRENA), tremendous progress has been made in the development of renewable electricity globally and in the APEC region over the last decade. As shown in Figure 1.9, between 2010 and 2019, global renewable energy installed capacity rose by 2.1 times, from 1226.9 GW to 2536.9 GW, while the APEC region's installed capacity increased by 2.4 times, faster than the rest of the world. From 2010 to 2018, global renewable energy generation increased by 1.6 times, from 4199.3 TWh to 6586.1 TWh. During the same period, energy generation in the APEC region increased by 2.4 times, equivalent to 1.5 times of the global growth rate, reaching a value of 3818.1 TWh from 1565.7 TWh. Renewable energy installed capacity in the APEC region reached 56.9% in 2019, making the region the most significant for global renewable energy development.

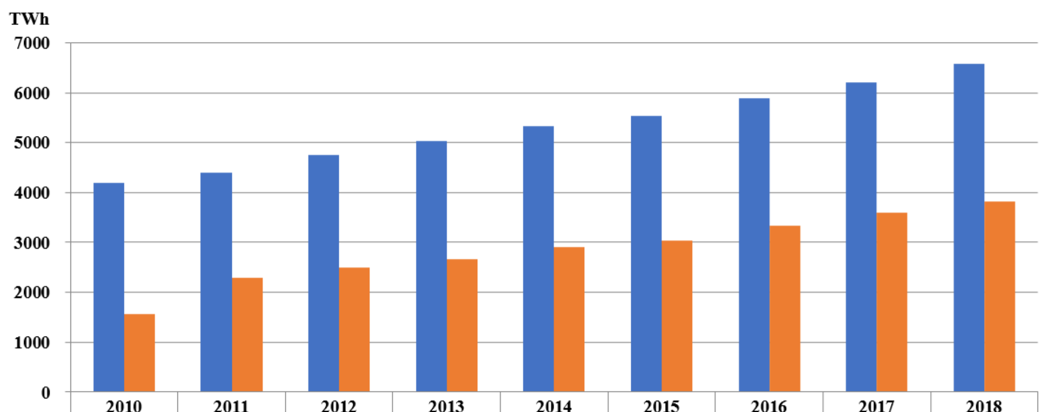


	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
World	1226.9	1332.2	1445.2	1563.2	1692.7	1846.1	2008.5	2182.4	2361.1	2536.9
APEC	610.5	663.4	728.6	809.3	893.0	996.9	1101.6	1213.8	1331.7	1444.3
APEC Share	49.8%	49.8%	50.4%	51.8%	52.8%	54.0%	54.8%	55.6%	56.4%	56.9%

Note: The installed capacity does not include the installed capacity of pumped storage power plants.

Source: IRENA, Renewable Capacity Statistics 2020

Figure 1.9 World and the APEC Installed Renewable Energy Capacity (2010-2019)



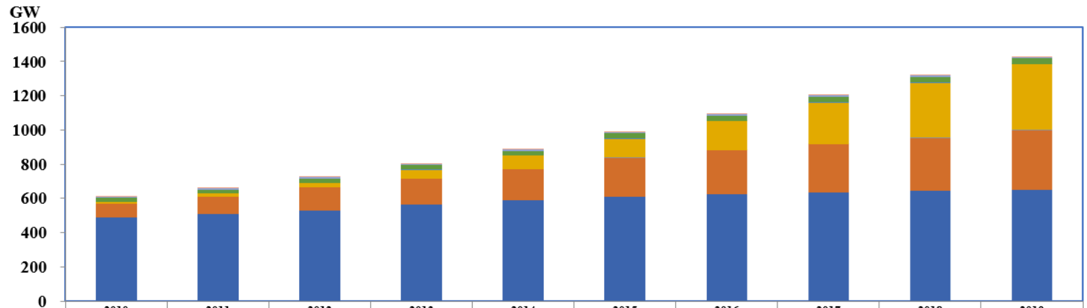
	2010	2011	2012	2013	2014	2015	2016	2017	2018
World	4199.3	4402.4	4755.8	5041.3	5330.7	5526.7	5897.6	6209.8	6586.1
APEC	1565.7	2282.1	2492.6	2671.8	2909.2	3042.1	3328.7	3589.5	3818.1
APEC Share	50.9%	51.8%	52.4%	53.0%	54.6%	55.1%	56.4%	57.5%	58.0%

Source: IRENA, Renewable Energy Statistics 2020

Figure 1.10 Global and APEC Renewable Energy Generation (2010-2018)

The main components of renewable energy in the APEC are hydropower, solar PV and wind power, representing 91.9% and 96.4 % of installed renewable capacity and power generation in 2018 and 2019. Compared to other resources, hydropower is considered the most dominant, accounting for 63.6 % and 45.5% of installed capacity and power generation in 2018 and 2019, respectively.

Regarding other renewable resources, from 2010 to 2019, solar photovoltaic and onshore wind power installations increased by 39.6 times and 4.4 times, respectively, from 9.63GW and 78.91GW to 380.88GW and 346.32GW. Photovoltaic installed capacity and power generation reached 9.6 % in 2018 and 26.7 % in 2019, respectively, while onshore wind installed capacity and power generation reached 18.7 % in 2018 and 24.3 % in 2019. The installed capacity of the other types of renewable energy sources, including offshore wind, solar thermal power, biomass power, geothermal power, and marine energy, was less than 5%, whereas electricity generation was less than 10%.

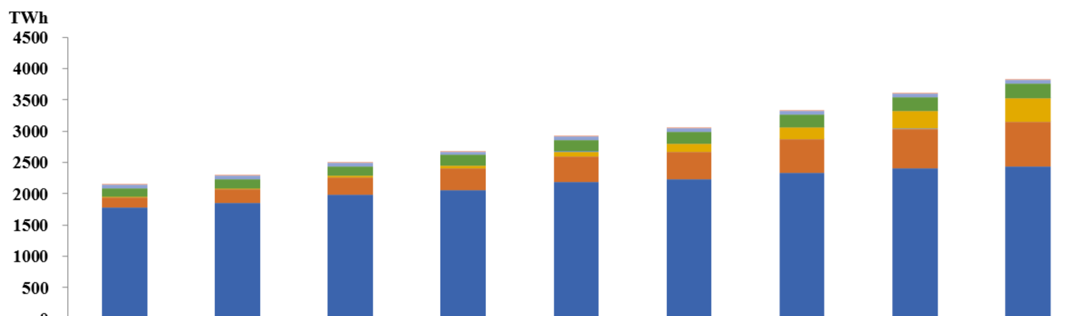


	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Ocean energy	0.03	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Geothermal	7.83	7.80	8.00	8.09	8.24	8.42	8.63	8.74	9.02	9.21
Biomass	25.48	22.74	23.80	24.55	27.54	29.79	30.47	31.78	32.65	33.06
Solar thermal	0.48	0.48	0.49	1.31	1.69	1.78	1.79	1.79	2.00	2.20
Photovoltaic	9.63	17.15	27.71	50.53	75.99	109.66	169.73	241.39	316.59	380.88
Offshore wind	0.13	0.24	0.32	0.49	0.52	0.72	1.71	3.04	4.86	6.32
Onshore wind	78.91	103.95	135.54	154.44	182.78	228.57		279.25	308.01	346.32
Hydro	488.03	506.93	527.86	562.23	589.34	609.72	623.16	636.34	645.02	649.47

Note: The installed capacity of hydropower does not include the installed capacity of pumped storage power plants

Source: IRENA, Renewable Capacity Statistics 2020

Figure 1.11 The APEC Renewable Installed Capacity (2010-2019)



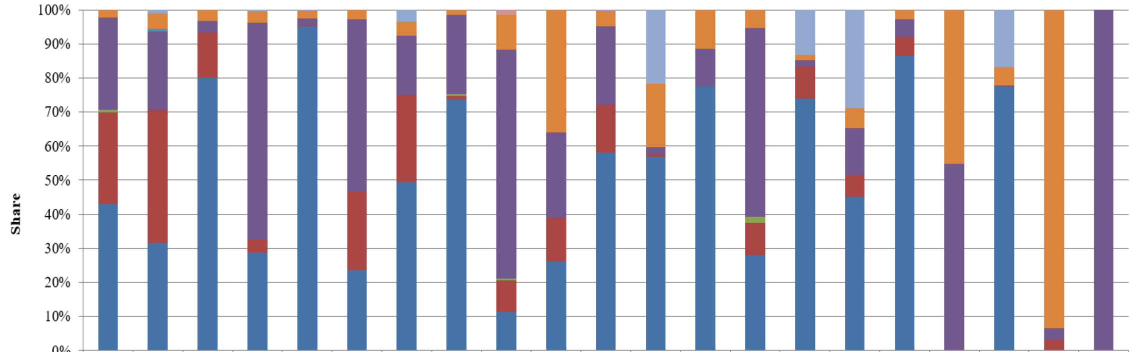
	2010	2011	2012	2013	2014	2015	2016	2017	2018
Ocean energy	0.04	0.09	0.50	0.51	0.52	0.52	0.52	0.51	0.51
Geothermal	53.03	53.52	53.44	53.54	55.96	57.60	57.79	59.11	59.34
Biomass	131.70	144.27	152.38	163.88	178.27	190.38	211.80	217.77	235.58
Solar thermal	0.88	0.90	0.97	1.02	2.70	3.56	3.71	3.60	3.95
Photovoltaic	9.81	16.22	26.37	46.22	84.93	128.02	187.72	276.84	366.17
Offshore wind	0.21	0.37	0.54	0.87	0.86	1.04	2.85	5.63	9.56
Onshore wind	166.97	219.53	276.16	348.55	394.85	439.37	538.74	628.18	714.59
Hydro	1775.59	1848.26	1983.04	2057.76	2193.51	2225.35	2327.91	2406.42	2432.39

Note: Hydroelectric power generation does not include the power generation of pumped storage power plants.

Source: IRENA, Renewable Energy Statistics 2020

Figure 1.12 Power Generation from Renewable Resources in the APEC Region (2010-2018)

The renewable installed capacity of APEC economies in 2019 is represented in Figure 1.13. In the 12 economies, including Russia, Peru, Canada, Malaysia, Papua New Guinea, New Zealand, Viet Nam, Chile, Indonesia, Mexico, the Philippines, and China, hydropower (excluding pumped storage power plants) is the primary source of installed renewable energy capacity, accounting for more than 40% of total installed renewable energy capacity. More than 75% of the total installed capacity is coming from the following five economies: Russia, Peru, Canada, Malaysia, and Papua New Guinea. Photovoltaics (PV) are dominant in Brunei, Korea, Japan, Chinese Taipei, Singapore, and Australia, each accounting for more than half of their installed capacity.



Installation (GW)	China	USA	Canada	Japan	Russia	Australia	Mexico	Viet Nam	Republic of Korea	Thailand	Chile	Indonesia	Malaysia	Chinese Taipei	New Zealand	The Philippines	Peru	Singapore	Papua New Guinea	Hong Kong, China (2016)	Brunei Darussalam
Marine energy	0.004	0	0.02	0	0.002	0.001	0	0	0.256	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal energy	0.026	2.555	0	0.525	0.074	0	0.936	0	0	0	0.04	2.131	0	0	0.965	1.928	0	0	0.056	0	0
Bioenergy	16.537	12.45	3.376	3.197	1.37	0.863	1.01	0.38	1.572	4.258	0.502	1.841	0.919	0.393	0.118	0.393	0.186	0.211	0.018	0.028	0
Concentrated solar power	0.421	1.758	0	0	0	0.002	0.014	0	0	0.005	0	0	0	0	0	0	0	0	0	0	0
Solar photovoltaic	205.072	60.54	3.31	61.84	1.064	15.928	4.426	5.695	10.505	2.982	2.648	0.198	0.882	4.15	0.115	0.922	0.341	0.255	0.001	0.001	0.001
Offshore wind energy	5.93	0.029	0	0.065	0	0	0	0.099	0.073	0	0	0	0	0.128	0	0	0	0	0	0	0
Onshore wind energy	204.548	103.555	13.413	3.721	0.102	7.272	6.591	0.275	1.439	1.507	1.62	0.076	0	0.717	0.689	0.427	0.372	0	0	0.001	0
Hydropower	326.113	83.617	80.879	28.114	52.579	7.468	12.671	18.069	1.808	3.107	6.679	5.616	6.245	2.092	5.389	3.024	5.741	0	0.258	0	0

Note: The data of Hong Kong, China is 2016.

Source: Hong Kong, China, 2016: APERC, APEC ENERGY OVERVIEW 2018; Renewable Capacity Statistics 2020, Renewable Capacity Statistics 2020

Figure 1.13 Renewable Installed Capacity Mix in the APEC Economies (2019)

1.2 Significance of Scaling-up Renewable Energy Development

(1) Inevitable Trend of Energy Transition

In most economies, energy policies have incorporated the energy transition, which focuses on utilising renewable energy to replace fossil fuels and reduce carbon emissions. Around the world, 164 economies have set renewable energy development goals, with another 145 adopting various renewable energy support programs.

Renewable energy resources are abundant in the APEC region, and all economies have developed short- and long-term renewable energy development strategies. Simultaneously, with the rapid advancement of renewable energy technology, the cost and price of renewable energy technologies such as solar and wind power have decreased dramatically, and renewable energy technology research has been deepened, and commercialization and business models have become more diverse and effective. Therefore, the large-scale development of renewable energy has become an inevitable trend of the energy transition.

(2) Eessential Measures to Tackle the Climate Change

Climate change is a major topic in international politics, economics, and the environment, and it will play a significant role in shaping up the world's future economic growth. On 22 September 2020, at the 75th session of the United Nations General Assembly, and on 12 December, at the Climate Ambition Summit, Chinese President Xi Jinping proposed that China aims at adopting more effective and ambitious policies and measures aiming at peaking carbon dioxide emissions by 2030 and becomes carbon neutral before 2060. Achieving carbon neutrality by 2050 has also been set by Japan and Korea. Energy consumption is a significant source of greenhouse gas emissions, dealing with climate change has become one of the key components of the energy policy agenda in the world's major economies.

Because renewable energy is CO_2-free during its use, quickening the large-scale development of renewable energy is the key step toward reducing global warming. Energy consumption and carbon dioxide emissions in the APEC region have risen dramatically in recent decades due to rapid industrialization and economic growth. The carbon emissions reduction in the APEC region will have a significant impact on the pace of worldwide emission reduction and achieving the international "Climate Convention" goals. All economies have pledged to the battle against global climate change and have taken necessary measures and had relevant policies in place. The development of renewable energy on a significant scale in the APEC regions is a crucial move to combat climate change.

(3) Important Force to Ensure Energy Security

Human activities and economic progress require energy as a basic component. As the world's industrialization accelerates, more people are becoming aware of the importance of energy. Among the many issues surrounding energy is energy security which is becoming increasingly crucial. The energy consumption structure and behaviour have led to a significant energy efficiency gap between industrialized and developing economies, resulting in high energy consumption and major environmental degradation, posing a serious threat to energy security.

Renewable energy contributes significantly to energy security, and it creates less pollution and environmental damage in the process of its use. Besides, increasing the energy supply and reducing the external dependence on fossil energy import, renewable energy also contributes to improving regional energy security levels over time. Following with continuous development of science and technology, combined with the need to protect the environment, the share of renewable energy in the energy consumption structure will continue to go up, ensuring the security of energy system supply from different sources. To ensure energy security, developing renewable energy sources at a large scale and boosting the share of renewable energy has become essential to improve energy security status.

(4) Development Direction to Solve Energy Access

Energy shortage is still globally, regionally, and locally existing. In 2019, 770 million[9] people worldwide lacked reliable and affordable electricity, while about 2.6 billion still rely on conventional solid fuels for cooking and heating, including some rural areas in Asia[10].

The APEC region still has a large number of people without access to electricity, the majority of whom live on isolated islands or in remote rural areas. These areas are frequently located away from economic canters and confront transportation and electrical grid extension challenges. Given the abundant and wide spread of renewable energy resources, the region’s development strategy for addressing the problem of energy access is to prioritize renewable energy and build distributed power supply based on local conditions to achieve universal energy access in the region.

1.3 Scope of the Study

The study investigates the experience and approach of renewable energy development in the APEC region, and a comprehensive analytical framework on the main factors regarding renewable energy development was structured and applied in the study.

The study renews, assesses, and summarizes the experience and practice of renewable energy innovation and development in the APEC region, and puts forward suggestions on promoting the

[9] https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity
[10] https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

large-scale development of renewable energy in the region, which seeks at providing support for realizing APEC renewable energy development goals.

The contents of the report comprise the following main parts.

(1) Background of Renewable Energy Development

The main focus of the study is the growth of renewable energy in the APEC region. Selected indicators such as power consumption per capita, energy intensity, the share of renewable energy in power generation, the share of installed capacity, and renewable energy investment are used to assess renewable energy development in the APEC economies. The population access rate and the number of people without electricity are used to examine energy access.

(2) Pathways of Development

This is the main body of the study. The task is to explore the development pathways of renewable energy development in the APEC region. Based on the different condition of the economies, the study mainly focuses on different economies' regulatory framework and relevant policy, plan and target, renewable energy resource endowment and assessment, renewable energy technology development and evaluation, cost composition renewable energy supply and its trend, business environment of renewable energy development, infrastructure support such as power grid reinforcement and flexibility, renewable energy project investment and financing mechanism and business model, and distributed renewable energy utilization.

The policy, viable technology and suitable business model and practice to accelerate energy development and achieve universal energy access through renewable energy application have been discussed.

(3) Case Analysis

This study conducts a comprehensive analysis of specific economy and location to scale to the development of a specific renewable energy technology and the promotion of successful experience. Technology innovation, the development of the installed scale, incentive measures, and experience summary are discussed in the report using the development history of solar PV in China and Thailand as case study respectively.

(4) Policy Recommendation

Policy recommendations are summarised for the APEC region to further accelerate and scale-up the development of renewable energy, achieving the APEC renewable energy doubling goal and contributing to tackle the global warming challenge.

Chapter 2: Methodological Approach

2.1 Background of Energy Transition

At the global and regional levels, energy systems have confronted with issues related to energy security, economic efficiency and environmental pollution, and other critical issues such as climate change, resource utilization efficiency, sustainable consumption and production, and energy access. These challenges are serious and complex, particularly those tightly linked and interdependent on one another, such as energy security, economic growth, climate change and environmental protection.

As having been experienced in most APEC member economies, energy transition and innovation toward sustainable and clean energy systems are now represented by the processes of decarbonization, decentralization and digitalization at supply side of the energy system, and energy efficiency and re-electrification processes at the end-user side, which are essential pathways to achieve sustainable development goals. Furthermore, energy transition offers the opportunities to create a circular economy and generate new sources of growth, with the shift from grey to green economic growth.

(1) Role of Renewable Energy

Renewable electricity supply is one of the key driving forces of clean energy transition. The clean energy transition is now made possible by innovations and the deployment of renewable energy technologies. Renewable energy development can be penetrated beyond the power sector, depending on a particular economy's circumstances and conditions. Renewable energy resources can play an essential role in substituting conventional fossil fuels throughout the energy supply and demand chain, such as power generation, transportation, industrial processing and production, and heating and cooling supply. Various economies in the APEC region have established related policies for renewable energy development, stipulated incentive measures, and continuously raised their renewable energy targets at different stages of the development.

The development and deployment of renewable energy have seen impressive progress in terms of significant cost reductions and increased competitiveness of the technology. The rapid rise of renewable energy in regional economies goes along with increased investments and funding, more employment opportunities, and increased social and economic welfare in many economies.

Having said that, achieving large-scale renewable energy consumption still remains a challenge for the economies in the region. We analyze related issues by identifying related difficulties and current roadblocks and sort out through relevant experience and good practice.

(2) Area of Action

Broadly speaking, climate change mitigation, adaptation and environmental protection is an act of maintaining, allocating and utilising of public social resources. To fully realize the potential development of renewable energy along energy transition, all economies and governments ought to establish appropriate policies and regulatory frameworks to support the development and utilization of renewable energy, promote the continued growth of renewable energy in energy supply, which is eventually competing to substitute conventional fossil energy.

Given the characteristics of the energy system, which is capital-intensive and has a long-life cycle, it necessitates effective long-term planning. The design and operation of related energy system facilities, including power generation, transmission and distribution, and electricity market, should be considered integrated. Key areas for actions to facilitate the energy transition and scaling-up renewable energy consist of:

- Economies would need to devise appropriate strategies and policies based on their energy resource endowment and availability, socio-economic conditions, and policy landscape for other sectors' development;
- Efficient and robust governance framework, as well as technological innovation and economic viability, are required to ensure effective energy transition;
- Deployment of renewable energy and encourage increased investments and financing in renewable energy resource harness;
- Promote capacity building, best practices, and accelerate development and deployment of renewable energy resource and technology application;
- Power grid is indispensable for large scale renewable energy development. It is critical to develop power system and improve its operation, and facilitate renewable energy grid integration;
- Spur innovation in the context of climate change. Call for research and development for clean energy technologies to promote international collaborative relationship;
- Access to finance and strengthened capacities need to be scaled up at a considerably faster rate, particularly for less developed economies;
- Building a strategical roadmap, taking the local specific situation and background into consideration, is essential for achieving renewable energy development goal;
- Reinforce and enhance regional, economy-wide and local initiatives, involving multiple stakeholders, including government, regulators, cities, communities, business and private sector;
- Support and create beanie condition for international and regional collaboration, including technology innovation, technology transfer and trade.

Renewable energy development can be accelerated if the energy transition is based on an appropriate energy policy framework. When designing energy transition strategies, the characteristics of each energy system must be considered in terms of energy supply and demand and social and economic background. The effective coordination among the key stakeholders such as government, regulators, cities, communities, businesses, and the private sector needs to be established and functional.

2.2 Framework of the Study

As discussed, the development and penetration of green energy technologies will significantly depend on the government's public policy, at least in the short term, until more green technologies become entirely cost-competitive with brown and grey technologies.

Figure 2.14 depicts the framework of the main factors and their possible interconnection for scaling-up renewable energy application and deploying related projects. It also reflects the main framework and study direction of this research project. Besides, the following is a brief summary of the relevant direction of the research tasks and activities of the study.

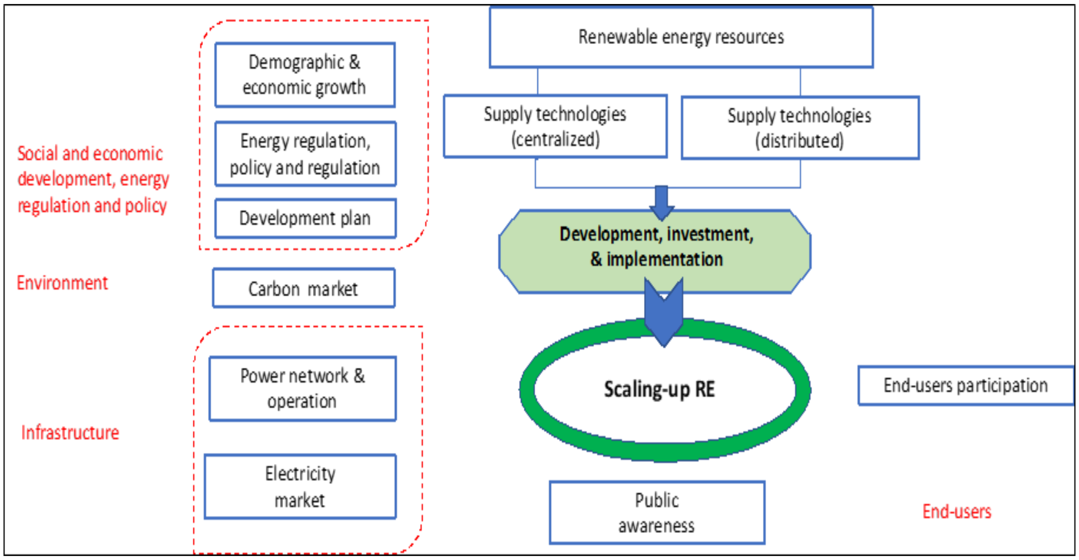


Figure 2.14 Project Research Framework

(1) Innovation and Technological Development

Energy transition, in general, can be successfully achieved by actively developing clean energy technologies and making full use of existing technologies. Affordable and scalable solutions are now available, enabling the energy system to leapfrog to cleaner and more resilient economies, allowing a larger number of population (the goal is to serve the entire population) to have access to more reliable electricity while supporting economic development. Basically, every economy and region in the world has abundant renewable energy resources, particularly solar and wind energy. Switching to renewable energy will reduce emissions and facilitate adaptation efforts. Some key technology and innovation include:

- Green power generation: renewable energy, biofuels, and energy storage;
- Electricity transmission and distribution: flexible power system, and smart power grid;
- Carbon capture and storage and utilization;
- The introduction of new energy carriers, such as the development and utilization of hydrogen energy;
- Green heat and cooling supply;
- Low-carbon transportation: fuel efficiency technology, electric, hybrid and fuel cell vehicles;
- Decarbonisation of industrial sector;
- Energy efficiency improvement: building and industrial process;
- The adaptability of the energy system to climate change.

(2) Policy Environment and Regulatory Framework

Successful transitions have been found technically achievable by the studies and experiences. It necessitates the rapid implementation of policies and fundamental political shifts in order to integrate global concerns, such as climate change, into local and domestic policy priorities, such as energy security, environmental pollution, and access to energy.

Due to the urgency of the challenge, concerted efforts need to be made to improve relevant policies in a timely manner to achieve fundamental changes. The following are some examples of important development policies and regulatory systems:

- Changes in the energy system for medium-and long-term technology choices in the energy industry;
- Support for energy technology innovation, research and development;
- Changes in the primary energy structure and renewable energy development goals, carbon emission goals, and economic efficiency targets of energy system;
- Development and building up energy industry chain, the improvement of the supply chain efficiency and sufficiency;
- Supervision of public utilities, and fostering competition for energy supply, establishment and operation of functional energy market;
- Support for the developing and operating renewable energy projects, including feed-in tariff system, project bidding etc, when condition allows and feasible.

(3) Fiscal and Financial Tools

Fiscal measures, such as reduced corporate income tax, corporate tax holiday, import duty exemption for eligible technologies and equipment, and exemption from value-added tax for clean energy technologies, can attract investors and small businesses to foster market stimulation.

Historically, the introduction of fossil fuel subsidies was rationalized by the need to alleviate energy poverty, boost domestic supply, re-distribute national wealth, and protect employment. However, international experiences indicate that the range and scale of the unintended outcomes of fossil fuel subsidies are significant. Phasing-out fossil fuel subsidies will narrow the investment gap in renewable energy.

(4) Support Investment in Renewable Energy Project

Following technological advancement and increased scale of deployment associated with cost reduction, more renewable technologies are gaining a competitive advantage over conventional fossil fuel-based technologies. The effective investment environment is however still required for the renewable energy projects development, which includes:

- When necessary, provide capital subsidy for renewable energy projects, and encouraging long-term power purchase agreement;
- Enhancing communication between business and financial sectors to increase transparency and develop risk mitigation measures to help mobilize private finance, while recognizing that public finance plays an important role;
- Support efforts to mobilize finance and improve the market and investment environment for clean energy projects, innovative technologies and quality infrastructure projects that facilitate energy transition;
- Contribution to relevant green and climate funds to assist developing economies in mitigation, adaptation and resilience practices and support energy transition and counter climate change impacts.

(5) Renewable Power Grid Integration

Electricity grids, along with their operational planning and market management mechanisms, have been designed over decades, primarily based on the characteristics of incumbent fossil fuel technologies. They have been facing challenges keeping up with the increased renewable electricity generation. Power systems need to become more flexible to avoid unforeseen impacts on electricity security, and electricity market designs need to be reformed to suit the new situation.

These require scaling-up existing system integration innovations from successful pilots to clear legislative initiatives, enabling effective renewable energy uptake in line with renewable energy and climate change goals. More particularly, this mainly includes:

- Long-term planning in which the design of power grids and electricity markets fully takes account of the shifting landscape of electricity generation;
- The integration challenges include localized grid congestion, frequency control and supply/demand imbalance that, if not managed well, can compromise system reliability;
- As various renewable penetration increases, without adequate planning and effective management, this can lead to forced curtailment of renewable penetration into the grid or prevention of capacity expansion of renewables.

(6) Development and Implementation of Market Mechanism

Environmental externalities, such as negative externalities from fossil-fuel-based technologies or positive externalities from low-emissions technologies, have mostly not yet been considered. Renewable energy technology, as well as other low-emission technology, are not yet fully incentivized by the applicable energy price signal in most economies.

Fossil fuel-based power generation technologies have a significant environmental and societal costs. While comparing the financial viability of renewable energy projects against the viability of fossil fuel-based projects, without taking these costs into account, the market becomes unevenly competitive. Internalizing externalities creates a competitive environment for renewable energy technologies.

While the challenge to estimating externalities still exists, policy makers can take appropriate steps to formulate energy and environmental policies that account for these externalities to a possible degree. To cover the costs of relevant damages, a pollution penalty, such as a carbon levy on energy generated from fossil fuels, e.g., carbon tax and carbon offsetting, may be imposed. There have been a few carbon pricing initiatives in the region. Externalities in the transport sector, for example, can be introduced by implementing specific regulations, such as higher fuel efficiency standards for fossil fuel passenger vehicles, which will lower the cost of electric vehicles.

(7) Energy Access Supported by Renewable Energy

Although most APEC region have gained access to modern energy, some areas are still yet uncovered, particularly in some rural areas with a small population. Power distribution network from the power grid to end-users is the experience of rapid and effective rural electrification of many economies.

However, there are existing problems with low load level, high construction and maintenance costs of power lines in some places. It offers circumstances for the energy of the entire people, based on distributed energy supply available in a variety of energy, including the usage of microgrid technology. The following are some of the pertinent issues:

- Government policy, effective planning mechanism, and workable financial support for energy access efforts;
- Adjustment of regulatory systems, including electricity pricing scheme, makes power consumption affordable for the consumers;
- Appropriate business models ensure rural power projects profitability and financial sustainability;
- Technical support and assistance, and capacity building corresponding to stakeholders.

(8) Effective Regional Collaboration

It has become ever more important to engage in cross-border cooperation and share best practice with other economies with increased renewable applications. The areas of regional cooperation could include:

- Develop energy transition roadmap;

- Knowledge sharing and technology transfer;
- Capacity building;
- Support fair regional and international trade of relevant products and technical services;
- Energy connectivity/interconnected grid;
- Monitoring and verification framework to effectively support the progress of energy transition.

Chapter 3: Status of Renewable Energy Development

3.1 Electricity Consumption

The electricity consumption per capita of global and APEC regions in 2010-2018 has seen a steady rise (see table 3.1), with an average annual growth rate of 1.49% and 1.30%, respectively. The electricity consumption per capita in the APEC region is significantly higher than the rest of the world, which is 1.8 times the global average. The average value of the electricity consumption per capita in the APEC region increases by 1.22 times, from 4321 to 5292 kWh/capita.

Table 3.1 Electricity Consumption per Capita (2010-2018)

Unit：kWh/Capita

No.	Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate (%)
1	Australia	9532	9500	9235	9072	8853	8873	8749	8563	8536	-1.27
2	Brunei Darussalam	7691	7740	7637	7592	8202	8185	7757	7398	7646	-0.48
3	Canada	15204	15461	14819	14737	14269	13208	13136	13922	14150	-1.05
4	Chile	3208	3361	3576	3710	3781	3728	3853	3779	3900	2.22
5	China	2944	3298	3475	3773	3927	4046	4279	4546	4894	6.80
6	Hong Kong, China	5967	5955	6025	5934	6078	6032	6013	5936	5947	-0.06
7	Indonesia	612	652	700	745	779	785	826	843	957	4.72
8	Japan	8085	7796	7768	7765	7650	7468	7479	7603	7473	-0.75
9	Korea	9068	9424	9591	9660	9593	9709	10094	10167	10291	1.51
10	Malaysia	3705	3747	4003	4177	4297	4376	4694	4710	4848	3.39
11	Mexico	1890	2021	2113	2032	2096	2113	2192	2179	2246	1.91
12	New Zeeland	9220	9057	8904	8752	8691	8627	8284	8117	7951	-1.49
13	Papua New Guinea	439	434	437	451	461	479	482	471	499	0.92
14	Peru	1088	1172	1229	1285	1320	1389	1467	1477	1509	4.47
15	The Philippines	588	587	609	623	630	664	715	740	775	3.22
16	Russia	5087	5098	5170	5185	5130	5082	5154	5266	5257	0.44
17	Singapore	8323	8295	8319	8328	8482	8583	8672	8846	8947	0.79
18	Chinese Taipei	9437	9616	9565	9711	9923	9847	10057	10254	10494	1.08
19	Thailand	2218	2198	2378	2421	2457	2640	2742	2783	2823	3.19
20	United States	12247	12130	11873	11920	11901	11788	11786	11497	11923	-0.77
21	Viet Nam	986	1065	1174	1280	1401	1519	1681	1827	2006	10.65
APEC		**4321**	**4477**	**4544**	**4696**	**4808**	**4781**	**4907**	**5047**	**5292**	**2.53**
World		**2591**	**2643**	**2675**	**2723**	**2742**	**2752**	**2805**	**2845**	**2938**	**1.49**

Calculation method: electricity consumption per capita=final electricity consumption/population;
Source: population data source APEC statistics database: http://statistics.apec.org/; world and China's final electricity consumption data source IEA: https://www.iea.org/countries/china; other economies final electricity consumption APEC Energy Database: https://www.egeda.ewg.apec.org/egeda/database_info/index.html .

In 2018, Canada had the highest electricity consumption per capita in the APEC region, reaching 5292 kWh/capita, while the lowest electricity consumption was in Papua New Guinea, with 499 kWh/capita, which is 28.5 times lesser than Canadian electricity consumption per capita. Only four APEC economies, namely Canada, the United States, Chinese Taipei, and Korea, with electricity consumption per capita exceeding 10000 kWh. Other ten APEC economies, including Malaysia, China, and Chile, had electricity consumption per capita below the APEC average, while other seven economies, including Thailand, Mexico, Viet Nam, Peru, Indonesia, the Philippines and Papua New Guinea, having electricity consumption per capita below the global average.

Moreover, in 2018, Indonesia, the Philippines, and Papua New Guinea consumed less than 1000 kWh/capita, which is one-tenth lesser than the average value in Canada, the United States and other developed economies.

As can be observed from the growth rate of electricity consumption per capita, seven APEC economies, New Zealand; Australia; Canada; the United States; Japan; Brunei; and Hong Kong, China experienced negative growth. In comparison, other 14 economies recorded positive growth. Eight of them, including Viet Nam, China, Indonesia, Peru, Malaysia, the Philippines, Thailand,

and Chile, had an annual electricity consumption that was growing by 2% on an annual basis, representing 10.6%, 6.8%, 4.7%, 4.5%, 3.4%, 3.2%, 3.2% and 2.2%, respectively. This demonstrates that the level of power development among APEC economies varies significantly. Developing economies, including China, have a huge gap with developed economies and have potential for further electricity demand increase.

3.2 Energy Intensity

From 2010 to 2018, the global and the APEC energy intensity both decreased, with an average annual decline of 1.12 % and 1.14 %, respectively, as shown in Table 3.2. The APEC region's average annual drop was larger than the global average. The average energy intensity of the APEC region decreased from 0.118 Toe/1000USD to 0.105 Toe/1000USD, a decrease of 10.8%. The APEC region's energy intensity is 88% lower than the global average.

The three economies with the highest energy intensity in APEC are Viet Nam, Russia and China, while the economies with the lowest energy intensity are Hong Kong, China, Singapore and Japan. Among them, Viet Nam has reached the highest energy intensity of 0.305 Toe/1000USD in 2018, while Hong Kong, China had the lowest energy intensity of 0.023 Toe/1000 USD, 13 times lesser than Viet Nam. The energy intensity of the world's largest economy, the United States, and the second-largest economy, China, both have reached 0.081 Toe/1000USD and 0.167 Toe/1000 USD in 2018, respectively, indicating energy intensity in China 2.5 lesser than in the United States. Malaysia, Indonesia, Papua New Guinea, Thailand, China, Russia, and Viet Nam are seven APEC economies with higher energy intensity than the global average.

Table 3.2 Global and the APEC Energy Intensity (2010-2018)

Unit：Toe/1000USD（Constant 2010 USD）

No.	Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate (%)
1	Australia	0.063	0.063	0.061	0.061	0.059	0.058	0.056	0.056	0.055	0.00
2	Brunei Darussalam	0.058	0.061	0.063	0.063	0.067	0.067	0.064	0.068	0.070	-2.22
3	Canada	0.104	0.105	0.101	0.101	0.098	0.095	0.093	0.094	0.097	0.61
4	Chile	0.104	0.105	0.099	0.102	0.094	0.094	0.096	0.096	0.097	0.84
5	China	0.270	0.262	0.252	0.242	0.231	0.221	0.208	0.197	0.167	2.74
6	Hong Kong, China	0.029	0.028	0.028	0.027	0.026	0.025	0.025	0.024	0.023	2.23
7	Indonesia	0.183	0.188	0.186	0.166	0.162	0.153	0.142	0.145	0.126	2.63
8	Japan	0.049	0.048	0.047	0.046	0.045	0.043	0.042	0.042	0.040	1.97
9	Korea	0.109	0.107	0.105	0.104	0.100	0.099	0.099	0.097	0.095	1.42
10	Malaysia	0.141	0.130	0.140	0.141	0.138	0.131	0.134	0.130	0.128	0.99
11	Mexico	0.104	0.103	0.100	0.099	0.095	0.094	0.092	0.091	0.091	1.33
12	New Zeeland	0.082	0.080	0.078	0.077	0.078	0.075	0.073	0.073	0.070	1.58
13	Papua New Guinea	0.198	0.201	0.197	0.195	0.176	0.165	0.160	0.158	0.162	2.49
14	Peru	0.105	0.101	0.099	0.100	0.098	0.101	0.101	0.096	0.096	0.84
15	The Philippines	0.125	0.121	0.115	0.114	0.111	0.112	0.113	0.111	0.106	1.62
16	Russia	0.249	0.246	0.239	0.226	0.235	0.238	0.244	0.249	0.252	-0.14
17	Singapore	0.041	0.040	0.038	0.038	0.039	0.039	0.038	0.037	0.037	1.01
18	Chinese Taipei	0.104	0.102	0.098	0.097	0.093	0.092	0.092	0.089	0.104	1.78
19	Thailand	0.206	0.205	0.197	0.198	0.192	0.192	0.187	0.181	0.183	1.15
20	United States	0.092	0.088	0.084	0.086	0.085	0.082	0.081	0.079	0.081	1.32
21	Viet Nam	0.393	0.388	0.375	0.363	0.359	0.383	0.379	0.369	0.305	0.42
APEC		**0.118**	**0.119**	**0.117**	**0.115**	**0.113**	**0.110**	**0.108**	**0.105**	**0.105**	**1.14**
World		**0.134**	**0.131**	**0.130**	**0.129**	**0.126**	**0.124**	**0.123**	**0.121**	**0.120**	**1.12**

Calculation method: energy intensity = final energy consumption / GDP, constant 2010 USD (in Millions);
Source: China's terminal energy consumption data source IEA: https://www.iea.org/countries/china; other economy terminal energy consumption data Source APEC Energy Database https://www.egeda.ewg.apec.org/egeda/database_info/index.html; GDP Data Source APEC Statistics: http://statistics.apec.org/ .

As can be observed from the annual decline in energy intensity in the APEC region, apart from Brunei, the rest of the 20 APEC economies, all have seen an annual decrease in their energy intensity from 2010 to 2018. Other nine APEC economies, including Thailand; Mexico; Japan; the United States; Chinese Taipei; Hong Kong, China; Papua New Guinea; Indonesia; and China, all experienced an annual fall of energy intensity by more than 1.5%.

According to the Asia Pacific Energy Research Centre (APERC), the APEC region's overall energy intensity declined by 22.1% between 2005 and 2017, as stated in the 2011 APEC Leaders' Declaration, which set the APEC energy intensity target of reducing the region's total energy intensity by 45% from 2005 levels by 2035.

3.3 Development of Renewable Energy

3.3.1 Renewable Electricity Generation

Table 3.3 indicates that the share of renewable energy generation increased in both the global and APEC region from 2010 to 2018, with average annual growth rate of 2.98 % and 4.54 %, respectively. The APEC region grew at a faster rate than the rest of the world on an annual basis. The APEC region's average annual growth rate was higher than the global average. However, by 2018, the world and APEC region had 24.6% and 22.3% of renewable energy generation, respectively, with the APEC region being lower than the global average.

Singapore; Chinese Taipei; Korea; Hong Kong, China; and Brunei are the only APEC economies that generate less than 5% of their electricity from renewable sources, whereas the rest of the economies generate more than 14%. Renewable energy generation in New Zealand, Canada, Peru, and Chile was 83.1%, 65.4%, 60.9%, and 46.8% in 2018, respectively. Viet Nam, Papua New Guinea, China, and the Philippines are among the economies that generated more than 20% of their electricity from renewable resources.

By observing the average annual growth rate of renewable energy generation from 2010 to 2018, it can be seen that the rate of Mexico, the Philippines, Papua New Guinea, Malaysia and Indonesia is negative, indicating that the development of renewable energy lags behind the growth of electricity demand, and the development of renewable energy still need to be accelerated in those economies. New Zealand, Canada, and Peru, which generate more than 40% of their electricity from renewable resources, are expanding at an average annual rate of 1.5%, 0.7%, and 0.8%, respectively, reflecting an average annual growth rate of less than 2%.

To continue scaling-up the use of renewable energy, innovative approaches are needed. Hong Kong, China; Russia; and Brunei’s renewable generations are growing at a rate of less than 2% on an annual basis. Speeding-up renewable energy growth is required in the region.

Table 3.3 Global and APEC Economies Share of Renewable Energy Generation (2010-2018)

Unit: %

No.	Economy	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate (%)
1	Australia	8.6	10.4	10.5	13.1	14.6	13.3	14.5	15.6	17.0	10.91
2	Brunei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.28
3	Canada	61.7	62.9	63.8	64.2	63.7	63.7	65.1	65.7	65.4	0.71
4	Chile	40.3	39.6	36.5	35.7	42.9	43.6	43.3	44.0	46.8	1.82
5	China	18.5	16.6	19.9	19.9	22.4	23.6	24.5	24.7	25.3	4.04
6	Hong Kong, China	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	15.13
7	Indonesia	20.0	16.1	15.0	15.9	14.8	14.0	15.5	16.2	14.2	-3.15
8	Japan	9.8	10.6	10.1	11.1	12.8	14.7	14.5	16.2	16.8	8.31
9	Korea	1.2	1.4	1.4	1.6	1.6	1.9	2.8	3.3	3.9	24.03
10	Malaysia	6.4	6.6	8.0	9.5	9.6	11.3	14.0	14.0	16.7	17.77
11	Mexico	16.6	14.9	13.8	13.3	17.5	15.3	15.3	16.0	16.3	-0.19
12	New Zealand	73.4	76.3	71.9	74.3	79.3	80.2	84.4	81.3	83.1	1.49
13	Papua New Guinea	32.8	35.7	35.0	33.5	31.6	29.8	29.0	29.1	28.2	-0.25
14	Peru	56.5	55.6	55.6	52.2	50.5	50.6	50.1	58.0	60.9	0.86
15	Philippine	26.4	28.8	28.5	26.5	25.7	25.5	24.3	24.7	22.8	-1.52
16	Russia	16.0	15.7	15.5	17.0	16.4	15.8	16.9	17.0	17.4	0.93
17	Singapore	3.3	3.4	3.4	3.9	4.0	4.2	4.6	4.3	4.1	2.80
18	Chinese Taipei	2.9	2.9	3.6	3.7	3.2	3.4	4.2	4.0	3.9	4.17
19	Thailand	5.7	12.7	12.1	11.8	12.0	12.2	20.5	19.4	22.8	33.63

20	U. S	10.1	12.2	12.0	12.7	13.0	13.2	14.8	16.9	16.8	7.29
21	Viet Nam	38.7	41.2	48.8	49.0	46.5	36.1	36.6	33.7	39.6	0.26
APEC		**15.9**	**16.3**	**17.4**	**18.0**	**19.2**	**19.8**	**21.0**	**21.9**	**22.3**	**4.54**
World		**19.4**	**19.7**	**20.8**	**21.5**	**22.3**	**22.6**	**23.5**	**24.1**	**24.6**	**2.98**

Calculation method: share of renewable energy power generation = renewable energy power generation / total power generation;
Source: renewable energy power generation in Hong Kong, China APEC Energy Database https://www.egeda.ewg.apec.org/egeda/database_info/index.html;
IRENA: Renewable energy statistics 2020: https://www.irena.org/publications/2020/Jul/Renewable-energy-statistics-2020; IEA: https://www.iea.org/countries/china;
APEC Energy Database: https://www.egeda.ewg.apec.org/egeda/database_info/index.html;
IEA: https://www.iea.org.

3.3.2 Renewable Generation Capacity

From 2010 to 2018, the share of renewable energy installed capacity in the world and APEC region grew at an average annual rate of 4.26% and 6.05 %, respectively, as shown in Table 3.4, indicating that the average annual growth rate in the APEC region was higher than the global average. However, in 2018, the global and APEC region accounted for 32.9 % and 29.8 % of renewable energy installed capacity, respectively, reflecting a lower growth rate in the APEC region than at the global level.

Table 3.4 Share of Renewable Energy Installed Capacity (2010-2018)

Unit: %

No.	Economy	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate (%)
1	Australia	18.7	20.8	22.8	25.1	25.5	27.1	28.8	30.8	36.7	8.06
2	Brunei	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-2.62
3	Canada	61.1	62.3	63.3	64.8	64.4	64.4	67.4	67.2	67.3	1.27
4	Chile	37.9	38.2	38.9	39.0	40.6	39.4	37.9	39.1	39.5	0.38
5	China	22.6	23.6	24.7	26.8	28.1	29.4	30.7	33.8	35.5	6.17
6	Hong Kong, China							0.2			
7	Indonesia	20.0	17.5	14.0	14.8	13.6	11.4	15.0	15.0	14.8	-3.13
8	Japan	12.6	12.8	13.1	14.7	16.5	19.3	21.7	23.4	26.1	10.83
9	Korea	3.3	3.9	3.9	4.7	5.7	7.5	8.0	8.6	9.5	19.68
10	Malaysia	11.0	13.5	14.5	17.8	21.2	24.8	24.0	22.0	21.9	12.47
11	Mexico	21.7	21.9	23.8	23.9	25.0	25.6	25.9	26.1	28.8	2.56
12	New Zealand	70.3	68.1	71.1	72.0	72.9	75.9	77.3	77.4	77.4	1.25
13	Papua New Guinea	41.1	41.1	42.8	39.2	36.0	38.9	38.8	38.3	34.3	-0.86
14	Peru	40.8	40.7	38.1	34.8	36.6	38.9	39.5	39.4	41.1	-0.43
15	Philippine	29.3	29.8	28.4	28.5	29.2	29.6	28.6	27.5	27.5	-0.80
16	Russia	21.3	21.3	21.2	20.9	19.7	20.0	19.3	19.9	20.1	-0.77
17	Singapore	1.3	1.3	1.3	1.5	1.6	1.9	2.3	2.4	2.7	11.08
18	Chinese Taipei	7.1	7.5	8.0	8.5	9.2	9.7	10.5	11.8	13.3	8.47
19	Thailand	10.1	10.7	12.0	14.1	13.4	13.6	15.5	16.9	17.8	8.34
20	U. S	13.2	13.9	15.4	16.0	16.8	18.2	19.8	20.9	22.0	7.22
21	Viet Nam	38.5	39.8	48.6	52.8	44.8	42.0	41.5	42.8	41.8	1.40
APEC		**19.3**	**20.1**	**21.1**	**22.6**	**23.5**	**24.9**	**26.3**	**28.2**	**29.8**	**6.05**
World		**23.8**	**24.6**	**25.6**	**26.6**	**27.5**	**28.9**	**29.9**	**31.5**	**32.9**	**4.26**

Calculation method: installed capacity of renewable energy = installed capacity of renewable energy/total installed capacity of power generation;
Source: APERC, APEC Energy Overview 2018: https://aperc.or.jp/publications/reports/energy_overview.php; IRENA, Renewable energy statistics 2020: https://www.irena.org/publications/2020/Jul/Renewable-energy-statistics-2020; Chinese Taipei's total installed power generation capacity data sourced from the Energy Bureau of the Ministry of Economic Affairs, Taipei, China; "Energy Statistics Handbook 2018": https://www.moeaboe.gov.tw; UN"2017 Energy Statistics Yearbook" : https://unstats.un.org/unsd/energystats/pubs/yearbook/.

New Zealand, Canada, Viet Nam, Peru, Chile, Papua New Guinea, China, and Australia all had more than 30% renewable energy installed capacity, New Zealand and Canada showing the greatest renewable energy installed capacity with 77.4% and 67.3%, respectively. Whereas Thailand; Indonesia; Chinese Taipei; Korea; Singapore; Brunei; and Hong Kong, China were among the seven economies with less than 20% of their installed capacity. It can be observed from the average annual growth rate of renewable energy installed capacity that Indonesia, Brunei, Papua New Guinea, the Philippines, and Russia experienced negative growth from 2010 to 2018.

The installed capacities in Chile, New Zealand, Canada, and Viet Nam grew at less than 2%, and therefore need to accelerate their renewable energy growth. Economies including China, the United States, Australia, Thailand, Chinese Taipei, Singapore, Malaysia and Korea increased by more than 5% every year. Other economies like Japan, Singapore and Malaysia increased at a rate of more than 10% per year.

During the past decade (2010-2019), the global installed capacity of renewable energy doubled from 1226.9GW to 2536.9GW, and the new installed capacity has reached 1310GW, of which 63.6% came from the APEC region as Table 3.5 indicates.

While in the APEC region, the installed capacity of renewable energy expanded by more than double from 610.5 GW to 1444.3 GW over the decade, and the global share has increased from 49.76 % to 56.93 %. The annual growth rate of renewable energy installed capacity in the APEC region has reached 9% over the last five years (2015-2019), outpacing the global average growth rate of 7.5 %.

China accounted for more than half of the installed renewable energy capacity in the APEC region in 2019, reaching 52.53%, followed by the United States (18.31%), Canada (6.99%), Japan (6.75 %), and Russia (3.82%). In the past five years, in the region, the installed capacity of renewable energy increased by 447.4GW, which 62.5% came from China, 15.6% from the United States and 7.9% from Japan. China, the United States and Japan accounted for 86% of the installed capacity growth. While Korea, Chinese Taipei, Singapore, Australia, China, Japan, Viet Nam, Thailand, Mexico and Peru grew at a rapid rate of over 8%, which was higher than the global average. Korea recorded the highest annual growth rate of 20.5%, followed by Chinese Taipei (17.5%) and Singapore (14.1%). China, the United States and Japan's average annual growth rates for the last five years (2015-2019) was 11.7%, 7.1%, and 11.5%, respectively. While in Russia, Malaysia, Canada, New Zealand, and Papua New Guinea, renewable energy was growing at a slower rate, averaging less than 2% annually over the last five years (2015-2019).

Table 3.5 Renewable Installed Capacity in the Global and APEC Economies (2010-2019）

Unit：MW

Economy	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Share of economies, 2019 (%)**	**Growth rate, 2015-2019 (%)**
China	233257	267898	302101	359516	414651	479103	541006	620846	695438	758626	52.53	11.7
U.S.	137724	146570	163940	170812	180202	194900	215087	229677	246596	264504	18.31	7.1
Canada	80816	82820	83967	85906	88925	95414	97176	99328	100140	100997	6.99	1.2
Japan	36028	37396	38794	44592	52098	61951	72617	78918	90579	97462	6.75	11.5
Russia	47375	47418	49384	50041	50958	51304	51338	54313	54611	55190	3.82	1.5
Australia	11242	12888	14649	16068	17370	18468	19304	20458	25438	31534	2.18	14.1
Mexico	13515	13480	14770	15176	16568	17296	18825	19462	22128	25648	1.78	9.7
Viet Nam	8814	10241	13713	14901	15264	16208	17486	18214	18712	24519	1.70	10.3
Korea	2819	3322	3687	4330	5716	7721	8901	10535	12050	15653	1.08	20.5
Thailand	4809	5061	5698	6701	7406	7968	9442	10243	11374	11860	0.82	9.8
Chile	6158	6697	7055	7677	8328	8451	9298	10288	10855	11488	0.80	7.2
Indonesia	6856	7147	7489	8261	8417	8513	8868	9155	9485	9861	0.68	3.2
Malaysia	2797	3895	4241	5677	6357	7551	7958	7333	7540	8046	0.56	1.3
Chinese Taipei	2888	3090	3286	3498	3750	3990	4428	4961	5940	7479	0.52	17.5
New Zealand	6650	6650	6841	6930	7132	7170	7182	7198	7243	7276	0.50	0.3
Philippine	4809	4817	4848	4855	5277	5618	6264	6412	6577	6695	0.46	3.8
Peru	3516	3539	3698	3841	4098	4701	5730	5825	6252	6640	0.46	8.2
Singapore	131	133	136	172	209	251	307	329	372	467	0.03	17.2
Papua New Guinea	301	301	313	314	314	333	333	333	333	333	0.02	0.0
Brunei	1	1	1	1	1	1	1	1	1	1	0.00	0.0
Hong Kong, China	--	--	--	--	--	--	30	--	--	--	--	--
APEC	610506	663364	728611	809269	893041	996912	1101551	1213829	1331664	1444279	100.00	9.0
World	1226853	1332236	1445233	1563196	1692680	1846060	2008547	2182449	2361061	2536853	--	7.5
APEC's global share (%)	49.76	49.79	50.41	51.77	52.76	54.00	54.84	55.62	56.40	56.93	--	--

Source: Hong Kong, China is 2016 data, source APERC, APEC ENERGY OVERVIEW 2018; data source for other economies are IRENA, Renewable capacity statistics 2020;
Note: The installed capacity of renewable energy does not include the installed capacity of pumped storage power stations.

(1) Hydropower

Table 3.6 shows the status of hydropower installed capacity in the global and APEC economies. During the last decade, the global installed hydroelectric capacity (excluding pumped storage power stations) almost doubled to 1189.4GW, including newly built capacity that reached 264.4GW, of which APEC regions accounted for 61.1%. Between 2010 and 2019, the installed hydropower capacity in the APEC region expanded by 1.33 times, from 488.0GW to 649.5GW, and the global share increased from 52.76 % to 54.60%; more than half of the APEC region's hydropower installed capacity came from China in 2019. China accounted for 50.21 %, followed by the US (12.87%), Canada (12.45%), Russia (8.10%), and Japan (4.33%).

The average annual growth rate of hydropower installed capacity in the APEC region was 1.3% over the last five years (2015-2019), lower than the global average growth rate of 1.7%; installed hydropower capacity increased by 39.7GW over the last five years, with 74.5 % capacity coming from China, 7% from the United States, 5.4% from Viet Nam, 4.1% from Canada, 4% from Peru. The five economies increasingly contributed to the installed capacity in APEC region by 95%. Hydropower installed capacity in Peru grew at the fastest rate of 7.7% during 2015-2019, followed by Viet Nam and China, that represented 2.7% and 2.0%, respectively; economies with growth rates of more than 1.0% include Malaysia, Indonesia, Russia, and the Philippines. New Zealand, Chinese Taipei, Australia, Japan, and Papua New Guinea. It is noted that there had almost no increase in hydropower installed capacity in the five economies of New Zealand, Chinese Taipei, Australia, Japan, and Papua New Guinea in the last five years.

Table 3.6 Hydropower Installed Capacity (2010-2019)

Unit：MW

Economies	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Share of economies, 2019 (%)**	**Growth rate, 2015-2019 (%)**
China	199127	214598	229138	258908	282750	296500	305380	314385	322271	326113	50.21	2.0
U.S.	82512	82354	82442	82903	83386	83374	83665	83644	83743	83617	12.87	0.1
Canada	74901	75396	75363	75363	75363	79246	80085	80657	80830	80879	12.45	0.4
Russia	46085	46128	48094	48752	49493	49782	49801	52579	52579	52579	8.10	1.1
Japan	27987	27770	27815	27813	27873	28111	28193	28120	28137	28114	4.33	0.0
Viet Nam	8653	10080	13552	14718	15069	15905	17131	17809	17989	18069	2.78	2.7
Mexico	11597	11571	11626	11633	12464	12223	12580	12642	12642	12671	1.95	0.7
Australia	7461	7461	7461	7461	7461	7461	7461	7461	7462	7468	1.15	0.0
Chile	5467	5946	5992	6094	6445	6499	6671	6684	6679	6679	1.03	0.6
Malaysia	2135	3121	3449	4535	4761	5742	6121	6145	6165	6245	0.96	1.8
Peru	3438	3451	3484	3556	3662	4148	5189	5249	5349	5741	0.88	7.7
Indonesia	3741	3953	4156	5177	5242	5275	5397	5465	5561	5616	0.86	1.3
New Zealand	5279	5279	5368	5381	5381	5381	5381	5381	5381	5389	0.83	0.0
Thailand	2988	3000	3008	3015	3048	3079	3089	3089	3107	3107	0.48	0.2
The Philippines	2826	2832	2843	2843	2858	2877	2887	2896	2983	3024	0.47	1.0
Chinese Taipei	1977	2041	2081	2081	2081	2089	2089	2089	2092	2092	0.32	0.0
Korea	1625	1718	1747	1752	1767	1771	1785	1789	1790	1808	0.28	0.4
Papua New Guinea	230	230	240	240	240	258	258	258	258	258	0.04	0.0
APEC	488029	506929	527859	562225	589344	609721	623163	636342	645018	649469	100.00	1.3
World	925077	952564	982946	1028654	1065799	1098643	1128527	1155689	1176969	1189448	--	1.7
APEC's global share (%)	52.76	53.22	53.70	54.66	55.30	55.50	55.22	55.06	54.80	54.60	--	--

Source: IRENA, Renewable Capacity Statistics 2020;
Note: Installed hydropower does not include installed pumped storage power station.

(2) Pumped storage power station

Table 3.7 shows the pumped storage installed capacity status during 2010 and 2019. The table indicates that capacity of global pumped storage power plants increased from 99.8GW to 120.8GW, which is an increase of 1.21 times during the last decade. The newly built capacity reached 21.1GW, of which the APEC region accounted for 81.0 %. The installed hydropower capacity in the APEC region increased by 1.26 times in the last ten years (2010-2019), and the global share had grown from 65.35% to 68.08%; China's pumped storage power plants in the APEC region are primarily concentrated in China, Japan, the United States, Korea, and Chinese Taipei, the five economies accounting for the majority of the global share reaching 95%. China is the largest with 36.82%, followed by Japan (26.61%), the United States (23.28%), Korea (5.71%) and Chinese Taipei (3.16%).

During the past five years (2015-2019), the average annual growth rate of pumped storage power plants in the APEC region was 2.1%, 1.6% higher than the global average; the installed capacity of pumped storage power plants had increased by 7.7GW in the last five years, of which China accounted for 94.8 % of new capacity while other new capacities came from the United States and Russia with 3.7% and 1.8%, respectively. By observing all these changes in pumped storage development, only China has been actively developing pumped storage power stations in the APEC region during the last five years, with an average annual growth rate of 6.3%. The United States and Russia have seen slow growth, with average annual growth rates of 3.7% and 1.8%, respectively, while other economies still lag in developing pumped storage power plants capacity.

Table 3.7 Installed Capacity of Pumped Storage Power Plants (2010-2019)

Unit：MW

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Share of economies, 2019 (%)	Growth rate, 2015-2019 (%)
China	16930	18383	20333	21533	22110	23030	26690	29390	29990	30290	36.82	6.3
Japan	19749	20649	21119	21119	21724	21924	21924	21894	21894	21894	26.61	0.0
U. S	18511	18589	18665	18686	18776	18866	19027	19059	19104	19152	23.28	0.3
Korea	3900	4700	4700	4700	4700	4700	4700	4700	4700	4700	5.71	0.0
Chinese Taipei	2602	2602	2602	2602	2602	2602	2602	2602	2602	2602	3.16	0.0
Russia	1216	1216	1216	1216	1216	1216	1216	1216	1356	1356	1.65	2.3
Australia	810	810	810	810	810	810	810	810	810	810	0.98	0.0
The Philippines	736	736	736	736	736	736	736	736	736	736	0.89	0.0
Thailand	560	560	560	560	560	560	560	560	560	560	0.68	0.0
Canada	177	177	174	174	174	174	174	174	174	174	0.21	0.0
APEC	65191	68422	70915	72136	73408	74618	78439	81141	81926	82274	100.00	2.1
World	99756	102993	105617	106856	108597	111853	116942	119849	120496	120844	--	1.6
APEC's global share (%)	65.35	66.43	67.14	67.51	67.60	66.71	67.08	67.70	67.99	68.08	--	--

Source：IRENA，Renewable capacity statistics 2020.

(3) Onshore wind power

Over the period of 2010-2019, the global onshore wind power installed capacity grew from 177.8GW to 594.4GW, showing an increase of 3.3 times during the decade, and the newly installed capacity reached 416.6GW, with 64.2 % coming from the APEC region as Table 3.8 demonstrates. The installed capacity of onshore wind power in the APEC region had increased from 78.9GW to 346.3GW, 4.4 times higher, and the global share increased from 44.38% to 58.26%; China accounted for 59.06% of the offshore wind installed capacity in the APEC region in 2019, followed by the United States (29.90 %), Canada (3.87%), Australia (2.10%), Mexico (1.90%) and Japan (1.07%).

In the last five years (2015-2019), the average annual growth rate of onshore wind power installations in the APEC region was 10.3%, exceeding the global average growth rate that only stands for 9.4%; onshore wind power installations increased by 117.8GW in the last five years, with 62.9% of that coming from China, followed by the United States (26.3%), Mexico (2.8%), Australia (2.6%), Canada (1.9%) and Thailand (1.1%). In the past five years, onshore wind power in the four economies, including Indonesia, Russia, Viet Nam, and Thailand, had developed by leaps and bounds, with a rapid increase in installed capacity hitting an average annual growth rate more than 100%. The six economies of Mexico, Chile, Korea, Australia, China and Peru experienced an average annual growth rate of more than 10% in the past five years.

Table 3.8 Onshore Wind Power Installed Capacity (2010-2019)

Unit：MW

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Share of economies, 2019 (%)	Growth rate, 2015-2019 (%)
China	29533	46145	61306	76314	96379	130489	147037	161586	180077	204548	59.06	11.4
USA	39135	45676	59075	59973	64232	72573	81257	87568	94388	103555	29.90	8.5
Canada	3967	5265	6201	7801	9694	11214	11973	12403	12816	13413	3.87	3.9
Australia	1864	2127	2561	3221	3797	4234	4327	4816	5818	7272	2.10	14.4
Mexico	519	601	1815	2122	2569	3271	4051	4199	4875	6591	1.90	20.3
Japan	2269	2394	2537	2596	2703	2755	3187	3418	3602	3721	1.07	7.0
Chile	163	184	202	301	736	910	1039	1305	1524	1620	0.47	15.6
Thailand	6	7	112	223	225	234	507	628	1103	1507	0.44	108.8
Korea	382	425	459	571	602	837	1027	1170	1347	1439	0.42	14.4
Chinese Taipei	476	523	571	614	637	647	682	684	705	717	0.21	2.2
New Zealand	524	524	623	623	682	689	689	689	689	689	0.20	0.0
The Philippines	33	33	33	33	337	427	427	427	427	427	0.12	0.0
Peru	1	1	1	1	143	240	240	240	372	372	0.11	11.0
Viet Nam	31	31	31	37	37	37	61	106	138	275	0.08	128.6
Russia	10	10	10	10	10	11	11	11	52	102	0.03	165.5
Indonesia	0	1	1	1	1	1	1	1	76	76	0.02	1500.0
Hong Kong, China	--	--	--	--	--	--	1	--	--	--	0.00	--
APEC	78913	103947	135538	154441	182784	228569	256516	279251	308009	346324	100.00	10.3
World	177794	216244	261575	292749	340808	404558	452485	495565	540191	594396	--	9.4
APEC's global share (%)	44.38	48.07	51.82	52.76	53.63	56.50	56.69	56.35	57.02	58.26	--	--

Source: Hong Kong, China is 2016 data, source APERC, APEC ENERGY OVERVIEW 2018;
Data source of other economies: IRENA, Renewable Capacity statistics 2020.

(4) Offshore wind power

As shown in Table 3.9, the global installed capacity of offshore wind power increased from 3.1GW to 28.3GW in the past ten years (2010-2019), an increase of 9.3 times and the newly installed capacity reached 25.3GW, of which 24.5% came from the APEC region. The installed capacity of offshore wind power in the APEC region had grown by 50.6 times, jumping from 0.125GW to 6.324GW in the last decade 2010-2019, and the global share has surged from 4.09% to 22.34%. Six economies had a positive contribution to the development of offshore wind power projects, of which more than 90% of offshore wind power installed capacity came from China, accounting for 93.77% in 2019, followed by Chinese Taipei (2.02%), Viet Nam (1.57%) and Korea (1.15%), Japan (1.03%) and the United States (0.46%).

During the past three years (2017-2019), the average annual growth rate of offshore wind power installations in the APEC region reached 36.1%, exceeding the global average growth rate of 16.8%; the offshore wind power installations in the past three years increased 3.3GW, of which 95.5% of the new capacity came from China, while 3.6% from Chinese Taipei, and 0.8% from Korea. Viet Nam, Japan, and the United States have not yet added new installed capacity for their offshore wind power projects during the period.

Table 3.9 Offshore Wind Power Installed Capacity (2010-2019)

Unit：MW

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Share of economies, 2019 (%)	Growth rate, 2015-2019 (%)
China	100	210	291	417	440	559	1480	2788	4588	5930	93.77	37.6
Chinese Taipei								8	8	128	2.02	500.0
Viet Nam				16	16	99	99	99	99	99	1.57	0.0
Korea			5	5	11	11	41	46	73	73	1.15	19.6
Japan	25	25	25	50	50	53	60	65	65	65	1.03	0.0
USA					0	0	29	29	29	29	0.46	0.0
APEC	125	235	321	488	517	722	1709	3035	4862	6324	100.00	36.1
World	3056	3776	5334	7171	8492	11717	14342	18837	23629	28308	--	16.8
APEC's global share (%)	4.09	6.22	6.02	6.81	6.09	6.16	11.92	16.11	20.58	22.34	--	

Source：IRENA，Renewable capacity statistics 2020.

(5) Solar PV

Table 3.10 indicates changes in solar photovoltaic (PV) installed capacity. Through the last decade (2010-2019), the global installed capacity of solar power generation rose from 40.3GW to 580.2GW, an increase of 14.4 times, with an additional new installed capacity of 539.9GW accounting for 68.8% of total capacity that represents the APEC region’s contribution. On the other hand, over the last ten years (2010-2019), the installed solar PV power generation capacity in the APEC region has increased by 39.5 times, from 9.6GW to 380.9GW, while the global share increased from 23.91% to 65.65 %; China accounted for more than half of the APEC region's installed photovoltaic power generation capacity, reaching 53.84% in 2019, followed by Japan (16.24%), the United States (15.89%), Australia (4.18%), and Korea (2.76%).

Table 3.10 Installed Capacity of Solar Photovoltaic Power Generation (2010-2019)

Unit：MW

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Share of economies, 2019 (%)	Growth rate, 2015-2019 (%)
China	1022	3108	6718	17748	28388	43538	77788	130801	175016	205072	53.84	74.2
Japan	3599	4890	6430	12107	19334	28615	38438	44226	55500	61840	16.24	23.2
U.S.	2909	5172	8137	11759	15984	21684	32958	41357	51426	60540	15.89	35.8
Australia	1088	2470	3796	4565	5284	5943	6686	7352	11303	15928	4.18	33.6
Korea	650	730	1024	1555	2481	3615	4502	5835	7130	10505	2.76	38.1
Viet Nam	5	5	5	5	6	6	6	9	106	5695	1.50	18963.3
Mexico	29	39	60	82	116	173	389	674	2541	4426	1.16	491.7
Chinese Taipei	22	118	223	392	620	842	1245	1768	2738	4150	1.09	78.6
Canada	221	497	766	1210	1843	2517	2661	2913	3100	3310	0.87	6.3
Thailand	49	79	377	824	1299	1420	2446	2697	2962	2982	0.78	22.0
Chile	--	--	2	15	221	576	1125	1809	2137	2648	0.70	71.9
Russia	0	0	0	1	5	61	76	275	535	1064	0.28	328.9
The Philippines	1	1	1	1	23	166	775	897	897	922	0.24	91.1
Malaysia	1	1	25	97	166	229	279	370	536	882	0.23	57.0
Peru	13	18	103	109	134	139	146	153	345	341	0.09	29.1
Singapore	3	5	8	12	25	46	97	118	160	255	0.07	90.9
Indonesia	15	17	26	38	42	51	58	60	62	198	0.05	57.6
New Zealand	3	3	4	8	21	36	52	69	90	115	0.03	43.9
Papua New Guinea	0	0	0	0	0	1	1	1	1	1	0.00	0.0
Brunei Darussalam	1	1	1	1	1	1	1	1	1	1	0.00	0.0
Hong Kong, China	--	--	--	--	--	--	1	--	--	--	0.00	--
APEC	9631	17154	27706	50529	75993	109659	169730	241385	316586	380875	100.00	49.5
World	40277	72030	101511	135740	171519	217243	290961	383598	483078	580159	--	33.4
APEC's global share (%)	23.91	23.82	27.29	37.22	44.31	50.48	58.33	62.93	65.54	65.65	--	--

Source: Hong Kong, China is 2016 data, source APEC, APEC ENERGY OVERVIEW 2018; data source for other economies is IRENA, Renewable capacity statistics 2020.

The average annual growth rate of installed photovoltaic power generation in the APEC region was 49.5 % in the last five years (2015-2019), exceeding the global average growth rate of 33.4 %; installed photovoltaic power generation capacity increased by 271.2GW by 2019, with China accounting for 59.6 % of the new capacity, while the United States and Japan 14.3% and 12.3% respectively, and other economies follows, such as Australia (3.7%), Korea (2.5%), Viet Nam (2.1%), Mexico (1.6%), and Chinese Taipei (1.2%). In the last five years (2015-2019), except for Canada; Papua New Guinea; Brunei; and Hong Kong, China the average annual growth rate of photovoltaic installations in the remaining 17 APEC economies exceeded 20%. The APEC region has seen great development in solar PV deployment, becoming the fastest-growing renewable energy source in the region.

(6) Solar thermal

Table 3.11 illustrates solar thermal capacity's changes during the decade 2010-2019. Over the period, global installed solar thermal power has increased by five times, from 1.2GW to 6.3GW, and 5GW of additional solar thermal power has been installed, with a share of 34.4 % of the global, in the APEC region. The installed solar thermal power generation capacity in the APEC region increased by 4.6 times from 0.476GW to 2.2GW over the decade, while the global share declined from 37.06% to 35.06%.

Solar thermal power plants have been significantly developed in the United States, China, Mexico, Thailand, and Australia, with the United States and China contributing for 99% of installed solar thermal power generation capacity. In 2019, the United States held 79.91% of the market, while China accounted for 19.14%. From 2017 to 201, the annual growth rate of installed solar thermal power in the APEC region was 7.7%, which was lower than the global average of 8.8%. Solar thermal power installed capacity jumped by 0.414GW in the last three years, with 96.6 % coming from China and 3.4% from Mexico. The United States, Thailand, and Australia did not add significant new solar thermal in their power generation fleets over the last three years.

Table 3.11 Solar Thermal Power Installed Capacity (2010-2019)

Unit：MW

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Share of economies, 2019 (%)	Growth rate, 2015-2019 (%)
U. S	473	472	476	1286	1667	1758	1758	1758	1758	1758	79.91	0.0
China			1	11	11	11	21	21	221	421	19.14	634.9
Mexico									14	14	0.64	--
Thailand			5	5	5	5	5	5	5	5	0.23	0.0
Australia	3	3	3	3	3	3	3	2	2	2	0.09	0.0
APEC	476	475	485	1305	1686	1777	1787	1786	2000	2200	100.00	7.7
World	1266	1705	2567	3842	4499	4750	4860	4959	5674	6275	--	8.8
APEC's global share (%)	37.60	27.86	18.89	33.97	37.47	37.41	36.77	36.02	35.25	35.06	--	

Source：IRENA, Renewable capacity statistics 2020.

(7) Biomass power generation

As shown in Table 3.12, global installed capacity of biomass power generation almost doubled the past decade (2010-2019), an increase from 65.6GW to 123.8GW, and the newly installed capacity reached 58.2GW, of which 41.5% is the new installed capacity coming from the APEC region. During the past decade (2010-2019), more than 50 % of biomass power generation capacity in the APEC region came from China and the United States, which accounted for 33.34% and 25.10% respectively in 2019, followed by Thailand (8.59%), Canada (6.81%), Japan (6.45%), Indonesia (3.71%) and Korea (3.17%).

The average annual growth rate of biomass power generation capacity in the APEC region was 6.3% in the last five years (2015-2019), exceeding the global average growth rate of 5.6%; power generation capacity increased by 11.8GW with a capacity contribution of 72.4 % coming from China, while Japan, Thailand, Canada, Korea, Mexico, Viet Nam, The Philippines contributing with 11%, 8.7%, 8.1%, 2.9%, 2.4%, 1.9% and 1.4% respectively. However, the biomass power installed capacity in the United States and Malaysia experienced a decline of 519MW and 661MW respectively over the past five years. While in Viet Nam, China, the Philippines, Japan, Mexico, Canada, Thailand, and Korea, installed biomass power generation capacity have grown at an average annual rate of more than 5%; among which, Viet Nam and China's growth rate exceeded 20%, 27.2% and 21.5%, respectively; the Philippines and Japan grew faster than 10%, reaching 13.7% and 13.6% respectively.

Table 3.12 Installed Capacity of Biomass Power Generation (2010-2019)

Unit: MW

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Share of economies, 2019 (%)	Growth rate, 2015-2019 (%)
China	3446	3808	4617	6089	6653	7977	9269	11234	13235	16537	33.34	21.5
U. S	10290	10487	11218	12284	12419	12969	12903	12838	12712	12450	25.10	-0.8
Thailand	1767	1975	2196	2634	2829	3231	3395	3824	4196	4258	8.59	6.4
Canada	1707	1642	1617	1512	2005	2417	2437	3335	3375	3376	6.81	7.9
Japan	1611	1780	1475	1514	1630	1901	2213	2608	2793	3197	6.45	13.6
Indonesia	1911	1950	1970	1701	1729	1748	1769	1821	1840	1841	3.71	1.1
Korea	161	194	197	192	601	1233	1292	1440	1454	1572	3.17	5.5
Russia	1197	1197	1197	1197	1370	1370	1370	1373	1370	1370	2.76	0.0
Mexico	405	382	445	516	606	723	879	1022	1105	1010	2.04	7.9
Malaysia	662	774	768	1045	1431	1580	1558	818	839	919	1.85	-8.4
Australia	825	826	827	817	824	826	826	826	852	863	1.74	0.9
Chile	528	567	859	1 267	926	466	463	466	467	502	1.01	1.5
Chinese Taipei	413	409	411	411	411	412	412	412	397	393	0.79	-0.9
The Philippines	102	104	124	131	143	233	259	276	341	393	0.79	13.7
Viet Nam	125	125	125	125	136	161	188	192	380	380	0.77	27.2
Singapore	128	128	128	160	183	205	210	211	211	211	0.43	0.6
Peru	65	70	111	175	159	175	156	183	186	186	0.38	1.3
New Zealand	118	118	120	120	124	123	119	118	118	118	0.24	-0.8
Papua New Guinea	15	15	16	18	18	18	18	18	18	18	0.04	0.0
Hong Kong, China	--	--	--	--	--	--	28	--	--	--	--	--
APEC	25476	26551	28421	30641	34197	37768	39736	43015	45889	49594	100.00	6.3
World	65626	71795	76611	83812	89891	96822	104594	110571	117740	123802	--	5.6
APEC's global share (%)	38.82	36.98	37.10	36.56	38.04	39.01	37.99	38.90	38.97	40.06	--	--

Source: Hong Kong, China is 2016 data, source APERC, APEC ENERGY OVERVIEW 2018; data source of other economies is IRENA, Renewable capacity statistics 2020.

(8) Geothermal power generation

Table 3.13 illustrates the geothermal power generation capacity's changes. In the past decade (2010-2019), the global installed capacity of geothermal power generation increased from 9.99 to 13.93 GW, an increase of 1.4 times, and the global new installed capacity was 3.9 GW, of which 35.7% of the new installed capacity comes from APEC. Over the past decade (2010-2019), the installed capacity of geothermal power generation in APEC increased from 7.83 to 9.24 GW, an increase of 1.2 times, and the global share decreased from 78.36% to 66.30%.

A total of 10 economies in APEC have developed geothermal power generation projects, including the United States, Indonesia, the Philippines, New Zealand, Mexico, Japan, Russia, Papua New Guinea, Chile and China, of which 70% of the installed geothermal power generation came from the United States, Indonesia and the Philippines. In 2019, the United States accounted for 27.66%

and Indonesia 23.07%, the Philippines 20.87%. In the past three years (2017-2019), the average annual growth rate of installed geothermal power generation in APEC was 1.9%, lower than the global average growth rate of 3.2%; In the past three years, the installed capacity of geothermal power generation increased by 0.5 GW, of which 64.4% of the new capacity came from Indonesia, 14.4% from the United States, 4.8% from New Zealand, 3.2% from Chile, 2.4% from the Philippines and 2.0% from Mexico. There was no new installed capacity of geothermal power generation in Russia, Papua New Guinea and China in recent three years.

Table 3.13 Geothermal Power Generation Installed Capacity (2010-2019)

Unit：MW

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Share of economies, 2019 (%)	Growth rate, 2015-2019 (%)
U.S.	2405	2409	2592	2607	2514	2542	2517	2483	2541	2555	27.66	1.0
Indonesia	1189	1226	1336	1344	1404	1439	1644	1809	1946	2131	23.07	5.9
The Philippines	1847	1847	1847	1847	1916	1916	1916	1916	1928	1928	20.87	0.2
New Zealand	726	726	726	798	924	941	941	941	965	965	10.45	0.9
Mexico	965	887	824	823	813	906	926	926	951	936	10.13	0.4
Japan	537	537	512	512	508	516	526	481	482	525	5.68	3.0
Russia	81	81	81	79	78	78	78	74	74	74	0.80	0.0
Papua New Guinea	56	56	56	56	56	56	56	56	56	56	0.61	0.0
Chile								24	48	40	0.43	22.2
China	24	26	26	26	26	26	26	26	26	26	0.28	0.0
APEC	7830	7795	8000	8092	8239	8420	8630	8736	9017	9236	100.00	1.9
World	9992	10081	10481	10718	11159	11814	12255	12700	13249	13931	--	3.2
APEC's global share (%)	78.36	77.32	76.33	75.50	73.83	71.27	70.42	68.79	68.06	66.30	--	--

Source：IRENA，Renewable capacity statistics 2020.

(9) Ocean energy power generation

As shown in Table 3.14, the global installed capacity of ocean energy power generation has increased from 250MW to 531MW in the past ten years (2010-2019), an increase of 2.12 times, and the new installed capacity is 281MW, which 90.7% of new installed capacity originated from the APEC region. In the past ten years (2010-2019), the installed capacity of ocean power generation in the APEC region increased from 28MW to 283MW, an increase of 10.1 times, and the global share has increased from 11.20% to 53.30%; the economies with ocean energy generation capacity includes Korea, Canada, China, Russia, and Australia. Three economies have developed ocean energy power generation projects. More than 90% of the installed ocean energy power generation capacity came from Korea. In 2019, Korea accounted for 90.46%, followed by Canada at 7.07%. In the past three years (2017-2019), there has been almost no change in the installed capacity of ocean power generation globally and the APEC region, with the newly installed capacity being only 1MW and 3MW, respectively.

Table 3.14 Installed Capacity of Ocean Energy Generation (2010-2019)

Unit：MW

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Share of economies, 2019 (%)	Growth rate, 2015-2019 (%)
Korea	1	255	255	255	255	255	255	255	255	256	90.46	0.1
Canada	20	20	20	20	20	20	20	20	20	20	7.07	0.0
China	4	4	4	4	4	4	4	4	4	4	1.41	0.0
Russia	2	2	2	2	2	2	2	2	2	2	0.71	0.0
Australia	1	1	1	1	1	1	1	1	1	1	0.35	0.0
APEC	28	282	282	282	282	282	282	282	282	283	100.00	0.1
World	250	503	509	510	513	513	524	528	529	531	--	0.2
APEC's global share (%)	11.20	56.06	55.40	55.29	54.97	54.97	53.82	53.41	53.31	53.30	--	--

Source：IRENA，Renewable capacity statistics 2020

3.4 Renewable Energy Investment

According to the Global Trends in Renewable Energy Investment Report 2020[11], global renewable energy investment reached $282.2 billion in 2019, increasing 1% from the previous year. In contrast, solar PV investment has declined by 3% to $131.1 billion, while wind power investment increased by 6% to $138.2 billion in 2019, exceeding solar PV for the first time since 2010. Investment in offshore wind power surged to $29.9 billion in the fourth quarter of 2019, an increase of 19% from the previous year. Developing economies continued to invest more in renewable energy than developed ones, with $152.2 billion in 2019 compared to $130 billion in 2019.

Table 3.15 Renewable Energy Capacity Investment in the World and APEC Major Economies (2016-2019)

Unit：$ billion						
No.	**APEC Economies**	**2016**	**2017**	**2018**	**2019**	**Share in global investment in 2019 (%)**
1	China	103.5	143	91.1	83.4	29.55
2	USA	41.4	45.7	43.4	55.5	19.67
3	Japan	14.4	13.4	17.6	16.5	5.85
4	Chinese Taipei	0.7	0.6	1.8	8.8	3.12
5	Australia	3.3	8.5	9.2	5.6	1.98
6	Chile	0.8	1.5	1.3	4.9	1.74
7	Mexico	6	6	3.8	4.3	1.52
8	Viet Nam	0.7		5.2	2.6	0.92
9	Korea	1.4	2.1	1.4	2.4	0.85
10	Russia			1.9	2.3	0.82
11	Canada	1.7	2.7	0.6	08	0.28
12	Indonesia	0.5	1	0.8	04	0.14
13	Malaysia	0	0.7	0.4	03	0.11
14	Thailand	1.4	0.7	0.3	02	0.07
15	Hong Kong, China		0.7			
16	Peru	0.4	0.3			
17	The Philippines	1	0.3			
18	Singapore	0.7				
Total APEC		172.5	227.2	178.8	188.0	66.62
World		241.6	279.8	272.9	288.2	
APEC global share (%)		71.40	81.20	65.52	65.23	

Source：Global Trends in Renewable Energy Investment 2017, 2018, 2019, 2020.

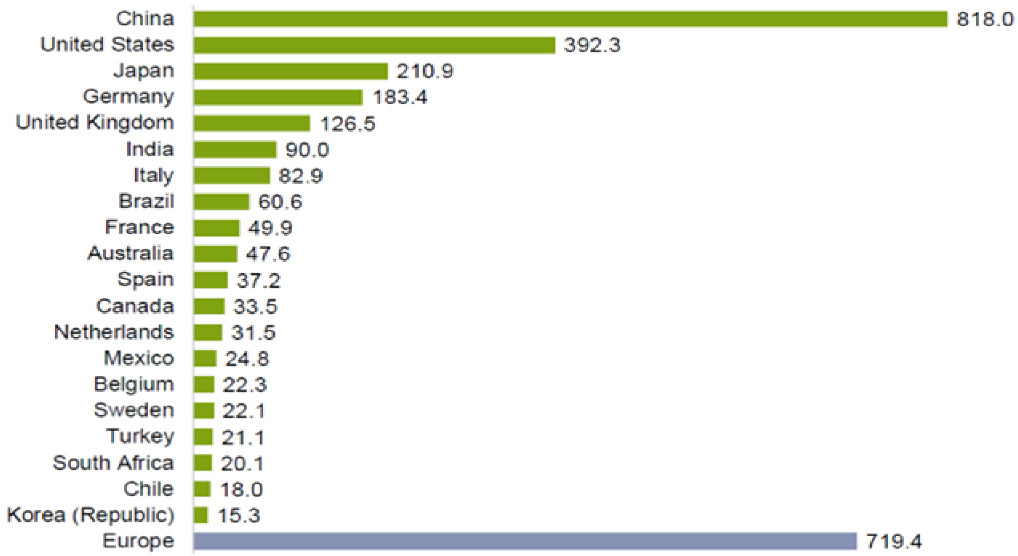
The APEC region recorded 10 of the world's top 30 renewable energy investment economies in 2019, namely China, the United States, Japan, Chinese Taipei, Australia, Chile, Mexico, Viet Nam, Korea, and Russia, with a total investment of $186.3 billion in renewable energy capacity in 2019.

Investment in renewable energy capacity in the world and major APEC economies over the period 2016-2019 is presented in Table 3.15. The APEC region accounted for more than 65% of global investment in renewable energy capacity. The APEC contributed to more than 65 % of investment in renewable energy capacity. Between 2016 and 2019, the APEC's major economies joint investment in renewable energy capacity reached more than $170 billion. China, the United States, and Japan are the top three economies in terms of investment in the APEC region, accounting for 30%, 20%, and 6% of global total, respectively, in 2019. China is the economy with highest investment. Although it has seen a downward trend, China's investment still reached $83.4 billion in 2019. While the United States also has a high record, reaching $55.5 billion of investment in 2019, an increase of 28% over the previous year.

Figure 3.15 depicts the global top 20 economies in terms of cumulative investment in renewable energy capacity from 2010 to 2019. China, the United States, and Japan were among the top three

[11] https://www.fs-unep-centre.org/global-trends-in-renewable-energy-investment-2019/#downloads

APEC economies, with cumulative investments value reaching $8180, $3923, and $210.9 billion, respectively.



Unit: Billion USD

Source: Global Renewable Energy Investment Trends Report 2020

Figure 3.15 Cumulative investment in renewable energy capacity in top 20 economies (2010-2019)

Chapter 4: Pathways to Scaling-up Renewable Energy Development

4.1 Renewable Policy and Plan

The APEC region has abundant renewable energy resources. Various economies have put forward energy policies to promote renewable energy and increase the amount of renewable power generation, based on criteria such as the region's energy resource endowment and energy demand. The mid- and long-terms renewable energy development plans in APEC economies are shown in Table 4.16.

Table 4.16 Renewable Energy Development Goals in the APEC Economies

Economies	Regional targets	Renewable energy development goals	
		Share of renewable energy in power generation (%)	Horizon
Australia	Capital Territory	100	2025
	Northern Territory	50	2030
	Queensland	50	2030
	Victoria	40	2025
		50	2030
Brunei Darussalam	--	10	2035
Canada	Alberta	30	2030
	British Colombia	93	--
	Saskatchewan	50	2030
Chile	--	25	2025
		60	2035
		70	2050
China	--	20 (non-fossil energy in Total energy consumption)	2025
			2035
Hongkong, China	--	3 - 4	2030
Indonesia	--	26	2025
Japan		24	2030
Korea		20	2030
		35	2040
Malaysia		20	
Mexico		35	2024
		38	2030
		40	2035
		50	2050
New Zeeland		100	2030
Papua New Guinea		100	2030
Peru		70	2030
The Philippines		100	2050
Russia		20	2024
Chinese Taipei		20	2025
Thailand		20	2036
United States	New York	70	2030
	New Mexico	50	2030
		80	2040
	New Jersey	50	2030
	Washington, DC	100	2032
	Washington State	100	2045
	California	60	2030
Viet Nam		24.3	2025
		23.1	2030

Table 4.17 shows main mid- and long -term electricity development targets of the APEC economies. It is noticeable that renewable energy in power generation has been becoming the key source of new installed capacity among energy development goals in the APEC economies.

Table 4.17 Power Development Plans and Goals of the APEC Economies

Economies	Power development goals			
	Economy-wide strategies	Launching year	Targets	Horizon
Australia	National Energy Guarantee	2018	The installed power capacity will reach 68.2-69.2GW, among which the renewable installed capacity will reach 37.4-38.4GW, accounting for 54.8-55.5% of total capacity; electricity generation will reach 198.4-201.1 TWh, in which the renewable generation will reach 69.2-71.6 TWh, accounting for 34.4-36.1% of total.	2030
Brunei Darussalam	Energy Outlook and Energy Saving Potential in East Asia 2016	2016	Under the current policy scenario, the electricity generation is projected to reach 10.47 TWh, with an annual growth rate of 3.7%; Under the alternative policy (ASP) scenario, the electricity generation is projected to reach 8.47 TWh in 2040, with an annual growth rate of 2.9%.	2040
	Energy White Paper 2014	2014	Renewable generation targeted to reach 0.954TWh (10%).	2035
Canada	Canada's Energy Future 2019	2019	• The installed power capacity will reach 171.9 GW, among which, hydropower 89.9 GW (52.3%), wind power 23.8GW (13.9%), biomass power 3.3GW (1.9%), solar power 6GW (3.5%), nuclear power 11.1GW (6.5%), coal power 1.4GW (0.8%), gas power 33.4GW (19.4%) and oil power 3GW (1.7) %). • The renewable generation targeted to reach 737.8 TWh, among which, hydropower 439.4 TWh (59.6%), wind power 69 TWh (9.2%), biomass power 10.3 TWh (1.4%), solar power 6.9 TWh (0.9%), nuclear power 82.2TWh (11.1%), coal power 1.4 TWh (0.2%), gas power 126.9TWh (17.2%) 1.7 TWh (0.2%).	2040
Chile	National Energy Policy 2050	2016	Power outages should not exceed 4 hours per year, and the share of renewable generation is targeted to reach 60% of total generation.	2035
			Power outages should not exceed 1 hour per year, and the share of renewable generation is targeted to reach 70%.	2050
China		2020	At the 2020 Climate Ambition Summit, China proposed that by 2030 China's carbon dioxide emissions per unit of GDP will be reduced by more than 65% compared to 2005, non-fossil energy will account for about 25% of primary energy consumption, and the total installed capacity of wind power and solar power generation will be more than 1200 GW.	
Hong Kong, China	Hong Kong Climate Action plan 2030+	2017	The share of renewable generation targeted to reach 3-4%, and carbon intensity will be reduced by 65-70% from 2005 levels.	2030
Indonesia	National Energy Policy (Government Regulation No. 79/2014)	2019	• The share of renewables in primary energy targeted to reach 23%; • The electrification rate will reach 99.4%; • The electricity generation will reach 527,979 GWh, of which 3,312 GWh from oil (0.6%), 265,599 GWh from coal (50.3%), 15,5352 GWh from gas (29.4%), 54,993 GWh from hydropower (10.4%), 42,484 GWh from geothermal (8.0%), 5,981 GWh from other new and renewable energy (1.1%), and imports will be 258 GWh.	2025
Japan	The 5th Strategic Energy Plan	2018	• Renewable energy targeted to reach 22-24%, nuclear power 20-22%, thermal power 56%; • Renewable energy has been identified as a "major energy source" for the first time by 2050; • Continue to develop nuclear power; • Inefficient thermal power generation technologies and related equipment will be eliminated to develop clean and efficient thermal power. Thermal power will be positioned as "the main power source in the transition period to achieve energy transition and decarbonization", and the average power generation efficiency will be required to reach 44.3%.	2030
Korea	9th Electricity Demand and Supply Basic Plan 2019-2034	2020	• Coal power installed capacity will be reduced from 34.7GW in 2020 to 24.0GW in 2034; • Natural gas capacity will increase from 41.3GW to 60.6GW; • Nuclear power will fall from 24.7GW to 19.4GW; • Installed renewable energy capacity will increase from 19.3GW to 78.1GW; • The share of nuclear and coal power in installed capacity will decrease from 46.3% in 2020 to 24.8% in 2034; • Between 2019 and 2034, the share of renewable power generation will increase five times from 5.2% to 26.3%; • The share of nuclear power will fall slightly to 23.6% from 25.9%. • Coal power is expected to fall to 28.6% from 40.4%, the biggest drop among the energy sources, liquefied natural gas (LNG) is expected to fall to 19.7% from 25.6 %, and other source for power generation is expected to fall to 1.8% from 2.9%.	2034

Malaysia	The Twelfth Malaysia Plan 2021-2025	2021	• Up to 45% reduction in greenhouse gas (GHG) emissions intensity to GDP by 2030 based on emissions intensity in 2005; • Achieving 31% Renewable Energy of Total Installed Capacity	
Mexico	National Electric System Development Program (PRODESEN) 2016-2030	2016	It is estimated that 57,122MW of new power generation capacity will be added during 2016-2030, requiring an investment of approximately $92 billion; The new capacity will consist of 38% of conventional technology (mainly combined cycle gas plants) and 62% of clean energy (efficient cogeneration, wind and solar); 15,820MW of installed capacity is expected to be retired, most of which comes from conventional thermal power plants; Wind power installed capacity is expected to grow from 3860.7MW in 2016 to 15101.1MW in 2030; The installed photovoltaic power generation capacity will grow from 1031.2MW in 2016 to 6890MW in 2030.	2030
Papua New Guinea	PNG Development Strategic Plan 2010-2030	2010	• In 2030, the total installed power capacity will reach 1970MW, including 1020MW hydropower, 30MW diesel, 390MW gas, 30MW coal and 500MW other renewable energy; • Intended Nationally Determined Contribution (INDC) Papua New Guinea: Achieve 100% renewable energy generation by 2030.	2030
Peru	National Energy Plan 2014-2025	2014	60 % of electricity will be generated from renewable energy resources by 2025, of which 55% will be hydropower and 5% will be from non-traditional renewable energy resources; The electrification rate reaches 99%.	2025
The Philippines	Philippine Energy Plan 2018-2040	2018	To achieve 100% electricity penetration by 2022; by 2040, the proportion of electricity in final energy consumption will reach 25.5%; electricity consumption will increase from 82,602 GWH in 2018 to 343,516 GWH in 2040; the installed power capacity will increase from 23,815MW in 2018 to 90,584MW (reference scenario) or 93,482MW (clean energy scenario), and the installed renewable energy will increase from 72,26MW in 2018 to 38,881MW (reference scenario) or 50,479MW (clean energy scenario).	2040
Russia	Russia's Energy Strategy	2020	Hydropower generation will reach 190-194TWH in 2035; Nuclear power will increase from 204.3TWh in 2018 to 227-245TWH in 2035; Photovoltaic and wind power will increase from 1.4TWh in 2018 to 46.4-52.2TWh in 2035.	2035
Singapore	Ministerial announcement during Singapore International Energy Week 2021	2021	Singapore plans to increase its installed solar capacity to at least 2GW by 2030 as it moves towards a low-carbon, sustainable future. Singapore achieved its 2020 solar deployment target of 350MWp in the first quarter of 2020.	2030
Chinese Taipei	Energy Agenda for Development	2017	Achieving non-nuclear goals.	2025
	National Power Resources Supply and Demand Report	2017	It is estimated that 10,907MW gas units will be added over 2018-2025; It will gradually reduce the share of coal-fired power generation, and no new coal-fired units will be added until 2025.	2025
	White Paper on Energy Transition	2020	Less than 30% of electricity is generated by coal. The renewable energy generation will account for 20%, and the installed target of all kinds of renewable energy will be 20000MW of photovoltaic, 6,938MW of wind power, 200MW of geothermal energy, 813MW of biomass energy, 2150MW of hydro power, and 60MW of fuel cell.	2025
Thailand	Thailand Power Development Plan 2015-2036	2016	The total installed power generation capacity will reach 70335M. From 2015 to 2036, 24736MW of installed power generation capacity will be retired, and 57,459MW of new installed power generation capacity will be added, including 21,648MW of renewable energy capacity, and 2101MW of the pumped storage power stations. Renewable energy will account for 20% of total electricity generation by 2036.	2036
United States	U. S Energy Information Administration Annual Energy Outlook 2020		From 2019 to 2050, coal power units are expected to decrease from 231.1GW to 123.4GW, renewable energy power installed capacity will increase from 231.5GW to 612.5GW, and the total installed power capacity will increase from 1040.6GW to 1686.0GW.	2050
Viet Nam	National Energy Development Strategy	2020	• The total installed power capacity will reach 125-130GW, and electricity generation will reach 550-600TWh; • The proportion of renewable energy in the total primary energy supply will reach 15-20% in 2030 and 25-30% in 2045.	2030

4.2 Renewable Energy Technology

4.2.1 Renewable Energy Resource Assessment

Most energy industry projects are characterized by a large investment scale, long construction period, and long project life cycle. Therefore, energy development strategies should be based on reliable resource information and data. One of the most significant foundations for project development is evaluating multiple energy technology possibility based on facts from each economy, specific energy resource endowment information, relevant technology cost data and parameters of specific technology.

This section provides an overview of energy resource assessment, potential analysis method and relevant recommendations, as well as issues that need to be addressed in project development to support the formulation of renewable energy large-scale development policies and project development, using solar and wind energy as example.

Renewable energy resources, particularly solar and wind energy, are abundant around the world. The efficient utilization of renewable energy resources in various economies depends on a combination of different factors including whether. These economies have adequate physical resources, with proper natural resource assessment to determine the availability, present potential resources that can be further exploited in a cost-effective manner. Resource assessment and mapping are among the initial steps in formulating renewable energy policies and development strategies, establishing appropriate targets, determining the feasibility of specific projects, and finally realizing the goal of utilizing these resources.

The World Bank Group is one of the international development organizations that has conducted renewable energy resource assessment and mapping at the economy level, funded by the Energy Sector Management Assistance Program (ESMAP), a large worldwide program that began in 2012[12]. Depending on each economy's objectives, renewable energy resource potential assessment and mapping can be done in three levels. Table 4.18 describes the relevant definitions of these three levels as well as the scope and application of resource assessment.

- Level 1 Assessment describes a wide range of global or regional resources that can be useful in understanding broad resource availability. IRENA organizes and publishes some relevant data and information[13][14][15]. A number of open sources are currently available for the relevant information;
- Level 2 Assessment improves on the above by adding validation and carrying out a bespoke, economy-level analysis with a level of resolution and accuracy required for strategic planning and preliminary site identification purposes. Normally, a Level 2 Assessment includes validation of the preliminary resource assessment using survey data or ground-based measurements, thereby providing potential users with a higher level of confidence in the final result;
- Level 3 Assessment is an essential input to analyze and evaluate a renewable energy project's commercial viability, or "bankability".

[12] ESMAP. RE resources mapping. https://www.esmap.org.
[13] IRENA. 2016a. Investment Opportunities in Latin America: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects. Abu Dhabi: International Renewable Energy Agency.
[14] IRENA. 2016b. Investment Opportunities in the GCC: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects. Abu Dhabi: International Renewable Energy Agency.
[15] IRENA. 2014. Global Atlas for Renewable Energy: Overview of Solar and Wind Maps. Abu Dhabi: International Renewable Energy Agency. Available at: http://www.irena.org/DocumentDownloads/ Publications/GA_Booklet_Web.pdf.

Table 4.18 Assessment Method and Classification of Renewable Energy Resource

	Level 1: Primary	Level 2: Validated	Level 3: Observed
Scale	Global Regional National	National State/provincial	Areas of high potential
Purpose	Resources overview Policy development	Resources estimation Strategic planning and regulation Prospecting	Resources validation Site assessment and optimization Financial analysis
Characteristics	Based on modelling results using earth observation and global or regional datasets	Modelling outputs are informed by and validated against measurement and/or survey date	Prefeasibility study using industry software with site measurement and/or survey date
Main stakeholders	International organization Regional agencies Resource assessment organization	National governments Development agencies University and research labs	Commercial developers Investor Electricity off-taker/utilities
Questions addressed	Location of RE resources? If worth to explore further?	Location of RE resources commercially viable? The location of the RE development?	Site's commercial viability? Cost of electricity generation?

Source: Adapted From WEC, WB/ESMAP

The assessment of energy resources involves many technological challenges. Firstly, there is a strong demand for reliable resource data during the project development stage because slight changes in resource potential can significantly influence on the power production output of the related project, and consequently, the project's cash flow.

Solar resource assessment and mapping has been increasingly a priority for economies that want to take advantage of ongoing cost reductions in solar PV technologies. The need for accurate resource data increases in relation to the size of the development being considered, as small differences in resource potential will have a big absolute impact on cash flow projects for the large-sized project. Conversely, accuracy is relatively less an issue for solar home systems or mini-grid project, where the economics are dictated more by the cost of the balance-of-system and other factors than the amount of radiation level.

Wind resource assessment and mapping is arguably the most methodologically developed among renewable resources, but it is also more complex due to the highly localized nature of wind resources, both between and within economies. For example, because of the effect of topography, land cover, and obstacles within any area of interest, the viable wind resource can vary significantly within a single grid cell on the map, even if the cell itself is in a high wind climatic zone.

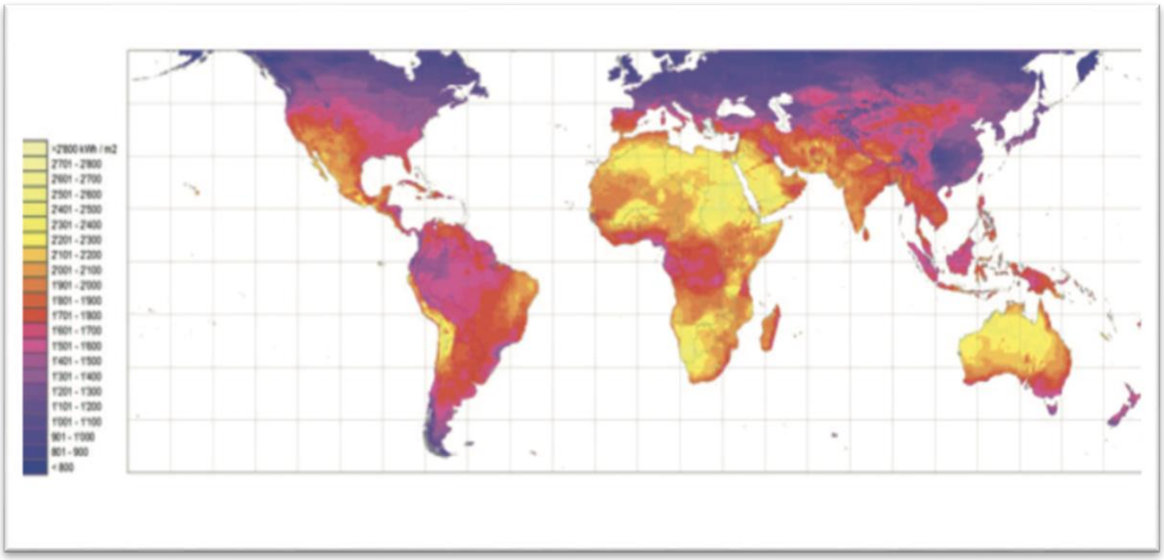
4.2.2 Availability of Renewable Energy Resource

With the joint efforts of various international organizations and the economies, Level 1 and Level 2 renewable energy resource assessment have been developed globally, including the APEC region, and relevant data sources have been made publicly available.

(1) Solar Resource

Solar energy is the most abundant and permanent energy resource on earth, which is available for use in direct (solar radiation) and indirect (wind, biomass, hydro, ocean etc.) forms. In this report, the solar energy that we analyse is confined to direct solar radiation.

Solar radiation varies from one place to another, and some parts of the globe receive more solar energy than the annual average. In Australia, for example, the average solar radiation is around 200W/m^2, whereas, in the United States, it is around 185W/m2. Assessment has shown that, broadly speaking, annual solar energy resources are distributed evenly in almost all regions of the world (within a factor of about 2). Therefore, the economically attractive application of solar energy is not just limited to the sunniest areas but also includes a wide range of geographical locations around the world. When it comes to solar energy utilization, numerous other factors also need to be considered while developing a given project and determining its practicality.



Source: www.meteonorm.com

Figure 4.16 Annual Sum of Global Horizontal Irradiation

In the rapidly rising solar energy system deployment era, solar resource parameters and their space/time specificity must be well-known among solar energy experts, planners, decision-makers, engineers, and designers. Since these parameters greatly depend on application method, including flat solar thermal collectors, solar thermal power plants, solar photovoltaic. They may differ widely, and might be unavailable for many locations, given that irradiance measurement networks or meteorological stations cannot provide sufficient geographically time/site-specific irradiance coverage. This coverage is beneficial because it allows assessment of the output of a solar system in relation to the technical characteristics of the system, local geography, and energy demand. It, therefore, allows a better assessment of the feasibility of a solar energy project and its value.

There is a significant disparity in the development of solar energy among the APEC economies (Table 4.19). According to data on unit photovoltaic power generation, Chile, Peru, China, Mexico, the United States, and Australia are relatively rich in solar energy resources with a high technological economy, development potential, and value. The large-scale use of solar energy in the APEC is divided into solar thermal power generating and, to a larger proportion, solar photovoltaic power generation. From both installed capacities, the dominant solar energy generating technology in the APEC economies by photovoltaic power generation is evident, and up to dozens of times, the gap between the two is enormous. China, the United States, Canada, Japan, and Russia are among the top five photovoltaic installed capabilities, representing 94.87 % of APEC solar installed capacity.

Solar energy resources are abundant and widely spread in economies like Chile, Peru, and Australia, installed capacity is yet modest and likely to rise rapidly in the future. The United States leads the world in installed solar thermal capacity with 1758 MW, followed by China with 221MW, and other economies have little or no installed capacity.

Table 4.19 APEC Regional Photovoltaic Resource Development Data

Economies	Theoretical resource data		Developed resource utilization data		
	Average daily photovoltaic generating capacity per unit [1] (kwh/kwp/d)	Area [2] (10,000 km²)	Installed photovoltaic capacity [3] (MW, 2018)	Photothermal installed capacity [3] (MW, 2018)	Solar power generation [4] (GWh, 2018)
China	2.21~5.82	960	175 016	221	178 071
USA	3.517~5.482	937	51 426	1 758	85 184
Canada	2.26 ~ 4.28	998	3 100	--	3 802
Japan	2.65 ~ 4.07	37.8	55 500	--	62 668
Russia	2.55~4.54	1709.82	535	--	460
Australia	3.60 ~5.32	769.2	11 303	2	9 930
Mexico	3.77~5.52	196.4	2 541	14	1 363
Viet Nam	2.59~4.40	32.9	106	--	106
Korea	3.32~4.02	10	7 130	--	9 208
Thailand	3.55~4.25	51.3	2 962	5	4 537
Chile	2.41 ~ 6.53	75.6	2 137	--	5 218
Indonesia	2.82~4.62	191.4	62	--	120
Malaysia	3.26~4.10	33.03	536	--	440
Chinese Taipei	2.56~4.11	3.6	2 738	--	2 740
New Zealand	2.11 ~ 4.26	26.8	90	--	98
The Philippines	2.98 ~ 4.50	29.97	897	--	1 251
Peru	2.96~5.85	128.5	345	--	797
Singapore	3.46~3.66	0.07244	160	--	171
Papua New Guinea	2.70 ~ 4.33	46.3	1	--	1
Brunei Darussalam	3.42~4.12	0.5765	1	--	--
Hong Kong, China	3.06~3.44	0.1107	--	--	--

Source: [1] https://globalsolaratlas.info/map ; [2] Baidu Encyclopedia; [3, 4] IRENA, Renewable capacity statistics 2020.

(2) Wind Resource

Wind resources are globally available everywhere, while compared to solar resources, there are wide variations in wind power in different locations. Based on the wind energy resource map of the World Wind Energy Association[16] and the analysis of Archer and Jacobson (2005)[17], the locations of the estimate best onshore wind resources are summarized in Table 4.20, which indicates that wind energy resources are well their distribution.

Table 4.20 Summary of the Most Attractive Regions and Locations for Wind Energy

Region	Location
Asia	North Asia, East Coast, some Island areas, Pacific Islands
North America	Most coastal areas, some central zones, especially mountainous area
Pacific Ocean	Most coastal areas
South America	Southern, eastern, and northern coastal areas are the advantageous.
Europe	Scandinavian Peninsula and Northwest UK, Mediterranean Area

Source: Archer and Jacobson (2005); WWEA

Offshore wind power generation is very appealing in high air pressure, and the wind speed is normally between 0.5 and 1.0 m/s higher than onshore. The technical and economic feasibility of offshore project also depends on the distance between the site of wind farm and the coast. Offshore wind power is primarily attractive because of its vast resource potential and low environmental impact. However, in some regions, greater wind speeds combined with abundant wind resources cannot entirely compensate for the higher infrastructure costs for the wind farms.

[16] https://wwindea.org

[17] Cristina Lozej Archer, Mark Z. Jacobson. Evaluation of global wind power. Published 2005, Journal of Geophysical Research

The distribution of onshore wind resources for different classes in major economies is shown in Table 4.21. The potential wind energy density is indicated by National Renewable Energy Laboratory in seven categories, measured at the height of 100 meters above sea level.

Table 4.21 Distribution of Wind Potential of APEC Economies: the Wind Power Density at 100m (W/m²)

Country/area	Wind Class 1 (%)	Wind Class 2 (%)	Wind Class 3 (%)	Wind Class 4 (%)	Wind Class 5 (%)	Wind Class 6 (%)	Wind Class 7 (%)	Avg Wind Power Density (W/m2)	Std Dev Wind Power Density (W/m2)
	<260	260-420	420-560	560-670	670-820	820-1060	>1060		
Australia	66	28	4	0	2	0	0	241	103
Canada	38	40	12	4	2	2	2	344	215
Chile	36	12	8	8	6	8	22	832	1,281
China	66	22	8	2	0	0	2	240	186
China, Hong Kong SAR	70	22	4	2	2	0	0	235	134
Chinese Taipei	82	10	4	2	0	0	2	158	197
Indonesia	98	2	0	0	0	0	0	69	54
Japan	30	28	28	6	6	0	2	384	201
Malaysia	100	0	0	0	0	0	0	46	33
Mexico	90	8	0	0	2	0	0	132	120
New Zealand	14	20	22	8	8	12	16	710	650
Papua New Guinea	88	8	2	2	0	0	0	120	130
Philippines	60	24	8	4	2	0	2	252	200
Republic of Korea	76	18	4	0	2	0	0	205	135
Russian Federation	64	24	6	2	2	0	2	258	206
Singapore	100	0	0	0	0	0	0	51	9
Thailand	96	2	2	0	0	0	0	122	75
United States of America	62	28	4	2	2	0	2	271	254
Viet nam	78	14	4	2	0	2	0	199	179

Source: IRENA

Table 4.22 presents the contents related to the APEC region in the global wind power resource data compiled by the international organizations.

Table 4.22 Wind Power Resource Development in the APEC Region

Economies	Potential resource data		Developed resource utilization data		
	Power density at 100 m height in 10% wind zone [1] (W/m²)	Area[2] (10,000 km²)	Onshore installed capacity [3] (MW, 2018)	Offshore installed capacity [3] (MW, 2018)	Wind power generation [4] (MWh, 2018)
China	669	960	180077	4588	366 452
USA	991	937	94388	29	275 834
Canada	831	998	12816	--	31 848
Japan	699	37.8	3602	65	7 481
Russia	793	1709.82	52	--	77
Australia	464	769.2	5818	--	15 164
Mexico	432	196.4	4875	--	12 877
Viet Nam	482	329	138	99	310
Korea	552	10	1347	73	2 465
Thailand	290	51.3	1103	--	1 641
Chile	3358	75.6	1524	--	3 588
Indonesia	144	191.4	76	--	6
Malaysia	89	33.03	--	--	--
Chinese Taipei	669	3.6	705	8	1 686
New Zealand	2407	26.8	689	--	2 068
The Philippines	611	29.97	427	--	1 153
Peru	235	128.5	372	--	1 502
Singapore	77	0.07244	--	--	--
Papua New Guinea	204	46.3	--	--	--
Brunei Darussalam	51	0.5765	--	--	--
Hong Kong, China	469	0.1107	--	--	--

Source: [1] https://globalwindatlas.info/; [2] Baidu Encyclopedia; [3, 4] IRENA; Renewable capacity statistics 2020.

As discussed previously, China, the United States, Canada, Australia, Mexico, and Japan have the most installed capacity of onshore wind power in APEC economies, totalling 301GW, and accounting for 97.9% of total installed capacity in APEC region, showing the uneven growth of wind power resources in APEC economies.

The use of offshore wind power technology is challenging and relatively less developed compared with European market. However, offshore wind power is globally becoming a research and development and application hotspot. Offshore wind power is seen as a key direction toward renewable energy development. As mentioned, China, Japan, Korea, Chinese Taipei, Viet Nam and the United States have the highest potential among APEC economies. The installed offshore wind turbine capacity of China has reached 4,588 MW, far ahead of the other APEC economies that are closely tied to China's wind power-related industrial and technological strategy and development.

(3) Hydropower Resource

Hydropower resources have seen a steady development in the APEC region. Among the top six economies in terms of potential hydro reserves are China, the United States, Canada, Indonesia, and Peru, reaching a total potential reserve of 16,209 TWh/year, accounting for 85.9% of the total APEC economies.

In general, hydropower resources in the APEC region are considered imbalanced. In the APEC region, in 2018, the top six economies accounted for 91.1% of total installed capacity. The installed capacity of China, the United States, Canada, Japan, Russia, and Australia has reached 695.438GW, 246.596GW, 100.140GW, 90.579GW, 54.611GW, and 25.438GW, respectively.

Thailand has the most developed utilization rate of hydropower resources (42.2%), followed by Viet Nam (26.7%), the Philippines (23.6%), China (19.77%), Canada (18.74%), and the United States (14.15%). The development rate of hydropower resources is yet low, compared to the total amount of resources.

Table 4.23 Hydropower Resource Development in the APEC Region

Economies	Total potential reserves [1] (GWh/year)	Installed capacity [2] (GW, 2018)	Hydropower generation [3] (GWh, 2018)	Developed utilization rate (%)
China	6083000	695.438	1202400	19.77
USA	2040000	246.596	288700	14.15
Canada	2067000	100.140	387300	18.74
Japan	718000	90.579	81000	11.28
Russia	2295000	54.611	190200	8.29
Australia	265000	25.438	17300	6.53
Mexico	430000	22.128	32400	7.53
Viet Nam	300000	18.712	80700	26.9
Republic of Korea	51780	12.050	2900	5.6
Thailand	18000	11.374	7600	42.2
Chile	227000	10.855	23260	10.25
Indonesia	2147000	9.485	16400	0.76
Malaysia	230000	7.540	24200	10.52
Chinese Taipei	--	5.940	7840	--
New Zealand	205000	7.243	25890	12.63
The Philippines	47000	6.577	11090	23.6
Peru	1577000	6.252	29360	1.86
Singapore	--	--	--	--
Papua New Guinea	175000	0.333	780	0.45
Brunei Darussalam	--	0.001	--	--
Hong Kong, China	---	--	--	--

Source: 1. Yearbook of Energy Statistics, UN Department of Economic and Social Affairs, 2017; 2. IRENA, Renewable Capacity Statistics 2020; 3. Hydropower Generation of Chile, Chinese Taipei, New Zealand, The Philippines, Peru, and Papua New Guinea in 2018 data from International Hydropower Association, Hydropower Status Report, 2019; Other data are obtained from IRENA, Renewable Capacity Statistics 2020.

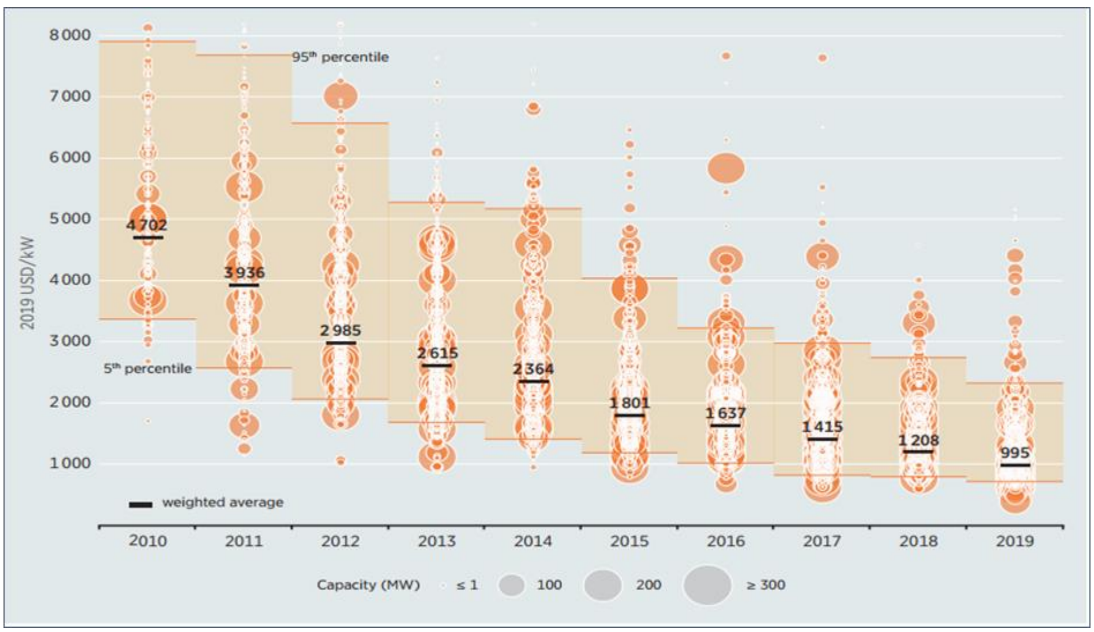
4.2.3 Cost Component of Renewable Energy

The cost of renewable energy is one of the fundamental factors for the large-scale growth of renewable energy. Given the variation in cost structure of the project and the policy settings of each economy, an in-depth assessment of the costs of renewable energy technology and interpretation of the results in various economic contexts is required to comprehend the current situation in various economic circumstances. This is critical for the formation of associated policies as well as the promotion of project development and related issues.

This section presents the current cost structure, the dynamics of the main cost reduction drives over time, identifying the key opportunities brought by future cost reductions of renewable energy project in related APEC economies. This has important implications for policy makers to formulate relevant policies and action plans, provide references for renewable energy project development and operation, and ensure continuous cost reduction of renewable energy.

4.2.3.1 Solar PV Photovoltaic

According to the IRENA, the global capacity weighted-average total installed cost of projects commissioned in 2019 was USD 995/kW (Figure 4.17), 18% lower than in 2018 and 79% lower than in 2010.



Source: IRENA, 2020

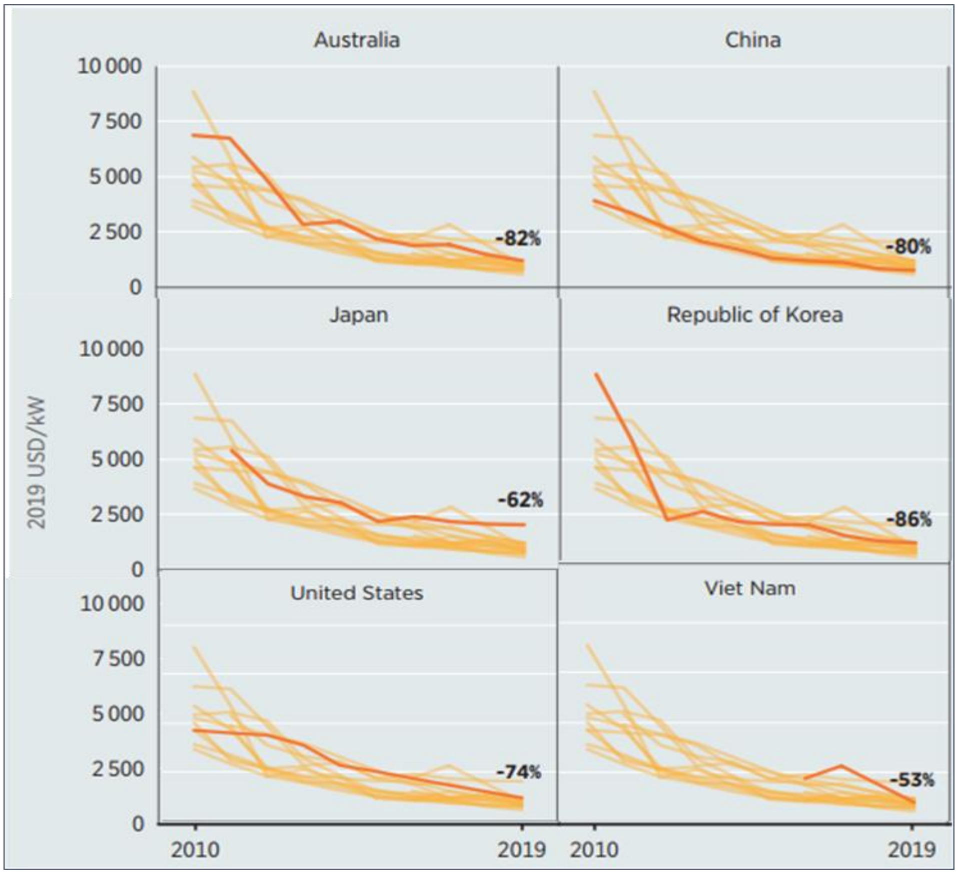
Figure 4.17 Global Weighted Average Total Installed Costs of Solar PV (2010–2019)

(1) Utility-scale solar PV

APEC economies such as China, Japan, Korea, and the United States constitute the major established solar PV markets, and in 2019, significant total installed cost reductions have occurred. The average total installed cost in China is 766 US$/kW. However, competitive costs structures are not confined to established markets anymore. For example, market growth in Viet Nam shows how solar PV continues to become a cost-competitive technology choice in a growing number of settings. The weighted-average total installed cost in 2019 was USD 1054/kW in Viet Nam.

In APEC markets between 2010 and 2019, total installed costs have declined between 74% and 88% in markets where historical data is available back to 2010. More than 80% cost decline took place in Australia, China, and the Republic of Korea. Meanwhile, between 2016 and 2019, total installed costs in Viet Nam have declined by more than 50%, as shown in Figure 4.18.

The total installed cost reductions are related to various factors. Improved manufacturing processes, reduced labour costs and enhanced module efficiency (new technologies) are the key drives of lower module costs. In addition, as project developers gain more experience and supply chain structures continue to develop in more and more markets, declining balance of system (BoS) costs have followed.[18]



Source: IRENA, 2020

Figure 4.18 Utility-scale Solar PV Total Installed Cost Trends in Selected Economies (2010–2019)

Between 2010 and 2019, the cost of solar photovoltaic modules fell dramatically, the cost of balance of systems[19] continued to reduce at a slower rate, and the capacity factor continued to grow progressively. As a result, the Levelized Cost of Energy (LCOE) of newly commissioned plant-scale solar PV power generation decreased by 82%, reaching an average LCOE in 2019 of $0.068/kWh[20]. This has led to an increased number of markets where solar PV systems were achieving competitive cost structures and resulting in a significant reduction in the global weighted average total installation costs.

[18] BoS costs for solar PV include cable and wiring, grid connection, racking and mounting, safety and security, electrical and mechanical installation, customer acquisition, financing costs, permitting, system design and profit margin.

[19] BoS costs for solar PV include cable and wiring, grid connection, racking and mounting, safety and security, electrical and mechanical installation, customer acquisition, financing costs, permitting, system design and profit margin.

[20] IRENA. 2020. Renewable Power Generations Costs in 2019

(2) Residential sector

According to IRENA, the residential, rooftop solar PV market generally has higher costs than utility-scale systems due to their small scale. Since 2010, the declining cost trend in installed costs has also been visible in a wide range of economies. Depending on the market, the total installed system costs decreased from USD 4277/kW and USD 7756/kW in 2010 to between USD 840/kW and USD 4096/kW in 2019, a decline of between 47% and 80%. Since 2013, however, India has become the new benchmark for the lowest-cost residential systems, although it had been joined by China in 2019. Figure 4.19 presents the development of installed costs in APEC economies and compares with India.

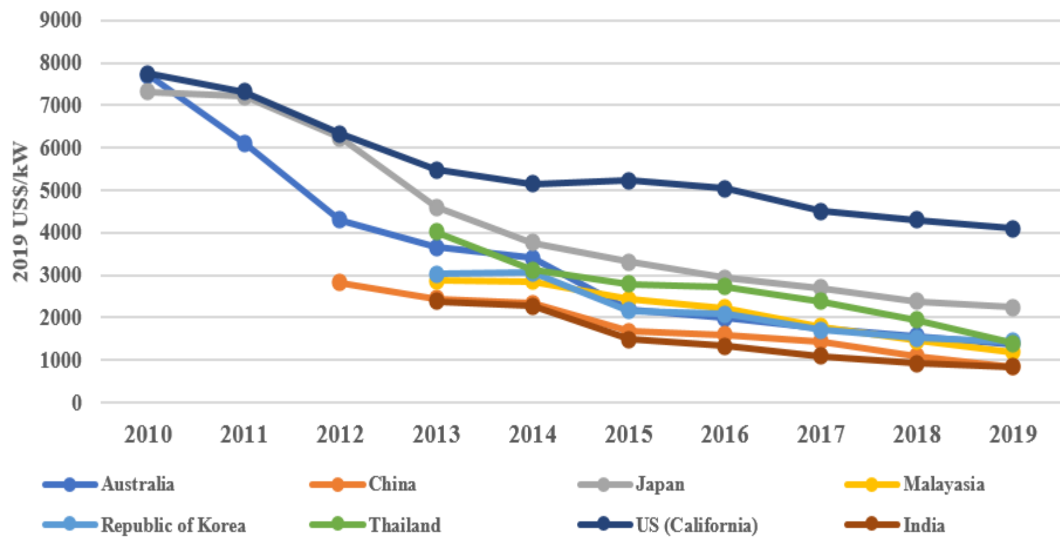


Figure 4.19 Capital Cost Development in Residential Rooftop Solar PV (2010–2019)

In the U.S. market, capital cost remains much higher than those achieved lowest cost like China, Malaysia. However, cost declined by 78% between 2015 and 2019. Japan is another high-cost APEC economies; however, cost declined by 67% between 2015 and 2019. In 2019, China achieved the lowest cost same as India at 840 US$/kW.

(3) Commercial segment

The total installed system costs in the commercial markets, according to IRENA, decreased from between USD 5405/kW and USD 8534/kW in 2010 to between USD 760/kW and USD 3 081/kW in 2019 (a decline of between 64% and 86%). Figure 4.20 presents the development of installed costs in APEC economies. Between 2017 and 2019, commercial costs in the markets evaluated declined between 12% in Australia and Japan to 38% in China. China in 2019 has shown the lowest cost and even lower than the Indian market.

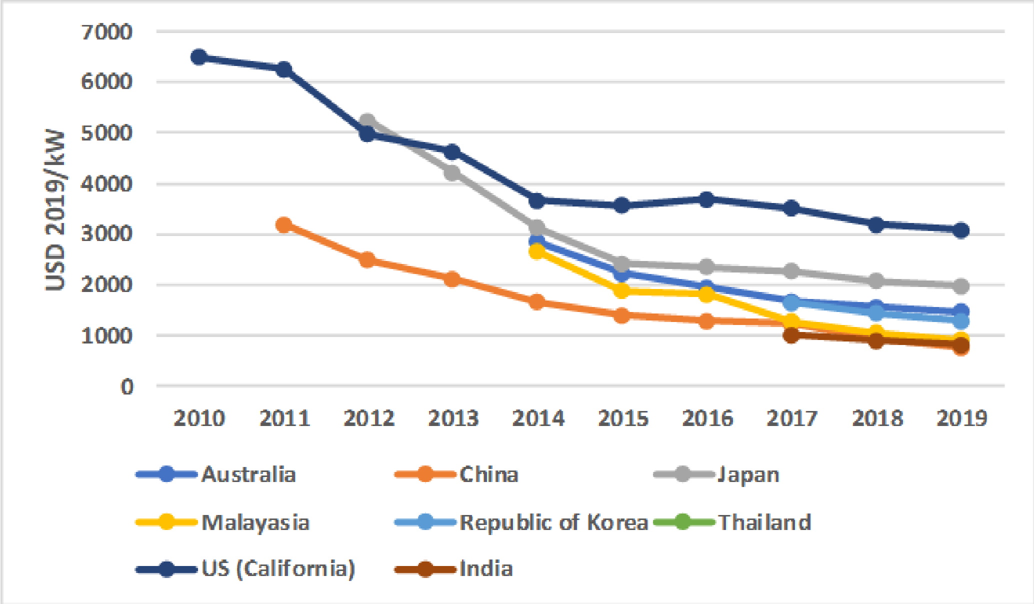


Figure 4.20 Capital Cost Development in Commercial Rooftop Solar PV (2010–2019)

(4) Regional difference on renewable technology costs and recommendations

One of the most important methods to effectively promote and achieve further reductions in solar PV cost is to understand the cost composition and variations of PV systems in different markets. The cost composition, major trends over the period, main drivers, and main stakeholders of solar PV power generation projects are summarized in Table 4.24.

Table 4.24 Cost Component and their Change of Solar PV Project

Components of solar PV project	Main trend and results	Cost structure	Key drivers to lower the costs	Technology development and adaptation of best practise
Module and inverter	Between December 2018 and December 2019, the decrease in installed costs for crystalline silicon module-based projects was driven by module price declines of between 4% (for low-cost modules) and 12% (for high-efficiency modules). This was supported by increased bifacial technology adoption in the market, given its potential for increased yield per KW, compared to mono-facial technologies.	At a global level, cost reductions for module and inverter accounted for 62% of the global weighted-average total installed cost decline between 2010 and 2019.	• Continued improvement in module efficiency with technology advancement. Efficiency gains associated with increased adoption of new cell architecture types. • Emergence of bifacial module as the new electricity cost-minimising choice and likely in a growing number of project over time which could provide further boost to capacity factor. • There have been some improvement in the overall efficiency by reducing inverter losses. • Improvements in the solar PV module manufacturing value chain e.g. reduced materials usage from diamond wire sawing, higher throughput in factories, module manufacturing process optimisation etc. • Increased economies of scale of manufacturing and experience gain, and increased labour productivity.	Main innovators in APEC region: China, US, Japan, Korea, and Australia (Solar modules and inverters are mainly manufactured in China.)

Components of solar PV project	Main trend and results	Cost structure	Key drivers to lower the costs	Technology development and adaptation of best practise
Balance of system	Balance-of-system costs have fallen slightly (less rapidly than module cost).	• On global average, in 2019, BoS costs (excluding inverters) make up about 64% of total system costs in the economies. In 2016, they made up about half of the total system cost. • BoS costs are also an important contributor to the declining global weighted-average total installed costs, with 13% of the global reduction coming from lower installation costs, 7% from racking, 3% from other BoS hardware (e.g., cables, junction boxes, etc.) and 15% from a range of smaller categories.	• Great competitive pressures among suppliers, more installation experience, the spread of best practice of installation with reduced soft cost. • Module efficiency improvements that reduce, in some area, the related BoS cost. • Project developers gained more experience and supply chain structures continue to develop in more and more markets.	Local project developers across the APEC economies.
Project financing cost	Different economies experienced different cost reduction levels.	• Interest payments. • Financing fees charged by interm ediary financial institutions, and the fees for related financing processes.	Maturity of technology and increased confident of lending agency on the performance of solar PV project.	Project financiers, and investors
Other Project development issues	Redcued at different level.	• Administration cost, fee for approval and permission • To meet the cost of the government's project audit • Engineering and technical services charges	• Reducing the administrative hurdles associated with the permit or connection application process and associated costs • With the right regulatory and policy settings, new markets have emerged that have been able to take advantage of international developer experience and local civil engineering expertise to rapidly scale local supply chains and achieve very competitive cost structures in 1-2 years. • Improvements in geographic information systems are helping developers identify locations with high solar resource potential for large-scale projects.	Government intuitions, regulators, public utilities, project developers
Operation and maintenance	The O&M costs of utility-scale solar PV plants have declined in recent years.	• Adaptation of preventive maintenance and module cleaning, with these making up as much as 75% and 90% of the total, depending on the system type and configuration. • The rest of the O&M cost can be attributed to unscheduled maintenance, land lease cost and component replacement cost.	• Operation and maintenance cost declines have been driven by module efficiency improvements that have reduced the surface area require per MW of capacity. • Competitive pressures and improvements in the reliability of the technology have resulted in system design optimised to reduce O&M costs and improved O&M strategies that take advantage of a range of innovations, from robotic cleaning to Big Data analysis of performance data to identify issues and preventative interventions ahead of failures, which drived down O&M costs and reduced downtime of the plants.	Plant owners and operators
Capacity factor	Global weighted-average capacity factor for new utility-scale solar PV increased from 13.8% in 2010 to 18.0% in 2019.		• Shift in deployment to regions and locations with higher irradiation. • Increased use of tracking device in utility-scale segment in large markets and a range of other factors that have made contribution (e.g., reduction in system losses).	Project developers and operator、
Power grid connection	Subject to the regulation on power utility	Grid connection facilities and construction cost	Positive integration policies	Power utility

Source: IRENA, RE21, Solar Association, BNEF

Though solar PV technology continues to mature, regional cost differences persist. This is true not only for the module and inverter costs components, but also for the balance of system as discussed before and listed in the table.

Across different economies, there is a range of markets where competitive module and inverter costs are offset by BoS costs significantly above best practice levels. As technology continues to mature and market share expands, it is expected that some of the remaining cost differences among them will tend to decline. Further understanding of differences in the individual cost components of the PV systems in individual markets remains one of key factors to unlock further cost reduction potential effectively. The trends are observed as below.

- **Convergence:** Given the highly replicable and modular nature of the solar PV project development, and a narrowing economy-level price differentials for solar PV modules (although exception exists, such as the United States and Japan, meaning that the most competitive capital cost structures for the solar PV have been increasingly less affected by individual project characteristics, comparing with other renewable power generation technologies;
- **Variation:** variation continues to exist within economies; however, economies with competitive markets can expect to see a convergence of installed costs toward the best-practice level, as local supply chains become more competitive, and project developers gain more experience.

Because the market matures and some of the remaining cost differences between markets begin to narrow, and the cost composition of solar systems varies by market, the recommendations to further unlock cost-reduction potentials include:

- Reducing the administrative hurdles associated with the permit or connection application process is a good example of a policy that can explore the cost reduction opportunities;
- Adopting policies that can bring down BoS, and soft costs, in particular, providing the opportunity of improving cost structures towards the best practice level;
- Supporting international collaboration and realising resource allocation efficiency potential of different economies.

4.2.3.2 Onshore Wind

Continuous technological improvement is the key drive for boosting onshore wind and renewable energy development in general. The global weighted-average LCOE of onshore wind projects commissioned in 2019 fell to USD 0.053/kWh, which was 9% lower than in 2018 and 39% lower than in 2010 when it was USD 0.086/kWh.[21] In a growing number of markets, costs of onshore wind have been consistently undercutting fossil fuels, often by a significant margin.

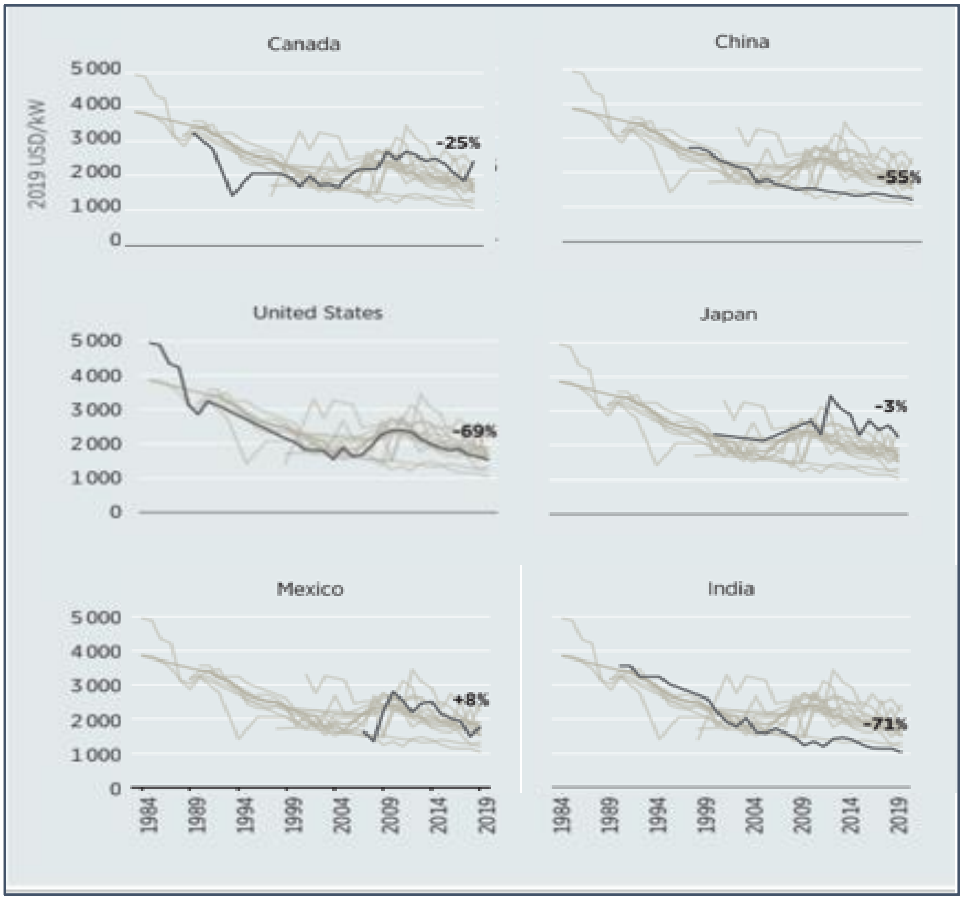
Apart from hydropower, onshore wind is one of the earliest renewables deployed at scale, and innovation continues unabated. Similar to solar PV, the cost of onshore wind power has been falling due to a positive and effective policy support environment, increasing scale of utilization and more project experience.

The global weighted-average total installed cost has fallen by 24%, from USD 1949/kW in 2010 to USD 1473/kW in 2019. This has been driven by wind turbine price and balance-of-plant cost reductions. Among the key players, China had a weighted-average total installed costs between 21% lower than other economies.

Figure 4.21 presents the cost evolvement of onshore wind since 1984 in selected APEC economies, which have seen the highest cost decline recently and the lowest cost currently. Among the APEC

[21] IRENA.2020. Renewable Energy Generation Cost 2019.

economies, the USA has registered the highest fall in installed cost at 69%. In contrast, Mexico saw an 8% increase over the period as shown. This is due to the different economy with different site-specific requirements such as logistics limitations for transportation, local content policies, land-use limitations, labour costs.



Source: IRENA, 2020

Figure 4.21 Average Installation Cost of Onshore Wind Power in Selected APEC Economies

Overall, the largest share of the total installed cost of a wind project is related to the wind turbines. Contractors for these typically include the towers, installation, and delivery, except in China. IRENA review and data suggest turbine prices declined by between 5-6% in 2019. Wind turbines now make up between 64% and 84% of the total installed costs of an onshore wind project (IRENA, 2018).

The higher turbine capacity however enables large-sized project to be deployed and reduces the total installed cost per unit for some cost components (expressed in MW). The other major cost categories of onshore wind project include the installation costs, power grid connection costs, and development costs.

Table 4.25 summarizes the cost composition of onshore wind power, the change of major cost components in recent years, and the main factors affecting and contributing to the change of related costs components of onshore wind project.

Table 4.25 Cost Components and their Changes of Onshore Wind Project

Components of wind power project	Main trend of change in cost	Cost structure	Key drivers in cost reduction	Technology development and adaptation of best practise
Turbine	• The decline in turbine price globally has occurred despite the increase in rotor diameters, hub heights, and nameplate capacities. • Price difference between turbines with differing rotor diameters has narrowed.	• Wind turbine makes up between 64% and 84% of the total installed costs of an onshore wind project. • With declining installation costs, the contribution of turbines made to the overall share of total installed costs has been trending towards the higher end of the range.	• The increase in the capacity of individual wind turbine made it possible to deploy larger capacity wind project. • Improvements and design of turbine technology: turbines with larger rotor diameters increase energy capture at sites with the same wind speed, which is especially useful in exploiting marginal locations for the project development. • The higher hub height that have become common enable higher wind speed to be accessed at the same location, which can yield materially higher capacity factor of the unit. • The higher turbine capacity also enables larger projects to be deployed. • Greater competition among manufacturers, margins have come under increasing pressure by reducing capital costs (e.g., the material and labour costs of manufacturing) and/or by increasing energy yields for a given resource (e.g., higher hub-heights with larger swept blade areas).	Main innovators in APEC region: the United State, China
Installation	• The global weighted-average total installed costs of onshore wind projects fell by 72% between1993and 2019, from USD 5179 to USD 1473/kW. • More competitive, established markets show larger reductions in total installed costs over longer time periods than emerging markets. • Total installed costs declined year-on-year in 2019 by 5% in the United States and China.	• Procurement • Balance of system • Engineering, technical services and management costs	• Economy of scale affect manufacturing cost, installation (with the reduction in the number of turbine units required for a project due to the higher turbine ratings), and O&M costs. • Optimising the site configuration to better exploit wind resources and reduce output losses due to turbulence with improved wind resource characterisation and improved project design tool and software. • The competition is being reinforced by the increased use of competitive procurement processes by a growing number of economies for the procurement of renewable energy. • Increased competition has also led to acquisitions in the turbine and balance-of-plant sectors, and a trend of production moving to economies with lower manufacturing costs.	All major wind power development economies
Operation and maintenance	The operation and maintenance costs of onshore wind farms have been reduced.	Operation and maintenance costs for onshore wind often make up a significant part (up to 30%) of the LCOE for this technology.	• Technology improvement, greater competition among service providers, and increased operator and service provider experience, improved O&M practices. • Improvement in the reliability and durability of new turbine, while larger turbines have reduced the number of turbines for a given capacity of a wind farm. • More players are entering the O&M servicing sector which resulted in stronger competition, driving down the cost. • Increased effort by turbine O&M firms to secure service contracts given the potentially higher profit margins available than in turbine supply. • The combination of digital technologies that has allowed for improved data analytics and autonomous inspections.	Owners of windfarms, O&M providers, and manufacturers
Project development	Varied at different levels.	• Cost of capital • Costs for environmental impact assessment and other planning	• Increased experience and favourable government regulations and policies have reduced project development and operation risks associated with onshore wind project, especially in established markets.	Project developers and owners

Components of wind power project	Main trend of change in cost	Cost structure	Key drivers in cost reduction	Technology development and adaptation of best practise
		requirements, project permission, and other related fees.	• Reduced project risk as development, installation and operational risks are now better understood, with adequate mitigation measures in place.	
Capacity factor	Between 2010 and 2019, the global weighted-average capacity factor for onshore wind increased by almost one-third, from just over 27% in 2010 to 36% in 2019.		• The trend towards more advanced and more efficient turbine technologies with larger rotor diameters and hub-heights has seen energy outputs and capacity factors rise in most markets over the last decade. • Resource quality has a significant impact on capacity factors, even as technology improvements have raised outputs across the board.	Project developers, plant operator
Power grid connection	Subject to the regulation on power utility	Grid connection facilities and construction cost	Positive integration policies	Power utility

Source: IRENA, BNEF, Wood Mackenzie

4.2.3.3 Offshore Wind

In 2019, the global weighted-average LCOE of offshore wind has dropped to USD 0.115/kWh, compared to USD 0.161/kWh in 2010. Recent auction results, including subsidy-free bids, showed a step-change in the competitiveness of offshore wind in the 2020s, with electricity prices expected to return to normal between USD 0.05 and USD 0.10/kWh. In Asia, the LCOE reduction between 2010 and 2019 reached 39% (from USD 0.180/kWh to USD 0.112/ kWh). This was largely driven by China, which has over 95% of offshore wind installations in Asia. With the recent increase in deployments, cost reductions have been further unlocked. This has been driven by technology improvements, economies of scale, and an increase in developer and turbine manufacturer experience.

Offshore wind farms have higher total installed costs than onshore wind farms. Prices rise when wind turbines are installed and operated in a tough marine environment offshore. As a result, planning and project development costs are higher, and lead-time are normally longer[22].The global weighted-average installed costs for offshore wind declined from USD 4650/kW to USD 3800/kW between 2010 and 2019. Offshore wind, however, has the advantage of economies of scale, meaning that many of these costs are not disproportionately that much higher than for onshore wind with similar capacity, and at the same time, offshore wind units have higher capacity factors to generate electricity.

Offshore wind was progressing in a limited number of economies, with European economies Germany, Denmark, the UK at leading front. Among APEC economies, in China, the grid connection assets are developed and owned by public entities or the transmission network owner, lowering the project-specific installed costs. As a result, the project-specific weighted-average total installed cost in 2019 was USD 3012/kW in China, down from USD 4424 in 2010. There was up to a 1% increase in the weighted-average total installed costs in Japan. In Japan, the market remained in the pre-commercial deployment phase, weighted average installed costs increased from USD 4877/kW in 2010 to USD 4900/kW in 2019, according to IRENA.

As far more and more offshore wind projects installed, the cost of offshore wind has been starting to drop. As mentioned, the main causes include technological innovation and progress, economies of scale, and the accumulation of technological progress and experience by manufacturers and project developers.

[22] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf

Table 4.26 summarizes the cost composition of offshore wind power, and the changes of the main determinant factors affecting the cost of offshore wind power projects in recent years.

Table 4.26 Cost Components and their Changes of Offshore Wind Project

Components of offshore wind project	Main trend and result	Cost structure	Key drivers to lower the costs	Technology development and adaptation of best practise
Turbine	Costs have dropped, yet no clear trends are shown.	Offshore, turbines, including towers, generally account for between 34% and 54% of the total installed cost.	• Technology improvement, economies of scale and increase in developer and turbine manufacturer experience. • The increasing maturity of the industry is also reflected in cost-saving programmes such as the standardisation of turbine and foundation designs, industrialisation of manufacturing for offshore wind components in regional manufacturing hubs, and the increasing sophistication and efficiency of installation practice. • While less significant than the higher turbine rating, the increase in rotor diameter is also important. This allows for higher energy capture from the turbines and smoother energy output. This also makes offshore wind particularly useful in reducing overall intermittency.	Main manufacturers in APEC: the United States, China, and Korea.
Project development	It has a lot of direct relevance to each project.	Cost of capital, government approval, and administrative fee. Development costs, which include planning, project management and other administrative costs, comprise up to 5% of the total installed cost.	• Lower risks from stable government policies and support schemes. • Cost of capital is among the major factor determining the feasibility of a project.	Government Policymakers and energy regulator
Installation	Vary across the economies, subject to site characteristics and policies.	Installation, foundation, and electrical interconnection. Globally, installation costs accounted for up to 19% of total installed costs, while contingency and other costs such as electrical interconnection and foundation costs can account for over 22%.	• Installation time and cost per unit of capacity are falling with more developer experience. • Major support came from lower product price, improved turbine design, standardisation of design and industrialised manufacturing, and improvements in logistics and other support.	Developers and pant owners. It is noted that in China, developers are not responsible for electrical interconnection costs (besides the cost of electrical arrays for connecting the turbines).
Operation and maintenance	Operation and maintenance cost fell with larger turbine size, expanded service capacity, and the emergence of cost synergies across growing maritime wind-farm zones.	O&M costs for offshore wind farms are higher than those for onshore wind. This is mainly due to the harsher, marine environment and higher costs for access to the wind site for performing maintenance on turbines and cabling. The latter is heavily influenced by weather conditions and the availability of skilled personnel and specialised vessels.	• Higher turbine ratings have reduced the unit O&M cost. • The introduction of specialised ships for maintenance has helped lower O&M cost. • The scale and optimisation benefits of providing O&M to large offshore wind farms zones also play a role, with the increased wind turbine availability as manufacturers constantly learning from experience and improving their products. • Increasingly sophisticated data mining of turbine performance data and predictive maintenance programmes that are designed to intervene before costly failures are contributing to lower the O&M cost. The latter is evident in widely, from larger, higher rated offshore wind turbines to improved foundations. • O&M practices have been continuously refined to reduce costs and improve availability. • As the sector grown, increased competition in O&M provision has emerged and has resulted in a variety of strategies to minimise O&M costs (e.g., the use of independent service providers, turbine OEMs service arms, in-	Plant owners, operators and O&M service providers

			house O&M, marine contractors, or a combination of these above).	
Capacity factor	Between 2010 and 2019, the global weighted-average capacity factor of newly commissioned offshore wind farms grew from 37% to 44%.	The capacity factors of offshore wind farms vary widely due to difference in technologies and configurations used in different locations, meteorological conditions, and operation and maintenance strategies.	• Capacity factors have been rising due to larger wind turbines, with higher hub heights and larger swept areas. • Better methods for wind resource characterisation when it comes to identifying the best sites and improved wind farm designs that optimise operational output. • Reduced downtime as manufacturers has integrated experience from operating wind farm models into more reliable designs. • Optimising O&M practices to reduce unscheduled maintenance.	Wind farm developers, and operators
Grid connection	Depending on specific economy's regulation	No clear trends are shown	• Grid connection technology options include AC/DC, voltage levels and grid connection mode and wind farm location	Project opening party, power grid company and technology supervisory

Source: IRENA, BNEF, Wood Mackenzie

4.2.4 Technological Learning and Cost Reduction

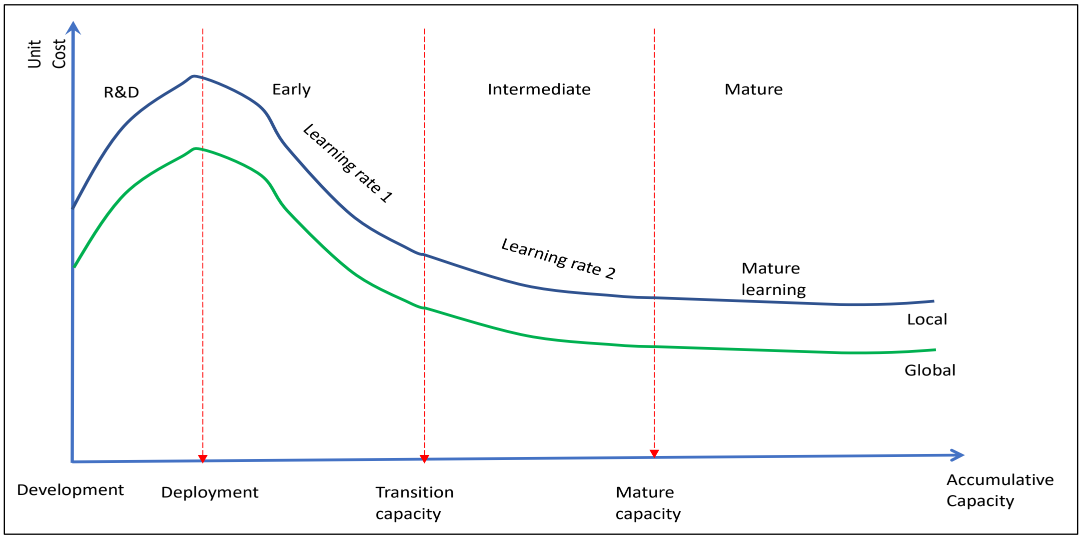
Technology cost reduction through learning-by-doing were initially observed in the 1930s during the process of aircraft manufacturing[23], and have since been observed and measured across a wide range of technologies and processes[24]. Cost reduction due to this phenomenon are normally demonstrated through the technological learning experiences. Learning rates can be measured by examining the change in unit cost with the cumulative capacity of technology over time. Figure 4.22 illustrates an indicative generic learning process as technology progresses through different development stages with commercialisation of technology begins.

Technologies are often made up of several components, and more often different components can be at different levels of maturity; thereby, the learning rates of the various components may differ. Furthermore, different parts of technology can be developed, manufactured, sold in different markets in different markets (global vs. regional and/or local), as illustrated in Figure 4.22, which can exsert impacts on the cost reductions as each region more likely have a different level of demand for certain technology, which will exert influence on technology adoption. The main factors affecting the trend of cost decline of a technology comprise the following aspects.

- **Product design:** Improvement in basic product design occurs in the early phase of technology adoption. At present, wind turbines are substantially larger and have far higher capacity factors than they were a decade ago. Although the new designs are initially more expensive, greater capacity and capacity utilization have outpaced related incremental costs these higher costs, lowering the cost of energy produced.
- **Manufacturing:** Another reason for the cost reduction is improvement in manufacturing efficiency, which for example, has lowered the costs of producing solar PV panels dramatically, particularly in China. Furthermore, the "soft" cost of unit installation has been declining as the project developers gain more experience, and installations have moved from small-scale to utility-scale projects.
- **Intermediate phase:** For many economies in the region, solar PV and onshore wind have been at the stage of intermediate and mature phases of the development, with rapid cost reduction due to increased new installed capacity each year.

[23] Wright, T. P. 1936, Factors Affecting the Cost of Airplanes. Journal of the Aeronautical Sciences, 3, 122-128.
[24] McDonald, A., & Schrattenholzer, L. 2001, Learning rates for energy technologies. Energy Policy, 29, 255-261.

- **Mature phase:** There are three main factors determining the cost of mature technology costs, including imported materials and equipment, domestic materials and equipment, technical engineering, and labours.



Source: McDonald, A. & Schrattenholzer

Figure 4.22 Illustration of Learning Process of Energy Technology

Generally, emerging technologies have a higher learning rate (15%–20%) at their initial stage when the technologies reach a market share of less than 5%; the technology are considered at the intermediate stage, with marketization about 10%. The learning rate will continue to decrease as long as the technology market share further increase. Once a technology is considered mature, the learning rate tends to be 0–5%. It has been observed that technologies that do not have a standard unit size and can be used in a variety of applications tend to have a higher learning rate for a longer period of time, and this is the case for solar PV[25] ,as indicated by the rapid decline in costs over last decade.

Relevant policies are important supporting the technology penetrations. Policies such as tax credits, preferential feed-in tariffs, and renewable portfolio standards (RPS), which directly target the use of renewables, and create economies of scale to meet the growing demand, have been credited with these remarkable cost reductions in renewable generation.

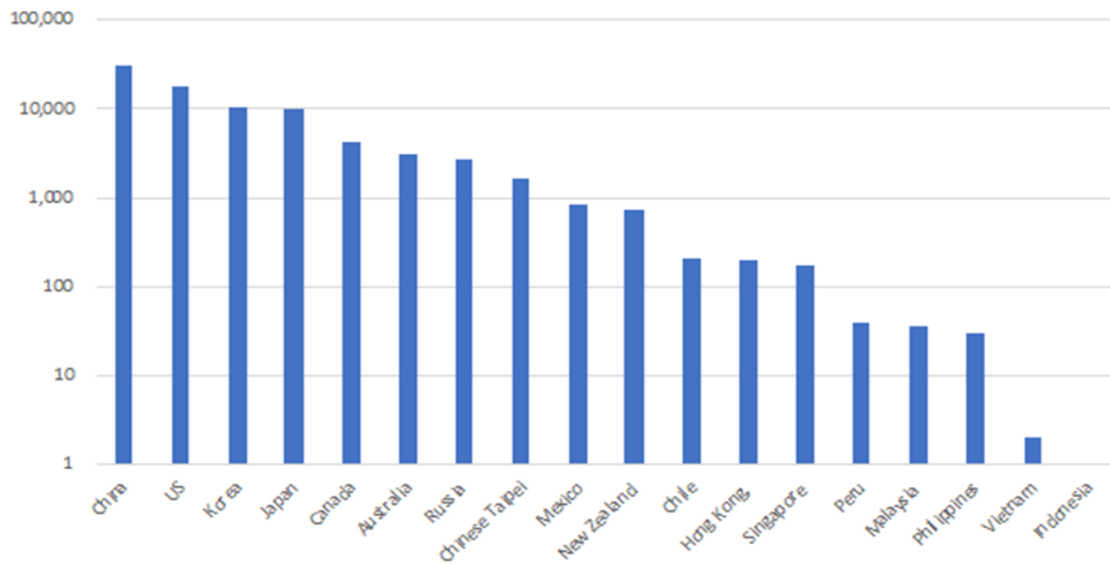
4.2.5 Research and Innovation

Innovation and technological progress have been among the most important factors in bringing down the costs of technology. One of the quantitative indicators to evaluate the level of innovation and technology development of an economy is the number of patents granted in the related field. The International Standards and Patents in Renewable Energy (INSPIRE)[26], is a platform that provides information on standards and patents in renewable energy based on the European Patent Office's (EPO)[27] classification of climate change mitigation technologies.

[25] Wilson, C. (2012). Up-scaling, formative phases, and learning in the historical diffusion of energy technologies. Energy Policy, 50(0), 81-94

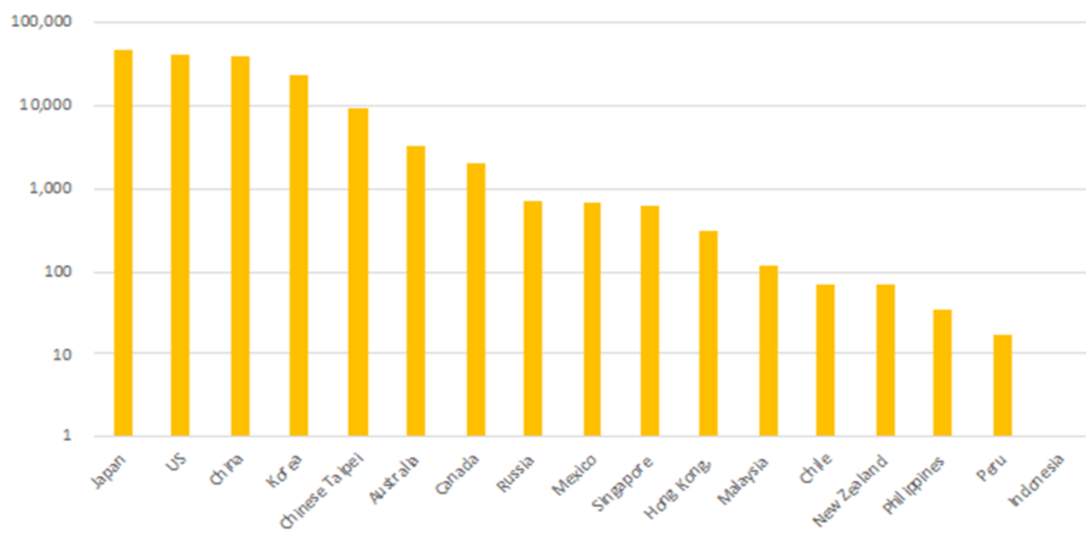
[26] The International Standards and Patents in Renewable Energy (INSPIRE). http://inspire.irena.org/Pages/patents/Patents-Search.aspx

[27] European Patent Office (EPO). https://www.epo.org/index.html



Source: European Patent Office (EPO). **https://www.epo.org/index.html /** The International Standards and Patents in Renewable Energy (INSPIRE). **http://inspire.irena.org/Pages/patents/Patents-Search.aspx**.

Figure 4.23 Accumulative Number of Patents Application by APEC Economies: Wind Power Generation



Source: European Patent Office (EPO). https://www.epo.org/index.html / The International Standards and Patents in Renewable Energy (INSPIRE). http://inspire.irena.org/Pages/patents/Patents-Search.aspx.

Figure 4.24 Accumulative Number of Patents Application by APEC Economies: Solar Power Generation

The Figure 4.23 and Figure 4.24 illustrate the accumulative number of the patent applications by APEC member economies in relation to wind and solar PV power generation technologies by the end of 2016.

As shown in the Figures, the APEC economies are among the most active economies in terms of research and development and patent applications. According to the EPO database, the top 10 patent application economies for wind power technologies are China, the United States, Japan, Germany, Korea, Canada, Denmark, Australia, Spain, and Russia, seven of which are APEC economies. As for solar PV, the global leaders of patent applications are Japan, the US, China, Korea, Germany, Chinese Taipei, Australia, France, Canada, and the UK, most of which are APEC economies. APEC economies are also among the leading economies in other related technologies supporting renewable energy development, named renewable technology enablers.[28]

4.2.6 Supply Chain of Renewable Energy Technology

(1) Solar PV

Since 2011, China has dominated production and supply of solar PV cells and modules, which implies that the economy also has dominated the prices of cells and modules, influencing the margins that other manufacturers receive. During the year 2019, 123.5 GW of cells and modules were shipped worldwide (up to 39% over 2018), mostly from manufacturers in Asia, particularly China. Over 80% of the 78 GW of cell and module volume, which were shipped by the top 10 suppliers, came from the Chinese companies, with the rest coming from Korea (Hanwha Q-Cells), Chinese Taipei (UREC), and the United States (First Solar). Seven of the top 10 manufacturers, and all the top three, were the Chinese companies. The economy's decision to limit domestic demand in 2019 resulted in an oversupply of cells and modules, which drove costs down and helped open significant new markets, counteracting the decline trend in China's installations.

Despite subsidy reductions and falling demand in China, several Chinese companies made significant investments during 2018 to increase their manufacturing capacity and formulated plans for further expansion, with an aim of further lowering the production costs through advanced technologies. The Chinese companies have also made significant investments in research and development in recent years.

Thailand, and Viet Nam had also more to play, sourcing for solar products to the world market. Elsewhere around the world, in 2018, most of the capital flowing into the solar PV sector went to downstream companies and project development. However, several economies including Malaysia and Thailand had measures in place to encourage local production.

Trade policy had impacts on the solar industry and project development. The United States added tariffs on Chinese solar inverters. In addition to tariffs on imports, several economies had measures in place to encourage local production or to penalise the use of foreign-made products. Trade disputes also affected the industry, weakening project pipelines, having affected growth in the United States.

(2) Onshore Wind

Globally the wind industry has seen more than 100 turbine suppliers over the years. The top 10 companies captured 85.5% of the capacity installed (up from 85% in 2018, 80% in 2017 and 75% in 2016). Many leading companies are in the APEC region, including Goldwind, Envision, Ming Yang, Windey and Dongfang (China), and GE Renewable Energy (United States) and others. Of the top 10 turbine manufacturers, half are based in China. It is noted that the Chinese manufacturers continued to rely almost entirely on the home market in 2018.

While most wind turbine manufacturing takes place in China, the EU, India and the United States, the manufacture of components (such as blades), the assembly of turbines and the locations of company offices are spreading to be close to growing wind energy markets, which include Argentina, Australia, and Russia, as the companies sought to reduce transport costs and to access

[28] Renewable technology enablers include uninterruptible or back-up power supplies integrating renewable energies, technologies improving the efficiency by using switched-mode power supplies i.e. efficient power electronics conversion, Power factor correction technologies for power supplies and reduction of losses in power supplies, Low frequency active rectification, i.e. from a low frequency AC grid or generator, converters benefiting from a resonance, e.g. resonant or quasi-resonant converters.

new sources of revenue locally. For example, Argentina's Newsan partnered with Vestas to convert an existing manufacturing facility in Buenos Aires into an assembly plant for wind turbines.

Some companies opened new facilities in overseas markets, besides reducing transport costs and accessing new revenue sources, the decision also responded to the minimal local content requirements of the renewable energy projects specified by the government policy. For example, MHI Vestas Offshore Wind (Denmark) signed a contract for blade materials in Chinese Taipei, Nordex opened a rotor blade factory in Mexico, Siemens Gamesa confirmed plans for a nacelle assembly plant in Chinese Taipei, and GE started constructing a factory in China for its 12 MW Haliade-X units.

Some trade policies increased the project costs and affected the pace of wind project development across the region. Vestas blamed its rising execution costs and falling margins in the United States (the company's most important market) on trade conflicts and tariffs, which had cascading effects on the global supply chain. US tariffs on steel and aluminium, which make up 70-90% of wind turbines, as well as tariffs on permanent magnets, have put pressure on the US network of suppliers. It was estimated, US tariffs on Chinese imports increased the costs of US wind projects by as much as 20%. Several other economies also have introduced new trade barriers on wind-related commodities and components, which affects the flexibility of supply chains, even as local content rules push for localisation of manufacture.

(3) Offshore Wind

In 2019, China had a record year and become the sector leader for the first time, installing 1.7 GW for a total of 4.4 GW of offshore wind generation capacity. The economy has also met with its domestic target, which called for 5 GW of offshore capacity by 2020. There are at least three Chinese provinces that also have offshore targets, including Fujian (2 GW by 2020), Guangdong (30 GW by 2030) and Jiangsu (3.5 GW by 2020). Elsewhere in Asia, Korea commissioned offshore project of 35 MW during 2018.

New offshore wind markets still faced challenges that the APEC region has addressed, including developing sufficient supply chains and associated infrastructure such as ports, rail links and installation vessels, as well as technology for gird connections. There were more efforts that can be made to change the situation. In Japan and Korea, local turbine suppliers are investing in the development of new, larger-sized turbines to advance a local offshore industry and supply chain, and, in early 2019, the state-run Korean National Oil Corporation agreed to jointly pursue commercial floating offshore wind power projects off the Korean coast.

4.2.7 Technology Development and Cost Reduction Support

The ability to innovate, develop and commercialise technologies is a key drive for a region or economy to advance and exploit emerging economic opportunities and promote the penetration of renewable energy technologies. Key players such as technology innovators, technology suppliers, and adapters, such as technology importers and trade-dependents, all could have an important contribution to technological development and cost reduction.

(1) Support technology adoption

Many economies are unlikely to be able to integrate the high value-added segments of renewable energy value chains unless necessary actions and urgent steps towards building and leveraging local capabilities are taken. Patent filings are one way to assess economies' technological innovation capabilities. Figure 4.25 shows that during 2018, among the total of 13,160, three-quarters of patents filled pertinent to the renewable energy sector in just four economies, China (57%), the USA (16%), Japan (8%) and Germany (1%).

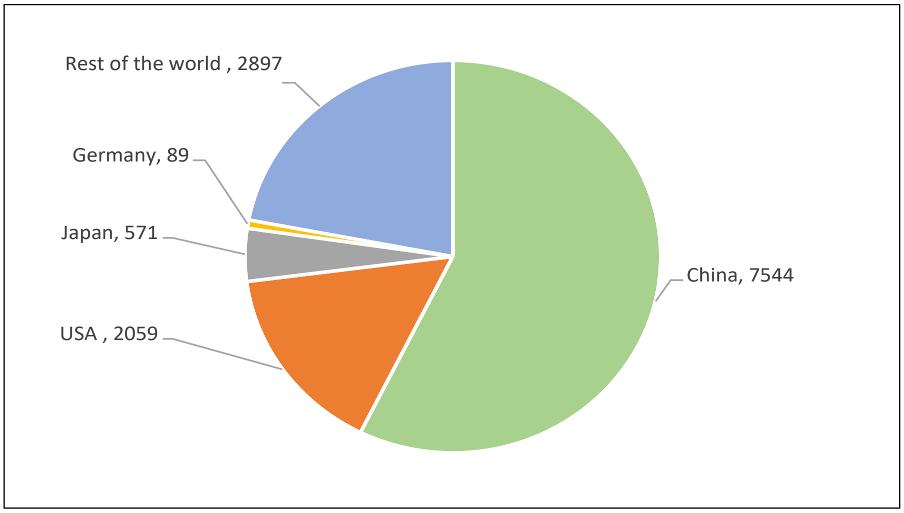


Figure 4.25 Leading Economies with Patents Filed for Renewable Energy Technologies in 2018

To support scaling-up of renewable energy technology, resolving barriers to technology adoption may need to be taken as a high priority, if not higher than these addressing barriers to innovation itself.

An important starting point of an economy can be mostly indicated in its pre-existing manufacturing capabilities and natural resources endowment, skilled labours and engineering capability. These factors are critical to the economy's ability to develop renewables and other green technologies. Some economies have succeeded in strengthening their capabilities and integrating high value-added segments of renewable energy value chains. China is an example, given its emergence as the dominant low-cost producer of renewable energy technologies such as photovoltaic cells and modules, also wind turbines. The economy has pursued a mix of enabling policies and has been able to draw on its well-developed domestic supply chains and manufacturing clusters, as in the Yangtze River Delta.[29]

(2) Policy formulation

As discussed, various potential hurdles to energy innovation can be found along the entire energy innovation chain (from research and development to demonstration projects, to cost buy-down, to widespread diffusion of technology). Some of these barriers reflect market imperfections or distortions; some reflect inadequacies in the public sector domain; some reflect differences of view about the differing perceptions of trade-off between market needs and business development priorities, and differing perspectives on time horizons and reasonable cost ranges of the technologies.

The level of assistance required to overcome the hurdles is determined by the maturity of technology and market potential, and different technologies confront different challenges. The amount of public support needed to overcome such barriers will vary from one technology to the next, depending on its maturity and market potential. Obstacles to technology diffusion, for example, may need to be given higher priority than barriers to innovation. Direct government support is more likely to be needed for radically new technologies than for incremental advances where the private sector functions are relatively effective.

[29] Ball, J. et al. (2017), The new solar system: China's evolving solar industry and its implications for competitive solar power in the United States and the world, Steyer-Taylor Center for Energy Policy and Finance, Stanford University, March.

Interventions should aim at helping the most promising energy innovations and surmount bottlenecks wherever they occur in the innovation chain. A complex and interactive system requires effective innovation networks, knowledge-sharing platform, and demand-pull as well as supply-push mechanisms. Over the past two decades, many economies have experimented with a growing number of policy instruments, ranging from goal setting and procurement policies to green labels and fiscal incentives. Table 4.27 highlights the challenges that energy innovation has faced, as well as policy options to overcome related obstacles.

Table 4.27 Barriers to, and Policy Options for, Energy Innovation

	Research and Development	Demonstration (pilot projects)	Diffusion	
			Early deployment (technology cost buy-down)	Widespread dissemination (overcoming institutional barriers and increasing investment)
Key barriers	• Governments consider R&D funding problematic • Private firms cannot appropriate full benefits of their R&D investments	• Governments consider allocating funds for demonstration projects difficult • Difficult for the private sector to capture benefits • Technological risks • High capital costs	• Financing for incremental cost reduction (which can be substantial) • Uncertainties relating to the potential for cost reduction • Environmental and other social costs not fully internalised	• Weaknesses in investment, savings, and legal institutions and processes • Subsidies to conventional energy technologies and lack of competition • Prices for competing technologies exclude externalities • Weaknesses in retail supply, financing, and service • Lack of information for consumers and inertia • Environmental and other social costs not fully internalised
Policy options to address barriers	• Formulating research priorities • Direct public funding • Tax incentives • Technology forcing standards	• Direct support for demonstration projects • Tax incentives • Low-cost or guaranteed loans • Temporary price guarantees for energy products of demonstration projects	• Temporary subsidies • Tax incentives • Government procurement • Voluntary agreements • Favourable pay-back tariffs • Competitive market transformation initiatives	• Phasing out subsidies to established energy technologies • Measures to promote competition • Full costing of externalities in energy prices • Concessions and other market-aggregating mechanisms • Innovative retail financing and consumer credit schemes

Source: Adapted from President's Council of Advisors on Science and Technology (PCAST), Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation (Washington, DC: PCAST, 1999).

As listed, some policy tools supporting renewable energy systems and technologies at all stages of the innovation chain include allocating a larger share of public sector funding for energy research and development to renewables, supporting demonstration projects (a likely approach is public-private partnership), and buying down the relative cost of new renewables technology in its early stages of development and commercialisation, while yet taking advantage of the marketplace's economic efficiency. Temporary subsidies were seen to be one of the most promising techniques, but in the medium and long term, effective market mechanisms should be fully employed to maintain economic efficiency. Suggestions in this regard are as follow:

- The government decision on whether to finance a particular field of the energy research should be based on major criteria such as the contribution of energy research field to achieving the transition to a sustainable energy policy and enhancing the competitiveness of (domestic) industries. It is also crucial that the research infrastructure in the field of interest is capable to fostering innovations and achieve these goals.
- Interventions should be aimed at assisting the most promising energy innovations in overcoming barriers at any stage in the innovation chain. However, this chain is increasingly being considered as a complex, interacting system that necessitates networks of innovation, knowledge-sharing platform, and demand-pull as well as supply-push mechanisms.
- The amount of public support needed to overcome such barriers will vary from one technology to the next, depending on its maturity and market potential. For specific

technologies, direct government involvement and support can be more effective than private sector involvement in achieving major technological breakthroughs such as radically new technologies, than for incremental advanced ones, where the private sector functions in a relatively effective manner.

- In terms of technology improvement and evolution, the private sector can often operate and deploy more efficiently and effectively, which is more likely to drive widespread adoption, commercialization, and scalability of new technologies as shown in the recent history.

As renewable energy technologies become more affordable, more and more economies undoubtedly benefit from increased access to clean energy. However, a bulk of renewable energy equipment, along with high-value service inputs, are still designed and manufactured in a handful of economies. Various economies, particularly developing ones, continue to be consumers rather than producers of technology, including solar PV panels and wind turbines, with contributions ranging from building to project operations and maintenance. These economies are most likely technology and trade-dependents. The situation presents policy makers with a basic choice, i.e., whether to focus on making renewable energy imports as cheap as possible or to take steps to nurture local capacities and localise certain inputs along the value chain. These choices will be contingent on the specific circumstances of each economy, notably its market structure and socio-economic outlook. Building local capacities may be of benefit to some economies. In such cases, a logical progression might be to start with domestic equipment assembly, develop specifications and standards that enable locally appropriate equipment designs, and eventually manufacture certain components or provide various services linked to renewable energy projects.

4.3 Support Infrastructure

4.3.1 Institutional and Regulatory Framework

The majority of APEC economies have adopted a power supervision paradigm that separates the government from the business. The design of macro policies and market regulation is achieved at the government level by establishing of relevant government authorities such as the Ministry of Energy, the Energy Bureau, and the Energy Commission.

In terms of public services, power transmission and supply are realized through grid companies. On the one hand, different aspects and in-depth power system reforms carried out by various economies have limited the utility monopoly and helped consumers to obtain sustainable, cost-effective, and reliable power services. On the other hand, the regulatory structure ensures that the power industry develops and operates in a planned and orderly manner to satisfy the needs of social and economic development. The energy regulatory departments and electricity public service agencies of each economy are listed in Table 4.28.

A robust electricity market monitoring system and development policy are the prerequisites for ensuring the sustainable and healthy development of renewable energy power generation. Different economies in the region have different legal frameworks when it comes to regulating procedures.

Table 4.28 Energy Regulatory Institutions and Electricity Public Service Agencies of the APEC Economy

Economies	Energy Regulatory Agencies	Electricity Public Service Agencies
China	National Energy Administration (NEA)	The State Grid Corporation of China, China Southern Power Grid.
The United States	The U.S Department of Energy, Federal Energy Regulatory Commission	PJM Western Hub, Indiana Municipal Power Agency, Southwest Power Pool, North Texas Power Company.
Canada	National Energy Commission	Hydro-Québec, Ontario Hydro
Japan	Ministry of Economy, Trade and Industry	Tokyo Electric Power Company, Chubu Electric Power, Kansai Electric Power Company.
Russia	Ministry of Energy of the Russian Federation, Federal Energy Regulatory Commission	Unified Energy System of Russia (RAO UES), OAO Rosset
Australia	Australian Competition and Consumer Commission, The Australian Energy Market Commission (AEMC), National electricity market management company and state government regulators	AGL Energy， Origin Energy, Energy Australia
Mexico	Energy Regulatory Commission	Federal Electricity Commission
Viet Nam	Electricity Regulatory Authority in Viet Nam, Ministry of Industry and Trade	Electricity of Viet Nam
Korea	Ministry of Trade, industry and Energy	Korea Electric Power Corporation
Thailand	Energy Regulatory Commission	The Electricity Generating Authority of Thailand, Electricity Generating Authority of Thailand
Chile	National Energy Commission	Northern Power Grid, Central Interconnected Power System in Chile (SIC), Aysén electricity system， SEA and Magallanes electricity system， SAM
Indonesia	Ministry of Energy and Mineral Resources	PT Perusahaan Listrik Negara (PLN)
Malaysia	Energy Commission (independent supervision)	National Energy（TENAGA）, Sabah Electricity，Sarawak Energy
Chinese Taipei	Bureau of Energy, Ministry of Economic Affairs	Taipower Company
New Zealand	Market Supervision Committee	NZ Power Company
The Philippines	Energy Management Committee (independent supervisory board)	National Power Company（electricity generation）, National Transmission Corporation (Transco) / National Grid Corporation of the Philippines
Peru	Ministry of Energy and Mines of Peru	National Grid Corporation of Peru
Singapore	Energy Market Authority (EMA)	Singapore Power Ltd
Papua New Guinea	Department of Petroleum & Energy	PNG Power Ltd - Papua New Guinea
Brunei Darussalam	Ministry of Energy	Department of Electrical Services, Berakas Power Management Company
Chinese Taipei	Electrical and Mechanical Services Department (EMSD)	Hongkong Electric Company, CLP Group

Source: 1. ASEAN Center for Energy, Hydropower and Water Resources Planning & Design General Institute, "ASEAN Power Cooperation Report"; 2. Compilation of public information

Table 4.29 presents the regulatory systems and policies for renewable energy in some economies of APEC regions. For example, Chile, Japan, Malaysia, Indonesia, Thailand, Peru, Russia, and Viet Nam have established feed-in tariff policies over the whole level of the economy. Local renewable energy feed-in tariff rules are prior policies for Canada and the United States.

Table 4.29 Regulatory Systems and Policies for Renewable Energy in Selected APEC Economies

Economies	Feed-in tariff	Quota System for Renewables*	Electricity price settlement policy	Renewable energy certificates (RECs)	Competitive bidding policy**
Australia	☆ .	●	◖	●	◖○
Canada	◖	◖	◖	☆	◖
Chile	●	●	●	●	●
Japan	●	--	--	●	●○
Korea	--	●	●	●	--

Economies	Feed-in tariff	Quota System for Renewables*	Electricity price settlement policy	Renewable energy certificates (RECs)	Competitive bidding policy**
New Zealand	--	--	◖	--	--
Singapore	--	●	--	--	●
The United States	◖	☆*	☆*	◖	◖
China	☆	☆	--	--	◖○●
Malaysia	●	●	☆	--	●○
Indonesia	●	●	--	--	●
Thailand	●	--	●	--	--
Papua New Guinea	--	--	--	--	--
Chinese Taipei	☆	--	--	--	--
Peru	●	●	●	--	●
Russia	●	--	--	--	●○
Mexico	--	--	●	--	●○
Viet Nam	●	●	●	●	○

Note: ☆ Revision Policy; ☆*Local revision policy; ● Existing national policy; ◖ existing local policy; ○ National auction will be help in 2019.

* "Quota system for renewables" here refers to the incentive system where the government sets the percentage or an amount of energy, usually annually, that comes from renewable resources and then allows the marketplace to determine the costs. The idea is that a certain amount of energy from RE is mandated, but how this is done and at what cost are left to the market to decide.". "Renewable Portfolio Standard (RPS)" is the term used as well.

** "Competitive bidding" has the same meaning as"Tendering", which refers to the procurement mechanism by which renewable energy supply or capacity is competitively solicited from sellers, who offer bids at the lowest price that they would be willing to accept. Bids may be evaluated on both price and non-price factors.

Source: REN 21, Renewables 2020 Global Status Report.

4.3.2 Power System

4.3.2.1 System Flexibility

The expansion of volatile renewable energy such as wind and solar PV will affects power sytem stability. Taking Viet Nam as an example, the total installed capacity of wind and photovoltaic power in Viet Nam was 6.07GW at the end of 2019, expanding more than 100 times over the previous five years. In particular, the installed photovoltaic capacity had increased from 106 MW in 2018 to 5.70 GW in 2019, and the target of 4.3 GW of photovoltaic installed capacity by 2030 was met ahead of time. The boom of solar installations in Viet Nam had a tremendous impact on the power system due to a lack of consideration of related supporting capacity; for example, in Ninh Thuan and Binh Thuan provinces, where photovoltaic projects are concentrated, the two provinces have approved 5GW of installed photovoltaic power generation capacity, which is more than twice the capacity of the existing system.

Measures to raise power system's flexibility in order to attain a high share of renewable energy need to be included in the planning and operation procedures.

By observing photovoltaic installed capacity and annual power generation, the equivalent utilization hours of APEC economies with an installed capacity greater than 2000MW are calculated as shown in Figure 4.26. Chile has the highest equivalent utilization hours of photovoltaic units, reaching 2442 hours per year, followed by the United States, Thailand, Korea, Japan, and China that have annually reached 1602, 1529, 1291, 1129 and 1016 hours respectively. Although Mexico and Australia have the larger installed capacity, the actual power generation is yet lower, resulting in lower annual average utilisation hours of the photovoltaic units. To make optimum use of resources, measures improving photovoltaic units' operation and grid connection conditions can ban examined.

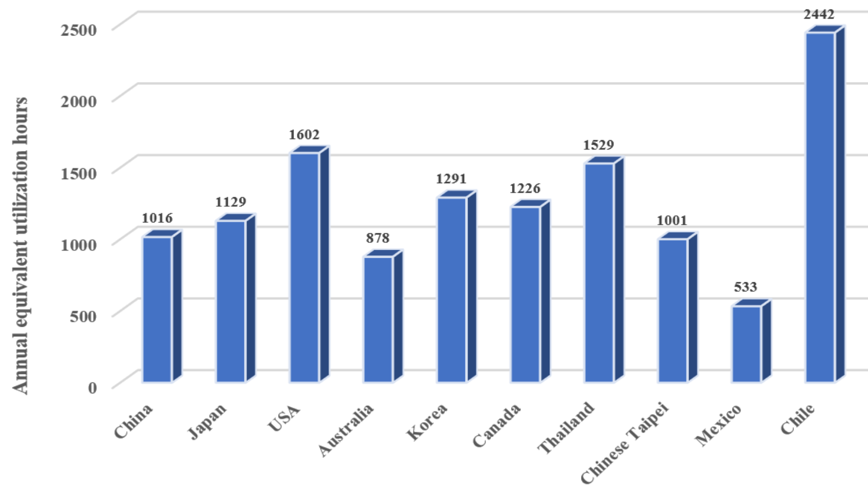


Figure 4.26 Annual Equivalent Utilization Hours of Photovoltaic Units in APEC Economies

For wind turbines, by observing wind installed capacity and power generation, the average annual equivalent utilization hours of wind turbines in APEC economies with installed capacity greater than 1000MW are calculated as shown in Figure 4.27. The United States had the highest annual equivalent utilization hours of wind turbines with 2921 hours, followed by Mexico, Australia, and Canada, reaching 2641, 2606, and 2485 hours per year respectively, while Thailand had the lowest equivalent utilization with only 1488 hours, a value that is equivalent to ½ of the United States.

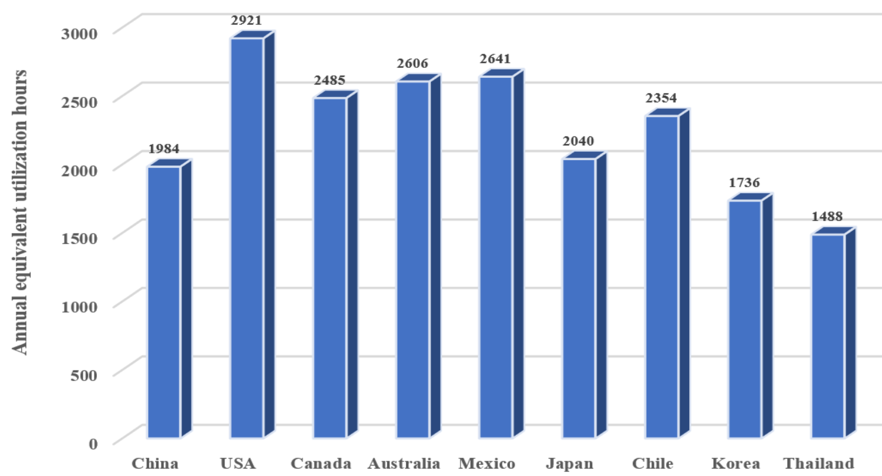


Figure 4.27 Equivalent Utilization Hours of Wind Turbines in APEC Economies

The enhancement of the flexibility of the power system is very crucial for the absorption of renewable energy and promotion of the large-scale use of renewables, which can be achieved through the following aspects.

(1) Raise the flexibility of thermal power unit

Thermal power, particularly coal-fired power, continues to play an essential role in many APEC economies. The methods raise the flexibility of the thermal power plants includes deep peak-regulation, ramping capability and the speed for starting and shutting-down. Flexible thermal power units can help absorb renewable energy by forming a complementary effect with variable renewable energy sources.

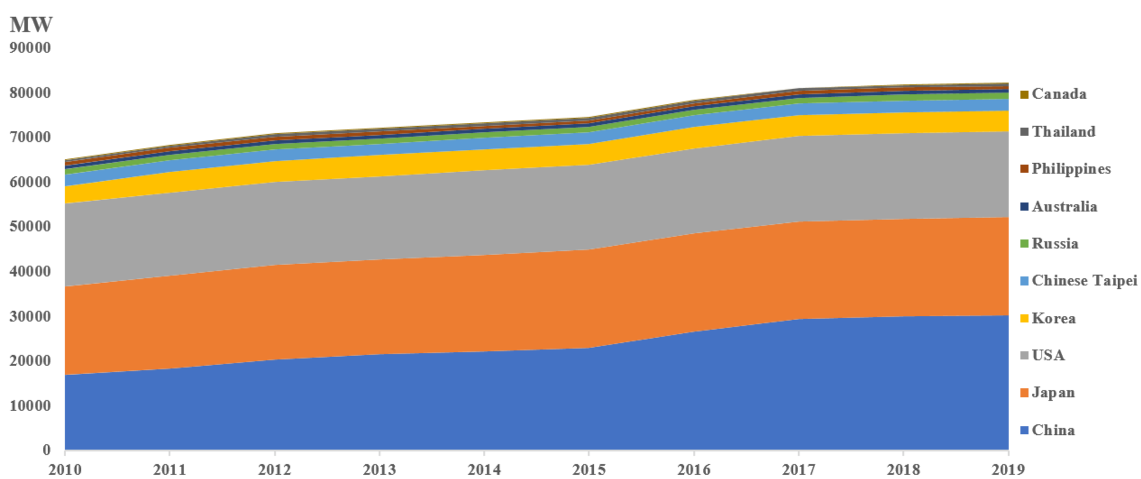
Some APEC economies have made efforts for greater flexibility of the thermal power units. China is an example. The demonstration pilot for more flexible thermal power unit has been operational since June 2016. The conversion of new installed thermal power units of 16.4 GW was made in 2019, with accumulatively 57.8 GW accomplished, which has effectively supported renewable energy absorption in the grid.

(2) Development of pumped storage

Currently pumped storage is the utility-scale energy storage technology with the largest installed capacity. With the increased capacity of renewable energy, pumped storage hydropower plants have become one of the important strategies to improve the flexibility of the power system.

Between 2010 and 2019, the installed capacity of pumped storage in the economies like China, Japan, the United States, and Korea increased gradually, as shown in figure 4.28. Other APEC economies, including Australia, Indonesia, the Philippines, Thailand, and Viet Nam, have also prepared their pumped storage development plans and begun exploratory work on a number of projects.

The Philippines built three pumped storage hydropower plants, namely Wawa Phase I and Phase II, Aklan and Bolusao, with a total installed capacity of 750MW. While Indonesia planned to build in Cisokan with a total installed capacity of 1040MW, and in Sumatra with a total installed capacity of 1,000MW, which were planned to put into commission in 2022 and 2025, respectively, in addition to a pumped storage hydropower plant with a total installed capacity of 1800 MW in the Java-Bali region. Thailand's Lam Ta Kong Phase I and Phase II pumped storage projects started construction, with a total installed capacity of 500MW, and planned to complete the Chulabhom and Srinagarind pumped storage projects in 2026 and 2028, with an installed capacity of 800MW and 801MW, respectively. In Viet Nam, it was planned to complete the Bac Ai pumped storage project with a total installed capacity of 600MW in 2023 and add 600MW of pumped storage capacity in 2025.



Source: IRENA, Renewable Energy Statistics, 2020

Figure 4.28 The Installed Capacity of Pumped Storage in Selected APEC Economies

(3) Enhancing power grid flexibility

Increasing power grid flexibility is one of the significant requirements for absorbing renewable energy. The measures implemented and planned in the region to improve the flexibility of the power grid can be summarized as follows:

- Strengthening the coordinated development of power sources and power grids, and arranging the approved construction progress of power supply and grid reenforcing projects to ensure effective planning and implementation of generation and grid integration while avoiding investment waste.
- Reinforcing the distribution network, promoting the smart grid technology, meeting the needs of distributed energy development, and comprehensively developing a modern power distribution system. Enhancing the "N-1" criteria of the high-voltage distribution network, supporting grid connection of the medium-voltage distribution network, and increasing the distribution automation coverage rate in accordance with the local specific needs.
- Improving grid dispatching intelligence as well as creating a multi-level intelligent power dispatching system. Optimizing the starting-up mode of the generator sets and establishing an appropriate backup capacity. Improving the ultra-short-term accurate power prediction of wind power and solar power, and the controllability of the power grid with higher penetration of renewable power generation.
- Improving wind and solar energy power output's predictability and controllability, and increasing the share of renewable energy participating in the medium and long-term as well as spot markets. Developing an effective anxiliary services market by increasing the number of thermal power plants with right technical capability and energy storage facilities to supply the relevant services.
- Bringing wind power, photovoltaic and other power generating units into power auxiliary service management, and bearing the corresponding auxiliary service costs. Establishing a real-time monitoring system of power and thermal loads of co-generation plants, and identifying the unit's generating curve based on the actual power and thermal load demand. Develop an intelligent scheduling mechanism through connecting flexible heat sources such as heat storage devices and electric heating boilers.
- Within the regional power system, adjusting regional power grid regulation as well as building a flexible adjustment mechanism for conventional power generating plants and sharing peak regulation and reserve capacity.

(4) Strengthening demand side management

The flexibility of the power system can be improved by utilising the demand-side resources. Among the APEC economies, demand-side response resources are mainly involved in the power market, ancillary service market, and capacity market, as indicated in Table 4.30.

Table 4.30 Demand Side Response and Management in the US and Canada

Economies	Operators	Electricity Market	Ancillary Services Market		Capacity Market
			Frequency Regulation	Backup	
The United States	CAISO	√	×	√	√
	ERCOT	√	√	√	√
	ISO-NE	√	×	×	√
	MISO	√	√	√	√
	NYISO	√	√	√	√
	PJM	√	√	√	√
Canada	ASEO	√	×	√	×
	IESO	√	×	√	√

Source: State Grid Energy Research Institute Co., Ltd., Analysis Report of Domestic and Foreign Electric Power Marketization Reform, 2019.

For example, in CAISO Electric Company in the United States, demand-side resources can participate in the electricity and capacity market but not in frequency regulation. Furthermore, it can be used as a backup to improve the flexibility of day-ahead transactions and real-time electricity dispatching to allow the real-time interaction between the "sources" and "loads", and improve the capacity of the power grid to absorb renewable energy.

4.3.2.2 Renewable Power Plants Integration

A large proportion of intermittent and fluctuating renewable energy connected to the grid will have a significant impact on the power system's safety and stability. One of the key issues in the large-scale development of renewable energy is effective renewable energy-related connection standards and rules. As shown in Figure 4.29, renewable energy standards can be divided into generating unit grid-connection standards, operating standards, power planning standards and power market standards[30].

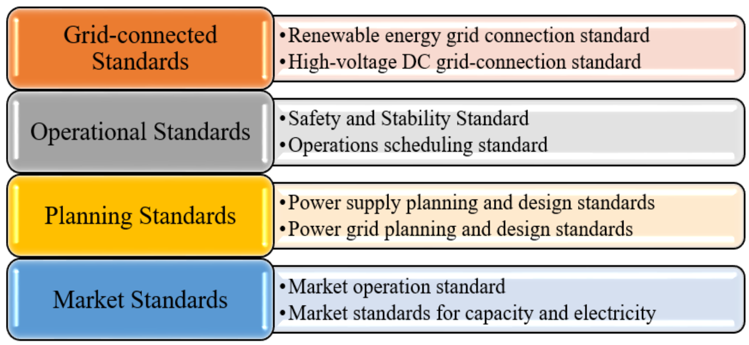


Figure 4.29 Renewable Power Generation Related Standards

Renewable energy grid connection technical standards are normative standards developed based on power grid conditions, renewable energy power generating units, and other relevant technical requirements, involving a wide range of stakeholders, including renewable energy power generation companies, power generation equipment manufacturers, power transmission and distribution companies, and power consumers. The development of standards is the outcome of joint efforts, considering different interests, balance, and collaborations. Renewable grid-connection requirements in the APEC region can be divided into international and economy level standards and rules, as demonstrated in Table 4.31[31].

Table 4.31 Technical Standard Related Organisations

Application Scope	Standard-setting bodies
The world	• International Electrotechnical Commission, IEC (including 82 members, 81 subsidiary organizations) • International Organization for Standardization, ISO (including 164 members)
APEC Economies	• Electricity regulation, research institutions and relevant standards departments of APEC economies.

In terms of international standards, the International Electrotechnical Commission (IEC) is broadly applicable and well-recognized in the APEC economies, which develops relatively authoritative renewable energy grid-connection standards. The technical sub-committees TC 4, TC 82, TC 88, TC 114, and TC 117 are the IEC bodies that establish and revise renewable energy power generation related standards. In addition, TC 8 and TC 57 work in areas covering the power system as a whole, its management and ancillary information, as well as renewable energy generation[32].

[30] IRENA, Scaling up Variable Renewable Power: The Role of Grid Codes, 2016.

[31] IRENA， International Standardisation in the Field of Renewable Energy, 2013.

[32] Zhang Zhankui,Li Yan,Chi Yongning,Tian Xinshou . Research on Domestic and Foreign Status and Progress of Renewable Energy Grid-connected Technical Standards. Power supply and consumption ,2017,34(09):9-13

The IEC Working Group on Renewable Energy connectivity standards are as follow:

- **Water and electricity:** 10 of the 21 APEC economies are members of the TC 4, including five full members and five observers, with 33 related standards formulated;
- **Solar power generation system**: 13 of the APEC economies are members of TC 82, and most of them (12) are full members. 147 relevant standards have been issued;
- **Wind power**: seven economies are members of TC 88, including six full members and nine observers, with a total of 39 standards issued;
- **Marine energy**: eight economies are members of TC 114, including seven full members and one observer, with a total of 16 standards issued;
- **Solar thermal power generation**: six economies are members of TC 117, including three full members and three observers.

Among the 21 APEC economies, Viet Nam, the Philippines, Peru, Papua New Guinea, and others have not participated in the development of relevant IEC international standards. Table 4.32 lists the participation of the APEC economies in IEC standard-setting, and Table 4.33 shows the comparison of renewable energy grid-connection technical standards in some APEC economies.

Table 4.32 APEC Economies' Participation in IEC Standard Development

WG	Content	Secretary	APEC members participants	Formulated part of the main standard name	Content
TC 4	Hydropower	Canada	Canada (P), China (P), the United States (P), Indonesia (O), Japan (P), Mexico (O), New Zealand (O), Russia (P), Malaysia (O), Korea (O)	IEC 60193:2019	Hydraulic turbine，storage pump and pump turbine. acceptance model tests of hydro turbine
				IEC 60308:2005	Hydraulic turbine control system test
				IEC 61362:2012	Guide to specification of hydraulic turbine governing systems
				IEC 62270:2013	Automatic Control for Hydropower Plants
				ISO 20816-5:2018	Part 5: Units in hydropower and pumped storage installations
TC 82	Solar Power Generation System	U. S	The United States (P), Australia (P), Thailand (P), Singapore (P), Russia (P), Mexico (P), Malaysia (P), Korea (P), Japan (P), Indonesia (P), China (P), Chile (O), Canada (P)	IEC 62446-2:2020	Photovoltaic (PV) systems. Testing - Part 2: Grid connection systems
				IEC 60904-1-1:2017	Photovoltaics - Part 1-1: measurement of current - voltage characteristics of photovoltaic (PV)
				IEC 60904-1:2006	Photovoltaics - Part 1: measurement of photovoltaic current and voltage characteristics
				IEC 61724-1:2017	Performance of photovoltaic systems - Part 1: Monitoring
				IEC TS 61724-3:2016	Performance of photovoltaic systems - Part 3: Energy assessment methods
TC 88	Wind power (including offshore and onshore wind power)	Denmark	The United States (P), Russia (P), New Zealand (O), Korea (P), Japan (P), China (P), Canada (P)	IEC 61400-25-5:2017	Wind power communication and control compliance testing
				IEC 61400-12-1:2017	Wind power generation systems - Part 12-1: Measurement of power performance for wind power generation
				IEC 61400-12-2:2013	Wind turbines - Part 12-2: Power performance of wind turbines
				IEC 61400-25-1:2017	Wind power systems - Part 25-1: General description of communication principles and models for monitoring and control of wind farms
				IEC 61400-26-1:2019	Wind power systems - Part 26-1: Availability of wind power systems
TC 114	Ocean Energy	U. K	Australia (P), Canada (P), China (P), Japan (P), Korea (P), Russia (O), Singapore (P), the United States (P)	IEC TS 62600-30:2018	Ocean energy, waves, tidal and other current converters. Part 30: Power quality requirements
				IEC TS 62600-100:2012	Ocean energy, waves, tides and other current converters, Part 100: Evaluation of power performance of wave energy converters for power generation

WG	Content	Secretary	APEC members participants	Formulated part of the main standard name	Content
				IEC TS 62600-101:2015	Ocean energy, waves, tides and other current converters, Part 101: Wave energy resource assessment and characterization
				IEC TS 62600-200:2013	Ocean energy, waves, tides and other current converters. Part 200: Power performance evaluation of tidal energy converters for power generation
				IEC TS 62600-300:2019	Ocean energy, waves, tides, and other current converters, Part 300: evaluation of power performance of river energy converters for power generation
TC 117	Solar thermal system	Spain	China (P), the United States (P), Russia (O), Mexico (O), Korea (O), Japan (P)	IEC TS 62862-1-1:2018	Solar Thermal Power Plant, Part 1-1: Terminology
				IEC TS 62862-1-2:2017	Solar thermal power plant, Part 1-2: General. Creation of annual solar radiation data set for solar thermal power plant simulation
				IEC TS 62862-1-3:2017	Solar thermal power plant, Part 1-3: general. data format of meteorological data set
				IEC 62862-3-2:2018	Solar thermal power plants, Part 3-2: systems and components. General requirements and test methods for large-scale parabolic trough collectors
				IEC TS 62862-3-3:2020	Solar thermal power plants, Part 3-3: systems and components. General requirements and test methods for solar receivers

Source: IEC, https://www.iec.ch/renewables/standardization.htm; Notes: Among participating APEC members, "P" represents full member and "O" represents observer.

Some APEC member economies, such as China, the United States, Australia, and the Philippines, have formulated their own renewable energy grid connection standards. The differences in a grid structure, voltage level, power plant configuration, energy storage station and spatial-temporal distribution characteristics of load in each economy lead to the differences in the grid connection standards of renewable energy units in each economy. As shown in Table 4.33, in terms of technical regulations for renewable energy grid-connection, China, the United States, Australia and the Philippines have made clear requirements on power quality, reactive power output characteristics, frequency response characteristics, fault low-voltage ride-through, communication and control. The requirements of the standards vary, depending on the actual situation of various economies. In China, for example, when system frequency exceeds 50.2Hz, it is required that the active power injected into the power grid by renewable energy must be lowered. Wind farms in the United States and Australia are also required to have frequency response capability; however, the frequency response value is not yet specified.

In terms of low voltage ride-through capability, 0.625s low voltage failure will not cause unit tripping, but China requires 20% of the rated voltage, and the United States requires 15% of the rated voltage. In Australia, the time required to stay connected is 0.430 seconds, and the reactive power support of 0.1seconds is required. The Philippines' low voltage range and time are the same as in China, but an extra 0.15 seconds of reactive power support is stipulated. In terms of communication and control, economies have roughly the same requirements on two-way data communication and control.

Table 4.33 Renewable Energy Grid-connected Standards in Some APEC Economies

Standard requirement	China[1]	The United State[1]	Australia[2]	The Philippines[2]
Electric power quality	Flicker, harmonics, voltage deviation ±10%.	Flicker, harmonic, voltage deviation steady state ±5%, transient ±10%, which is greater than the power system (161kV), ±2.5%.	Flicker, harmonics, voltage fluctuations.	Flicker, harmonics, voltage fluctuations.
Reactive power output	Power factor 0.95 between lag and lead; When the reactive power does not meet the requirements, it is necessary to configure the reactive power compensation device.	The power factor of 0.95 lags between the lead, and at 0 active output can be a certain voltage control.	Under any voltage level and active output, it must be able to provide 39.5% of reactive power Q.	For large-scale wind farms with an active power output higher than 58%, it must be possible to ensure that the reactive power Q is within ±20% of the active power range.
Frequency support	When the system frequency is higher than 50.2Hz, it must be able to reduce the active output.	Units are required or encouraged to provide active frequency response support when the frequency is too high or too low。	Frequency-power curve requirements.	When the frequency is too high, it must be able to limit the active output; large power plants must be able to limit the ramp rate.
Low voltage ride through (LVRT)	When the voltage is low at 20%, it should be kept connected for 0.625 seconds without tripping. When the system voltage is restored to 90% within 2S seconds, the unit shall be continued to operate without tripping.	Not tripping for 0.625 seconds at 15% lower than voltage; continuous operation without tripping at 90% of the normal voltage。	When the voltage is low, it must be kept for 0.430 seconds grid connection; it can provide reactive power support for 0.1 seconds when it fails.	Wind power must be grid connected for 0.625 seconds at 20% low voltage; it can provide 0.15 seconds of reactive power support; photovoltaics can keep off the grid for 0.15 seconds at 0 voltage, and 0.625 seconds at 30% low voltage.
Wide area communication	Bi-directional communication capability; capability of accepting commands from the control center.	Capability of uploading operating data in real time; support emergency energy management.	Bi-directional communication capability; a large renewable power plants must be able to receive power control instructions and report various status information.	Bidirectional communication ability, capability to receive power control, voltage control instructions and start and stop instructions.

Source: 1. NREL, Comparison of Standards and Technical Requirements of Grid-Connected Wind Power Plants in China and the United States, 2016; 2. IRENA, Scaling up Variable Renewable Power: The Role of Grid Codes, 2016.

4.3.2.3 Dispatching and Power Grid Operation

System dispatching is important to realizing the large-scale absorption of renewable energy. Taking China as an example, the optimal scheduling of "source-grid-load-storage", that has been promoted, allows for the flexible absorption of increased amount of renewable electricity. China has upgraded its power grid infrastructure, particularly the UHV AC and DC transmission networks, which raises the grid capacity for renewable energy absorption, supporting large-scale renewable development, balancing regional energy supply demand, and promoting consumption of renewable energy across the economy.

(1) Measures for effective grid operation and dispatching

Some measures for effective grid operation and dispatching include these listed as below.

- **Enhancing the grid capacity:** toward the reinforcement of power network and transmission capacity, in China, more efforts have been given for the development of transmission lines delivering renewable energy in Qinghai, Inner Mongolia, and other resource-rich areas. The construction of the grid in these provinces and other resource-rich areas has been strengthened, with a focus on solving the problem of insufficient across-regional transmission capacity.
- **Improving inter-provincial connection:** Full use of the frequency regulation and peak regulation capabilities of coal-fired power plants at both ends of the transmission lines, optimising power transmission curve through improved short-term and ultra-short-term

prediction of renewable energy output. In China, it has been planned that renewable energy would account for an average of 30% of electricity transmitted in the major inter-provincial transmission lines by the end of 2020.

- **Reinforcing urban and rural smart distribution network:** The urban power distribution networks and rural electrical grids need to be upgraded on a regular basis. It is essential to promote the development of smart power networks, expand the coverage of power distribution automation, and improve the power grid capacity to absorb more distributed clean energy, and support clean heating.
- **Exploring joint dispatching strategy of multiple energy resources:** Investigate and optimize the joint operation of thermal power and renewable energy, as well as the formation of a joint dispatching units of renewable energy power stations and thermal power plants, in which thermal power provides ancillary services such as peak regulation and frequency regulation for renewable energy power stations. The joint dispatching unit participates in the electricity market and follows the direction of the grid dispatching agency. The joint dispatching unit with joint operation of various power sources can be explored in the areas where hydropower is the primary power source, while wind and photovoltaic power generation are also available, also in the areas where wind and photovoltaic power generation have been developed intensively. Subject to local condition, nuclear power projects could encouraged to be developed along with the peak-regulating sources such as pumped storage based on local conditions.
- **Increasing the stability and reliability of the power system:** The dispatching agency should set up suitable operation mode and develop power balancing mechanism appropriately for large-scale renewable energy integration. Grid-related safety management measures, sustained power grid reliability adapting to the long-distance transmission of renewable energy, and relevant technical standards for grid connection need to be improved. It is required to improve the operation safety level of the renewable power generation units by developing relevant supervision and management schemes of renewable energy technologies, strengthening the monitoring system for renewable generating units to ensure safety and security of the power system, as well as information security. Given the stability and other operation issues resulted by the renewable energy expansion and increased grid-connected capacity of renewables, generation companies should take more responsibility and measures to for system security and stability.

(2) Renewable energy curtailment

In recent years, the APEC region has seen steadily increased share of renewable energy in its energy supply. However, in some areas, power grid development is relatively sluggish, followed by insufficient ancillary service mechanism and capacity, which are among the challenges faced by renewable energy development and utilisation. Renewable energy curtailment, and at the same time, insufficient power supply in some load centers exist in various places of some economies. Power supply reliability deteriorated, and power system frequency and voltage stability issues came up, and power blackouts happened more often. It is, therefore, crucial to strengthen the electricity infrastructure and put appropriate processes to improve electric power system stability, reliability and power supply quality.

In recent years, the National Development and Reform Commission, the National Energy Administration, and other ministries in China have taken a series of measures to address China's renewable energy curtailment and utilization issues, which has reached a remarkable achievement. In 2018, renewable energy consumption continued to improve significantly, with an average hydro energy utilization rate over 95%. Wind power consumption reached 93%, an increase of 5% year on year basis. The utilization rate of PV reached 97%, 2.8% higher from the same period in 2017. Simultaneously, China planned to accelerate the construction of peak regulation capacity, including pumped storage power plants and the hydropower plants, improve the market mechanism for auxiliary services, implement flexible hydropower station retrofitting, increase deep peak-regulation capacity of generating units, and raise the utilization rate of existing hydropower plants. The Chinese government committed to continue the policy of portfolio standard, guaranteed grid connection, prioritised power generation from renewable resources, promote local absorption of renewable energy, and other policy measures to support clean energy consumption, and make efforts to effectively solve renewable energy curtailment issues.

(3) Power network reinforcement and development

In the region, some main issues to be addressed as part of the development of the electric power grid are as follow:

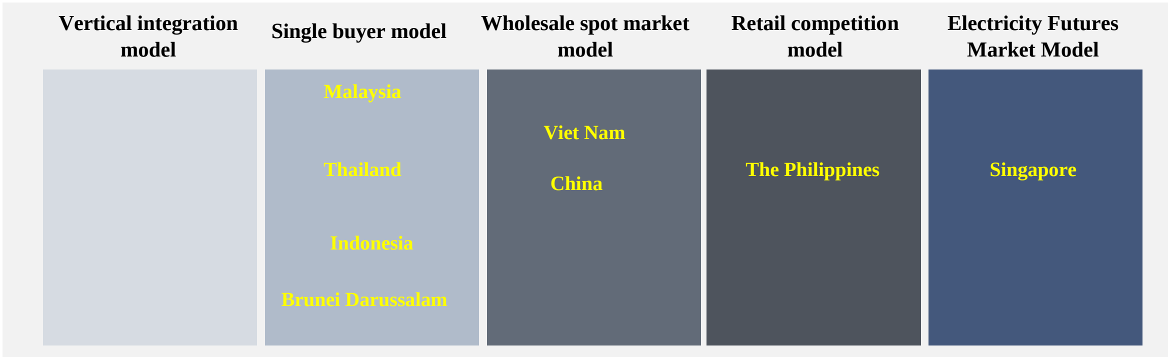
- **Financial burden:** The main financial challenge is the economy's loan repayment capacity. It is not uncommon that some developing economies have limited financial payback capabilities. For the power transmission project development, possible application for low-interest loans, and other new financing mechanisms are needed.
- **Political issues:** In an economy, government functions play a significantly important role for the power sector development. The approval procedures are directly linked to the timeline of the power line projects, while government support and commitment are among the key factors to the success of the projects. It involves various stakeholders; therefore, coordinating the stakeholders and their interests effectively, and ensuring the maximizing of all parties' interests has become one of the critical moves.
- **Regional interconnection:** The intelligence level of the power grid in each economy is diverse, resulting in a high frequency of various types of accidents in the power system. The insufficient connection capacity would affect the regional power flow and limit regional energy transaction of the system. Furthermore, it is likely dedicated transmission projects for regional interconnection are needed for cross-border power trades since economies continue to emphasize their own power supply and grid planning. Aside from the added costs, the operation of regional interconnection will undoubtedly confront the dual challenges of stability and reliability.
- **Other barriers:** The difficulty of acquiring confidential data and information and the lack of a consistent legal framework on this and information security need to be addressed at the regulatory and operation level toward an effective regional power cooperation within the economy or between the economies.

4.3.3 Electricity Market

4.3.3.1 Market Structure

In APEC economies, the structure of the electrical market varies widely, with different levels of openness and competition. Vertical monopoly mode, single buyer mode, spot wholesale market mode, retail competition mode, and power futures market mode are the various structures of the electricity market used in the region.

In general, the reform and development of the electricity market has been in the direction of further improving a fair and orderly competitive condition of electricity trade. Figure 4.30 shows electricity market models in selected APEC economies.



Source： IRENA, Renewable Energy Market Analysis Southeast Asia

Figure 4.30 Electricity Market Model in Selected APEC Economies

With the exception of the Philippines, Singapore, and Viet Nam, the single buyer is the most common power market model in the economies mentioned in Figure 4.30. The electricity market in Singapore and the Philippines is liberalized retail competition model; independent power producers (IPPs) play a significant role in the electricity market. All electricity consumers in Singapore now have multiple choices of suppliers, which have been implemented since 2018. Since 2016, electric power producers in Viet Nam have been permitted to sell electricity directly to state-owned power enterprises at the agreed prices.

In March 2015, China began a new phase of power system reform, the development of China's electricity market has been constantly promoted, and impressive results have been achieved, thanks to the joint efforts of all stakeholders across the economy. The fundamental structure of the domestic unified electricity market and the two-level operations (wholesaler and retailer) has been basically established. Eight pilot provinces (regions) have carried out trial operations, and the market development has yielded positive outcomes, while power network development has made it possible for the establishment of domestic electricity market.

The pricing mechanism for power transmission and distribution at all volage levels of the network has been largely established, setting the foundations for electricity pricing for the domestic electricity market. To support the efficient operation of the electricity market, a reasonably independent and standardized trading platform and operation mechanism have been set up. The scale of marketized transactions continues to grow, and the reform dividend benefits a large number of users, for example, in 2019, the operating region of State Grid Corporation's market transaction of electricity reached 2080 TWh. Fostering market competition of increased sales by allowing a diverse set of market players and creating a market-based system are important moves to encourage clean energy consumption and continue to support clean energy transition.

4.3.3.2 Market Operation

With the development of ultra-high voltage transmission technologies, one of the concerns of APEC economies is to reasonably formulate electricity market operation rules, promote large-scale renewable energy consumption, create a fairer electricity market condition and electricity pricing mechanism that takes into account the interests of all stakeholders, and improve the operation efficiency of the electricity market.

APEC economies have launched a number of power market reform initiatives, set policy goals, and pushed the pace of energy transition. Considering renewable energy and flexible resource regulation in the power market and system design has become increasingly apparent. Table 4.34 summarizes relevant development on electricity market reform.

In terms of electricity pricing mechanisms, Japan, Canada, Korea, Peru, and other economies have adopted the single market pricing mechanism, while the United States adopted node pricing model and Australia regional pricing method. The difference between the wholesale electricity prices and the retailer prices reflect economy's regulation on and policy in power sector, and electricity market structure.

Table 4.34 Electricity Market Development in APEC Economies

Economies	Electricity Market Development (till 2019)
China	The independent electricity transmission and distribution pricing system has been basically established. According to the electricity transmission and distribution pricing model of "permissible cost + reasonable benefit", the verification on electricity transmission and distribution prices in the first supervision round of all levels of power grids has been completed. The strategy for generating and using electricity was further liberalized, the pricing system has been continuously improved, the development of spot market was further advanced, and an embryonic power market system was established. Diversified electricity suppliers participate in the market, and the market competitive condition emerges. With 404 approvals by 2019, pilot projects for incremental distribution networks have moved even further, standardizing the investment, implementing, and operating the incremental distribution networks.
The United State	On April 19, 2018, the FREC issued Decree No. 844, requiring the electricity market operation mechanism to improve the transparency of rising cost allocation and optimize the allocation scheme. Nevada, Maryland, and New Jersey are among the states that have established low-carbon policies that will steadily increase the amount of renewable energy. The capacity market mechanism has been optimized by PJM, New England, and other electricity markets. At the same time, emerging market players such as energy storage and demand-side response have been increasingly integrated into the electricity market in the United States.
Canada	The Alberta government announced in July 2019 that there would be no transition to the capacity market and would instead focus on developing a single energy market. On March 26, 2019, Ontario's independent electricity operator announced plans to conduct an annual capacity auction in order to lower residential electricity prices.
Japan	In July 2018, the Japanese government announced the newly formulated "Fifth Basic Energy Plan", which for the first time identified renewable energy power generation as the "main source" of decarbonization to achieve economic independence by 2050. With the full liberalization of the electricity retailing, a TEPCO’s subsidiary company has been engaged in retailing business in the market.
Russia	The major goal of the power reform, which drew a considerable amount of investment and rapidly increased power capacity, has been mostly achieved ten years after the re-organization of Russia's Unified Electric Power System. The economic efficiency and safety level of the power grid have improved significantly, and the unified command and operation of the power grid have achieved expected results. The social cost of electricity has remained constant during the reform process, and the increased rate of residential electricity prices has basically kept pace with inflation. However, the stability of electricity prices has not yet had a significant impact on limiting the overall price increase in Russia.
Australia	The Australian government announced retail electricity tariffs and market regulation measures in July 2018. The Australian Energy Market Commission has released a unified settlement framework for the customers side of the wholesale market. It was expected that unified settlement rules for retailers can effectively reduce related transaction costs.
Mexico	In 2014, the marketization of the power sector was established according to relevant laws and regulations. Power dispatching and trading center became independent in August 2014. The electricity market guidelines were issued in February 2015, and the spot market were put into operation in 2016, with joint optimization of day-ahead and real-time trade, and ancillary services.
Viet Nam	The Plan for institutional reform of the power industry from 2016 to 2020 and Vision 2025 was released in February 2017. Following the goal of boosting production efficiency and the electric power industry's operation and the marketization level, the electric power transmission has been undertaken by the Viet Nam state-owned power transmission corporations, distribution, retail under state-owned electric power supply corporations. As for the electricity retail competition, the electric power supply regulation mechanism was formed among the power providers to meet the market demand for electricity. BOT power plants are permitted to participate in competitive electricity sales simultaneously.
Korea	In June 2019, the State Council adopted the Third Basic Energy Plan 2019-2040, aiming at increasing the share of renewable energy to 30%-35% by 2040, rapidly reducing the share of coal power generation and nuclear power generation, reducing CO_2 emissions and achieving a clean and secured energy supply. The target also aimed to strengthen demand management in industry, transportation, construction, and other sectors, rationalize the pricing system, improve energy consumption efficiency by 38 %, and reduce the energy demand by 18.6 % by 2040.
Thailand	Thailand has been reducing fossil fuel subsidies, supporting renewable energy development through market mechanism, using auction for renewable energy project development, aiming at higher proportion of renewable energy in the energy mix. After 2017, Thailand's renewable power generation capacity growth has been driven mainly by cost competitiveness of the technologies and the competition among the developers.

Economies	Electricity Market Development (till 2019)
Chile	Chile was one of the first economy in the world to liberalize power market prices and to privatize the electricity market. The Chilean power market has been privatized, and the electricity generation, transmission and distribution have been divided under different regulatory authorities. Toward a fair and competitive electricity market, the Chilean government has taken measures such as establishing an independent dispatching center, improving the payment system, expanding the scope of enterprise participation in the market. The goal is to ensure more competitive, safe, and reliable power supply.
Indonesia	The state-owned power utility still generates most of Indonesia's electricity and has a monopoly on transmission and distribution. Indonesia mainly relies on government subsidies for electricity, and the average cost of electricity generated in the economy is generally greater than the average price paid by consumers.
Malaysia	Tenaga Nasional Berhad is the only power supply company in Peninsular Malaysia, while the power supply in Sabah and Sarawak are respectively handled by Sabah Electricity Sdn Bhd and Sarawak energy. Tenaga Nasional Berhad monopolizes all aspects of power generation, transmission, and distribution. It also stays dominant in some surrounding areas. The government, rather than the market, determines the electricity prices, and there is a subsidy for residential consumers. In 2019, the Malaysian government discussed opening the competition in Peninsular Malaysia.
Chinese Taipei	The revised draft of the Renewable Energy Development Regulation was released in 2018, allowing for the exchange of wholesale and direct supply and transfer of supply, so that green electricity that has been contracted can also be withdrawn from wholesale electricity and join the green electricity trading market. It is required to install renewable energy generation capacity for large customers. Those who cannot cooperate with the installation can purchase renewable energy certificates or pay vouchers. This is among the first steps for Chinese Taipei to open the market for the liberalization in the power sector.
New Zealand	The New Zealand wholesale electricity market is an open, competitive, voluntary, and self-regulated market. New Zealand electricity market consists of electricity wholesale market and power distribution competitive market. The market comprises primary spot trading with secondary futures contract trading. Due to the limited transmission capacity of HVDC cable between North Island and South Island, different price zones are set up in North Island and South Island, respectively. Generators compete to sell their electricity to wholesale markets, which sell it to electricity buyers. Through the retail market, retailers buy and sell electricity to end-users of different sizes.
The Philippines	The formal reform of the electricity market in the Philippines began in 2001 when the State Power Corporation's vertical monopoly of the electricity market was transformed into a partially open electricity market. The power generation sector and transmission and distribution sector were officially separated. In 2002, the wholesale spot electricity market was established and first operated in Luzon Island in 2006. Power generation enterprises and electricity purchasers may purchase and sell electricity through bidding in the power pool. At present, the power generation and distribution sectors have basically been fully opened, except that the state still monopolizes the power transmission network.
Peru	The Peruvian government promulgated the Electricity Law in 1992, dividing the electricity industry into generation, transmission, and distribution, establishing non-regulatory prices for competitive activities, customizing prices for activities that need to be regulated, stipulating that electric energy and capacity are the most basic trading products of the electricity market, and establishing the competitive wholesale electricity market.
Singapore	Singapore electricity market was formed in 2003, and now consists mainly of power generation companies, wholesale electricity market operators, the grid operator, market support services provider, retailers, and consumers. In the wholesale electricity market, generation companies compete to generate and sell electricity every half-hour, retailers buy electricity in bulk from the wholesale electricity market and compete to sell electricity to consumers
Papua New Guinea	Only about 12% of Papua New Guinea's population has access to electricity, and current electricity prices are set by Independent Consumers and the Competition Commission. The government aims to increase the population's electricity access to 70 % by 2030.
Brunei Darussalam	Brunei, which depends on natural gas for the majority of its electricity needs, plans to generate 10% of its electricity from renewable sources by 2030.
Hong Kong, China	The Hong Kong government has signed the current Scheme of Control Agreement with CLP Power and Hong Kong Electric on 25 April 2017 for a 15-years period. Traditionally, Hong Kong's electricity has been supplied by CLP Power and Hong Kong Electric, each of which owns and operates its own energy supply chains, including power plants, transmission and distribution networks. Under the new Scheme of Control Agreement, the permitted rate of return for power companies reduced to 8%.

(1) Wholesale electricity price

Some APEC economies have formed spot electricity markets, and competitive electricity price are formed at different degree in power generation markets, such as the United States, Canada, Australia, Japan, New Zealand, Peru, Korea, etc. China have developed domestic electricity spot market through a period of and a number of pilots. The prices of wholesale electricity in APEC economies differ significantly. Electricity prices at all hub nodes in the United States, for example, were usually higher in 2018 than that in 2017, with noticeable regional differences. Regional power spot market prices in Australia fluctuated dramatically; China and Japan were relatively behind in reforming competitive electricity markets, and the wholesale electricity prices were relatively stable. (Table 4.35)

Table 4. 35 Wholesale Electricity Prices in Selected APEC Economies

Economies		2017 ($/MWh)	2018 ($/MWh)
China		54.53	54.20
The United States	New York ISO ZJ	39.15	47.37
	New England ISO	37.68	50.11
	PJM West	34.25	41.79
	Indiana	34.22	39.01
	Southwest Power Depot	30.43	30.43
	Northern Texas	26.44	41.51
	Northwest Mid-C	26.17	37.94
	California ISO NP15	38.04	42.22
	California ISO SP15	38.50	47.35
	Palo Verde, Southwest	33.03	40.96
	Southern part	29.62	30.80
Canada	Alberta	16.43	37.26
	Ontario	--	17.98
Japan		94	94
Australia	Queensland	75	83
	New South Wales	85	92
	Victoria	99	124
	South Australia	109	128
	Tasmania	88	88

Source: 1. National Energy Administration, Regulatory Bulletin on National Electricity Prices in 2017 and 2018; 2. State Grid Energy Research Institute Co., Ltd., analysis report on domestic and foreign power market reforms, 2019.

(2) Retail electricity price

The majority of APEC economies distinguish between residential and commercial electricity prices, as listed in Table 4.36, while Viet Nam; Thailand; and Hong Kong, China use the same pricing scheme. Russia, Malaysia, Mexico, Viet Nam, and China have the lowest household electricity prices. Among different economies, Japan had the highest residential electricity price, $0.28 /kWh, which is 4.7 times higher the economies with the lowest prices. As for the commercial electricity prices, Indonesia, Viet Nam, Russia, Canada had the lowest, whereas Japan the highest, at $0.21/kWh, which is three times that of Indonesia. The United States, Canada, Japan, Australia, Korea, Chile, Indonesia, the Philippines, Peru, and Singapore are among the ten economies where household power prices are greater than commercial electricity prices, with the maximum price difference reaching $0.07/kWh. China, Russia, Mexico, Malaysia, and Chinese Taipei are the five economies where household electricity prices are higher than commercial electricity prices.

Table 4. 36 Retail Electricity Prices in APEC Economies (2019)

Economies	Residential electricity price ($/kWh)	Commercial electricity price ($/kWh)	Differences in residential and commercial electricity price（$/kWh）
China	0.08	0.10	-0.02
United States	0.14	0.11	0.03
Canada	0.11	0.09	0.02
Japan	0.28	0.21	0.07
Russia	0.06	0.09	-0.03
Australia	0.23	0.19	0.04
Mexico	0.07	0.14	-0.07
Viet Nam	0.08	0.08	0
Korea	0.11	0.10	0.01
Thailand	0.12	0.12	0
Chile	0.19	0.14	0.05
Indonesia	0.10	0.07	0.03
Malaysia	0.06	0.10	-0.04
Chinese Taipei	0.10	0.13	-0.03
New Zealand	0.22	--	--
The Philippines	0.20	0.13	0.07
Peru	0.20	0.14	0.06
Singapore	0.18	0.14	0.04
Papua New Guinea	--	--	--
Brunei Darussalam	--	--	--
Hong Kong, China	0.14	0.14	0

Source: www.globalpetrolprices.com/

4.4 Capital and Investment

4.4.1 Investment in R&D

The R&D activities have proven effective in bringing the costs of the renewables down, increasing the technological capabilities of local renewables manufacturers, and enhancing the competitiveness of renewable technologies in regional and local markets. The renewables R&D activities are expensive and risky, and therefore need financial support from the government to move the technologies from laboratories to market. Historically, R&D on technologies takes place in industrialized economies, whereas the developing economies depend on technology transfer and buying technologies. Although major R&D on technology, policy, and institutional issues on renewable technology occur in both industrialized and emerging APEC economies, such as the United States, Japan, and China, the developing economies in the region need more R&D efforts to make the technology and policy adaptable in local conditions.

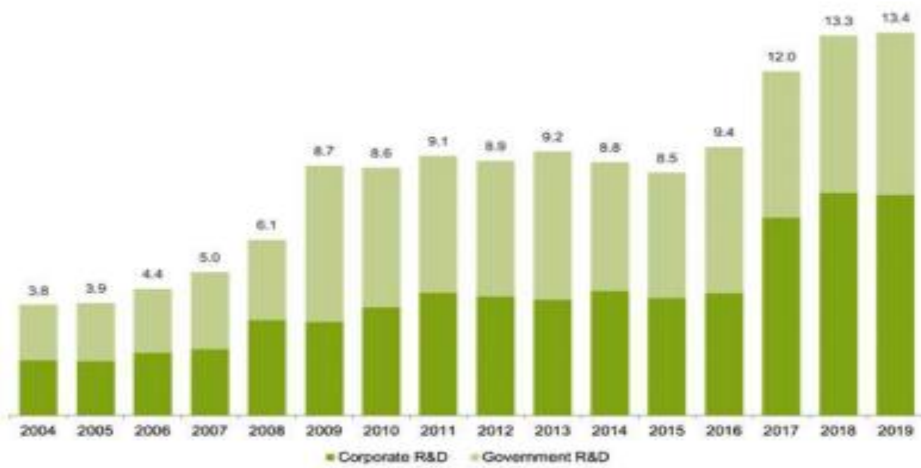
The R&D needs of developing economies relate to the challenges that address the embedded socioeconomic needs, the identification of appropriate energy technologies informed by the local conditions, and the need for R&D on sustainable business models to stimulate local renewable industries[33]. Also, efforts are needed to improve the forecasting of variable renewable energy to enable more accurate supply and demand planning. As mentioned, before, with the share of renewable resources increase, grid integration of the renewable electricity and power system flexibility are among the other important areas of research. For example, Belgium company Elia is helping Viet Nam assess the power system's stability with increasing renewable energy shares and developing a state-of-the-art wind generation forecast architecture[34].

Figure 4.31 presents the global government and corporate R&D spending on renewable energy over 2004-2019[35]. R&D spending has increased manifold in this period from 3.8 billion USD in 2004 to 13.4 billion USD in 2019. Corporate R&D has a larger share. In recent years, corporate

[33] https://www.fvee.de/fileadmin/publikationen/Themenhefte/sf2004/sf2004_05_01.pdf
[34] https://www.eliagrid-int.com/elia-grid-international-active-in-Viet Nam-with-three-projects-to-support-renewable-integration/
[35] https://www.fs-unep-centre.org/wp-content/uploads/2020/06/GTR_2020.pdf

spending has increased while government spending remains almost at the same level. Important corporate houses include General Electric (USA), Vestas (Denmark), Equinor (Norwegian) etc.

China, as enacted in the Renewable Energy Law, sets to push the R&D and industrialization of renewable energy. Some dedicated renewable energy research centers were established between 2005 and 2016[36]. These R&D centers have been successfully improving the Chinese renewables' technological capabilities. For instance, China is now advanced in core wind energy technologies, including largescale wind turbines, wind turbine blade air-foil, and offshore wind farm design and construction. China's capability to manufacture low-cost solar cells and polysilicon is also associated with the success of its R&D institutions in making technological breakthroughs[37], benefiting not only the economy but also the rest of the world. The Chinese manufacturers have then become the global market leaders in the solar PV and wind turbine manufacturing industries. In 2015, by market share, five of the top six global solar PV manufacturers and five of the top ten wind turbine suppliers in the world were Chinese[38]. Prices of solar PV modules and wind turbines have been the lowest in the world. The Chinese companies have also been expanding their renewable investments to other economies, such as Brazil, Australia, Canada, and the United States, to gain more opportunities to grow R&D funds.



Source: UNEP, Frankfurt School-UNEP Centre, BNEF

Figure 4.31 Global Government and Corporate and Renewable Energy R&D (2004-2019)

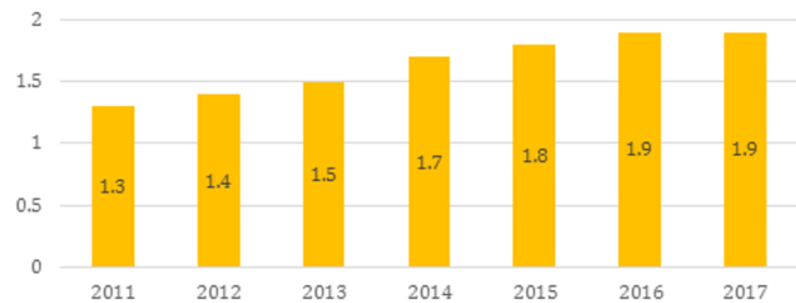
The Chinese government has kept increasing its spending on renewable energy R&D from USD 1.3 billion in 2011 to USD 1.9 billion in 2017 (Figure: 4.32)[39]. This confirms China's strong commitment to the development of renewable energy in the economy as R&D is among the keys to bringing the costs of renewable technologies down. The lower costs increase the competitiveness of Chinese renewables technologies and help maintain China's position as one of the global renewables market leaders.

[36] IESR, 2018, Igniting a rapid deployment of renewable energy in Indonesia: Lessons Learned from Three Countries, Institute for Essential Services Reform, November 2018, Jakarta, Indonesia.

[37] Zhao, Z.-Y., Chen, Y.-L., & Chang, R.-D. (2016). How to stimulate renewable energy power generation effectively? - China's incentive approaches and lessons. Renewable Energy, 147-156.

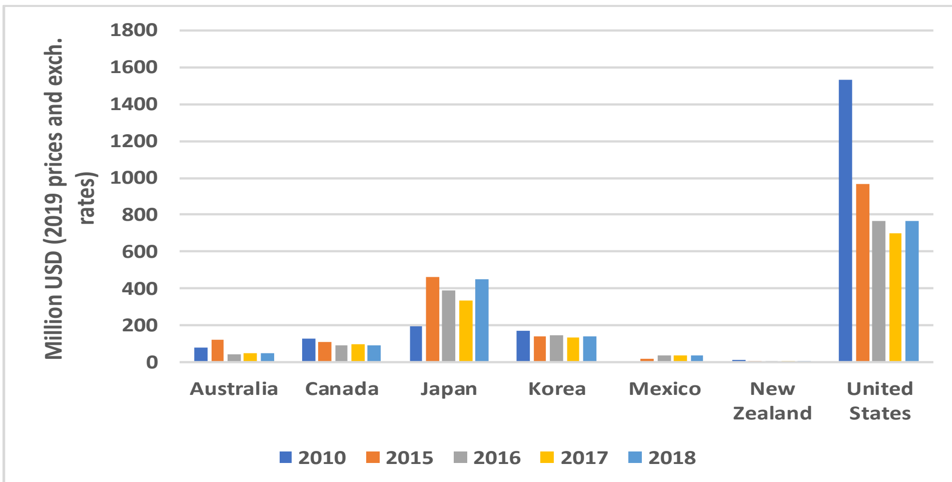
[38] Buckley, Tim, and Simon Nicholas. "China's global renewable energy expansion: How the world's second-biggest national economy is positioned to lead the world in clean-power investment." Institute for Energy Economics and Financial Analysis. Available at http://ieefa. org/wp-content/uploads/2017/01/Chinas-Global-Renewable-Energy-Expansion_January-2017. pdf (2017).

[39] IESR, 2018, Igniting a rapid deployment of renewable energy in Indonesia: Lessons Learned from Three Countries, Institute for Essential Services Reform, November 2018, Jakarta, Indonesia.



Source: IRENA, 2018

Figure 4.32 China's R&D Expenditure on Renewable Energy Technologies



Source: IEA

Figure 4.33 Public R&D Expenditure in Industrialized APEC Economies

Public R&D expenditure on renewable energy sources in developed APEC economies is available from IEA statistics[40], which is presented in Figure 4.33 for the period 2010-2018. Private sector spending data is not available.

As illustrated in Figure 4.33, the United States spent heavily on research and development, followed by Japan. However, expenditure varies greatly depending on government goals and policy changes of different administrations. The United States led the world in 2010 with $1.5 billion in R&D investment on renewable energy technologies, thanks to the Obama administration's commitment to combating climate change. Nonetheless, under the Trump administration, investment has dropped by half in just a few years.

According to the IEA, Japan's public sector R&D investment in energy is one of the highest among OECD economies as the share of GDP stands at 0.06%. R&D expenditure in Japan increased from $193 million in 2010 to $461 million in 2015, then it stopped slightly and rose again to $446 million in 2018. In 2010, Korea spent $167 million on renewable energy technologies, with an annual investment of over $140 million from 2015 to 2018.

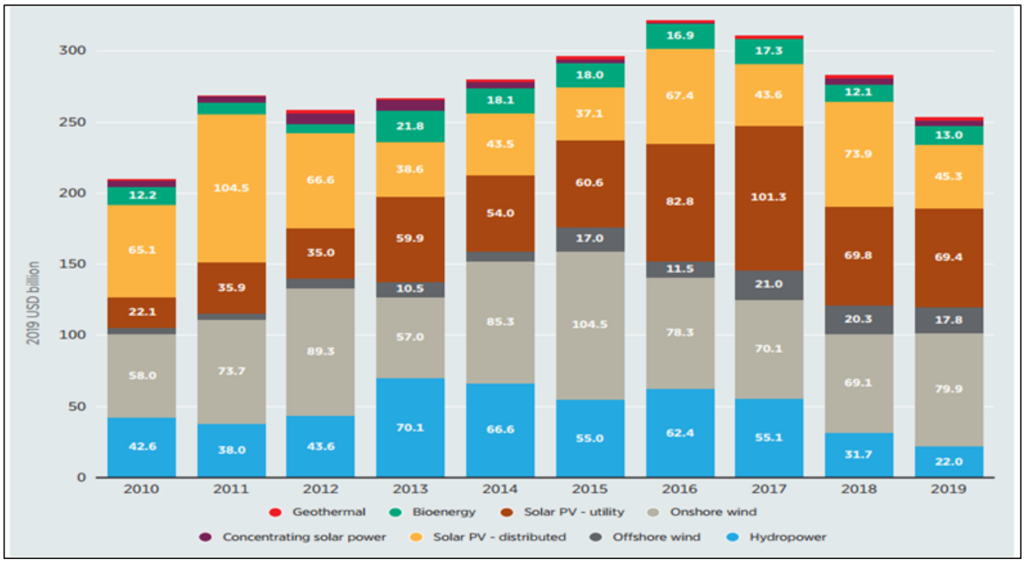
R&D data for other APEC economies are not available. The government of these economies should take similar steps as China by providing funding that can be accessed by the universities, research

[40] https://www.iea.org/statistics/rdd/

institutions, and companies to conduct R&D so that these technologies could be adaptable under the local conditions the economy.

4.4.2 Renewable Energy Investment Trend

As shown in Figure 4.34, the world invested $282.2 billion in renewable energy capacity in 2019[41]. Wind and solar stood over the other renewable energy technologies in terms of amount of investment. It may need to note that with falling technology costs, more capacity had been installed, although investment declined recently.



Source: BNEF, 2020

Figure 4.34 Investment and New Capacity Added by Renewable Technology (2010-2019)

Table 4.37 provides the investment trend on renewable power generation capacity in selected APEC economies. The leading economies in the region for investment were once again China, the United State, and Japan. China has been the largest investor in renewable energy capacity. Between 2010 and 2019, China had committed around $319 billion, with the United States coming in second with $271 billion and Japan third with $128 billion, as Table 4.37 illustrates.

Table 4.37 Investment in Renewable Power Capacity in Selected APEC Economies (US$ billion)

APEC Economies	2015	2016	2017	2018	2019
China	125.4	107.20	146.8	88.5	83.4
US	58.4	56.4	57.6	42.8	55.5
Japan	42.6	27.9	23.4	17.6	16.5
Chinese Taipei				1.8	8.8
Australia	2.2	3.6	9	9.2	5.6
Chile	3.4			1.3	4.9
Mexico	1.8	1	6.2	3.8	4.3
Viet Nam				5.2	2.6
Korea				1.4	2.4
Russia				1.9	2.3
Canada	3.8	1.3	3.3	0.6	0.6
Indonesia				0.8	0.4
Thailand				0.3	0.2
Malaysia				0.4	0.3

Source: BNEF

[41] https://about.bnef.com/new-energy-outlook-2020/

China leads in investment not only in the region but also globally. However, there has been a fall in two successive years, 2018 and 2019. China's market decline was due largely to policy uncertainty. The economy was in the process of restructuring its renewable energy market, shifting from high-speed capacity growth and dependence on direct financial support through uncapped FITs to the expansion of high-quality technologies and systems through auctions and subsidy-free deployment to reduce costs and improve overall system performance.[42] The domestic government ceased approvals for new subsidized projects at the end of May 2018 and took more than a year to provide clarity on a revised FIT policy. It was reported that the market also was tempered by ongoing delays in FIT payments for existing facilities, challenges related to grid connections, land availability and access to finance as well.[44] Financings in the United State leapt 28% to $55.5 billion, as the developers rushed to qualify for tax credits before they expire. Japan showed a continuous declining trend, and investment in 2019 was only 39% of the investment made in 2015. Part of the reason for the fall was lower unit costs for solar, cutting the dollar amount committed per MW capacity, and partly the economy's continued grid and land constraints that held back developers' activity and auction bidding[43].

Chinese Taipei showed a spectacular rise with a near-quintupling of its investment volume to $8.8 billion, thanks mainly to a trio of offshore wind deals; Viet Nam faced a cooled-off in 2019 with investment just 50% of the previous year due to policy uncertainty after its solar boom in 2018, which saw $5.2 billion. Despite having strong potentials for various renewable energy resources, Indonesia's renewable industry struggled to compete against the conventional power plants which are primarily based on coal.

4.4.3 Trend of Capital Cost of Renewable Technology

World Energy Outlook 2020 presents capital cost and LCOE development for years 2019 and 2040 for main energy markets in the world, which include two APEC economies, the US and China. As shown in Table 4.38, costs are presented for three important technologies solar PV, wind onshore and wind offshore in the Stated Policy scenario and Sustainable development scenario.

Table 4.38 Trend of Cost Development of Renewables (2020-2030)

		Stated Policy scenario				Sustainable development scenario			
Country	Technology	Capital costs (US$/kW)		LCOE (US$/MWh)		Capital costs (US$/kW)		LCOE (US$/MWh)	
		2019	2040	2019	2040	2019	2040	2019	2040
United States	Solar PV	1220	680	50	30	1220	580	50	25
	Wind onshore	1560	1440	35	35	1560	1400	35	35
	Wind offshore	4260	2160	115	55	4260	1960	115	50
China	Solar PV	790	450	40	25	790	390	40	20
	Wind onshore	1220	1140	50	40	1220	1100	50	40
	Wind offshore	3000	1640	100	45	3000	1480	100	40

Source: IEA, World Energy Outlook 2020, International Energy Agency, Paris

Capital costs and LCOE are significantly lower in China than in the US market today, and that will continue in 2040. In both economies, there will be only a small decline in onshore wind cost over the period 2019-2040. However, for the other two technologies, the decline in capital cost is in the range of 50-55% in the Stated Policy scenario, and the fall is even higher in the Sustainable development scenario. The decrease in LCOE is also in the same range. This lays the foundation

[42] https://www.ren21.net/gsr-2020/

for further higher investment efficiency, in terms of increased capacity per unit of investment, over the days to come.

4.4.4 Impact of COVID-19 on Renewable Energy Investment

The COVID-19 pandemic has delivered a brutal shock to economies around the world, including APEC economies. The immediate focus of governments has necessarily been on healthcare, with parallel emergency financial and economic interventions to provide essential support to citizens and businesses and help avert an economic downturn.[43] According to IMF June 2020 forecast, other than China and Viet Nam, the economy of all major APEC economies was expected to shrink in 2020, ranging from USA -8%, Canada -8.4%, Japan -5.8%, Russia -6.6%, Mexico -10.5%[44]. China is expected to grow at 1% and Viet Nam at 2%. However, for 2021, positive economic growth is projected for all economies.

The COVID-19 pandemic is having a major impact on energy systems worldwide, curbing investments and threatening to slow the expansion of key clean energy technologies.[45] With a shrinking economy, volatile commodity prices and suppressed energy demand leave many energy companies with weakened financial positions and strained balance sheets. In addition, project workers have been confined to their homes, planned investments have been delayed, particularly in 2020, deferred or shelved, and supply chains have been disrupted. According to the IEA's World Energy Investment 2020, investment in the energy sector in 2020 experience its largest decline on record with a reduction of one-fifth, almost $400 billion, in capital spending compared with 2019.[46]

In the power sector, the ability of many companies to invest in new capacity has also been weakened by the crisis. This is particularly true of state-owned enterprises (SOEs) in emerging economies, many of which were already under financial stress, as well as equipment suppliers.[47] Larger renewables-focused utilities in advanced economies appear on firmer footing but also face some revenue risks from shifting market demand and price trends. According to IEA's World Energy Investment Outlook 2020, investment in renewable energy has been relatively resilient. Overall, ongoing investment in renewable power projects is expected to fall by around 10% for the year, less than the decline in fossil fuel power. Capacity additions were set to be lower than 2019 as project completions get pushed back into 2021. Final investment decisions (FIDs) for new utility-scale wind and solar projects slowed in the first quarter of 2020, back to 2017 levels. Distributed solar investments have been more dramatically hit by lower consumer spending and lockdowns.

World Energy Outlook explored different pathways out of the COVID-19 crisis, with a particular focus on a pivotal next ten years to 2030[48]. Uncertainty throughout the pandemic, its economic and social impacts, and the policy responses opened up a wide range of possible energy futures. By considering different assumptions about these key unknowns, along with the energy market data and a dynamic representation of energy technologies, the Outlook examines:

- **The Stated Policies Scenario (STEPS)**, in which COVID-19 is gradually brought under control in 2021, and the global economy returns to pre-crisis levels the same year. This scenario reflects all of the announced policy intentions and targets insofar as detailed measures for their realization back them up;
- **The Delayed Recovery Scenario (DRS)** is designed with the same policy assumptions as in the STEPS, but a prolonged pandemic causes lasting damage to economic prospects.

[43] https://www.iea.org/reports/sustainable-recovery/covid-19-and-energy-setting-the-scene
[44] https://www.imf.org/en/Publications/WEO/Issues/2020/06/24/WEOUpdateJune2020
[45] https://www.iea.org/articles/the-impact-of-the-covid-19-crisis-on-clean-energy-progress
[46] IEA, 2020, World Investment Outlook 2020, International Energy Agency, Paris
[47] https://www.iea.org/reports/world-energy-investment-2020/key findings?utm_content=buffer47e92&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer
[48] IEA 2020, World Energy Outlook 2020, International Energy Agency, Paris

The global economy returns to its pre-crisis size only in 2023, and the pandemic ushers in a decade with the lowest rate of energy demand growth since the 1930s

- **In the Sustainable Development Scenario (SDS)**, a surge in clean energy policies and investment puts the energy system on track to achieve sustainable energy objectives fully, including the Paris Agreement, energy access and air quality goals. The assumptions on public health and the economy are the same as in the STEPS.

The starting point for the Outlook is an updated assessment of what has happened to the energy sector and energy-related investment during 2020. Energy demand in 2020 is set to be down year-on-year by around 5%, and renewables are the least affected. Power generation from renewables is the only major source of energy that has continued to grow in 2020, and this resilience sets the tone for the next decade and beyond. However, the Outlook gives the projections by economy/region for STEPS and SDS scenarios, not the DRS.

In the current analysis, we compared the projections on renewable capacity made by the last Outlook (WEO 2019) in the Stated Policies Scenario (STEPS) with the projections of the Outlook 2020 (WEO 2020) for the first three largest markets in APEC regions that is, China, Japan and USA in the same scenario for the years 2025 and 2030 (Figure 4.35).

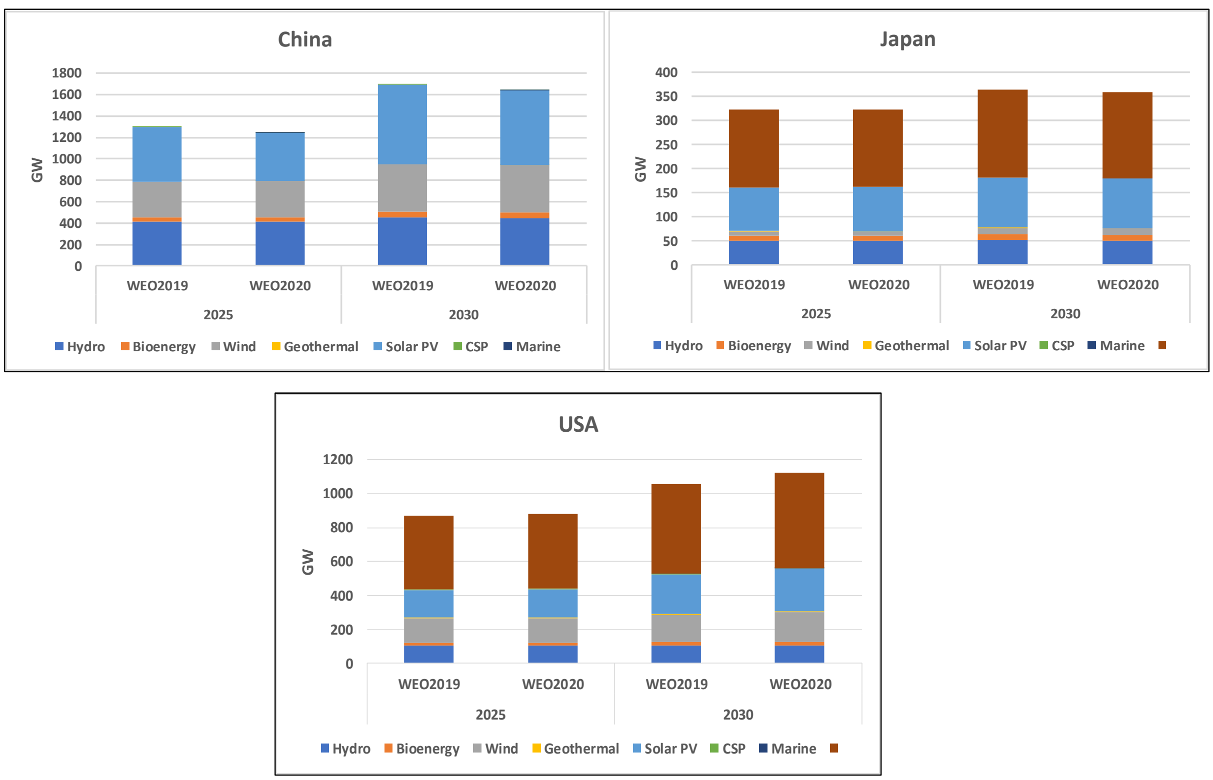


Figure 4.35 COVID-19 Impact on Generation Capacity Investment

For China, WEO 2020 projects about 4.3% and 3.2% reduction in renewable capacity investment for the years 2025 and 2030, respectively, compared to the projections made by the last Outlook. In absolute term, it is respectively 56.5 GW and 54.5 GW for the years 2025 and 2030. The key loser will be solar PV, expected to be down by respectively 61 GW and 43 GW in 2025 and 2030. This is followed by large hydro, and respective figures are 4.6 GW and 9.8 GW. Wind, on the other hand, will go up by 8.6 GW in 2025 and down by about 2 GW in 2030.

As for Japan, the Outlook 2020 projects no change in renewable capacity projection for the year 2025 when compared with the assessment made by the last Outlook. However, for the year 2030, there will be about a 1.5% reduction in renewable capacity when compared with the last assessment. This will be contributed by about 1.3 GW and 0.8 GW reduction in solar PV and hydro capacity in Japan.

For the USA, the Outlook 2020 assessment is an increase in renewable capacity (respectively 1.1% and 6.2%) for both the years 2025 and 2030, compared to last year's assessment. In absolute terms, the increase is about respectively 5 GW and 33 GW in 2025 and 2030, contributed by solar PV and Wind.

Additionally, in Viet Name, the MOIT reported that the COVID-19 pandemic had harmed renewable projects generally, in particular the wind power projects, due to delays in the supply of wind turbines as a result of shutdowns in manufacturing and supply chains, as well as restrictions on the entry of foreign technicians and experts into Viet Nam.

4.4.5 Financing Sources for Renewable Energy Projects

Compared with fossil fuel, renewable energy projects are typically still capital intensive, generally smaller in size, so less upfront capital cost, however, while still relatively less familiar to the financing community, particularly in developing economies [49]. Information uncertainties concerning renewable energy resource adequacy, intermittency, land availability, and unsured development cycles make renewable energy projects riskier, hence more difficult to finance [50]. However, renewable energy is an especially good match for small investors since it is typically not subject to the economies of scale of fossil fuels. These small investors are also embedded and close to the community, making it easier to obtain social and political support for a project. Traditionally renewable energy projects have two ways of obtaining funds, namely equity capital or owner's capital and debt/borrowing.

- **Equity capital**: it includes project developers/owner's own resources/capital, selling stakes or shares in the business, among others. Equity capital has greater expected returns due to the level of risk that is taken. In some cases, some companies might expect between 25-35% of a return due to the perceived risk versus the real risk[51].
- **Source of borrowing/debt capital:** it could be local, regional, and international development banks; local, regional and international commercial banks, financial institutions, export credit financing, special funds created by the governments with support from the development financing organizations etc.

Two main ways in which projects are financed, either on-balance-sheet by utilities, energy companies and developers, or on a non-recourse financing or project financing via a special purpose vehicle, or SPV, set up for that specific project (non-recourse project finance) by the independent power producer (IPP). In the first approach, the company or companies that own the project may raise bonds or other debt finance (loan) to help pay for construction, but this will be done via their own corporate balance sheets. They will therefore bear the whole risk of project execution. In the second approach, the developer/IPP forms an SPV and is likely to own all or part of the equity in the SPV, but this will usually be supplemented by raising debt, so that only a proportion of the project risk will reside with the project developer.

Global energy companies often have access to corporate equity and on-balance sheet corporate debt. Independent Power Producers (IPPs) and domestic renewable energy project developers have often relied on project financing capitalized by development finance institutions (DFIs) and domestic

[49] Barroco, Jose, and Maria Herrera. "Clearing barriers to project finance for renewable energy in developing countries: A Philippines case study." Energy Policy 135 (2019): 111008.
[50] World Bank, 2013. Financing Renewable Energy Options for Developing Financing Instruments Using Public Funds.. Hussain, M.Z., 2013 World Bank, Washington DC
[51] Omri, A, 2014. An international literature survey on energy-economic growth nexus: Evidence from country-specific studies. Renewable and Sustainable Energy Reviews, 38, pp.951–959

development banks or investment funds. Government support in the form of subsidies, viability gap funding mechanisms or guarantees also plays an important role in some economies.[52] Commercial banks have had relatively limited involvement due to the 15-20-year loan tenors needed to meet investment return targets for investments in renewable electric power generation. The more stringent Basel III capital and liquidity requirements have also reduced commercial bank interest in utility scale renewable energy development[53]. However, some commercial banks have structured innovative renewable energy financing, often with development banks or institutional investors. Besides, development finance institutions such as World Bank, Asian Development Bank, act as guarantors in raising syndicated loans, where a group of banks joined together with one participant acts as lead.

Besides decreasing financing costs, we expect continued innovation in financing options (e.g., infrastructure trusts and green bonds). Further, an increased momentum from public markets (with more renewable energy firms being listed for public offerings, increased secondary market transactions and market consolidation) is expected to provide financing needs for required RE investments.

Foreign ownership of a company developing a renewable energy project in the Philippines is limited to 40%[54]. However, economies are loosening this restriction. Viet Nam now allows foreign investors to own up to 100% of the equity in renewable projects[55]. We divide APEC economies into developed/industrialized economies (USA, Canada, Japan, Korea, Australia and New Zealand), emerging economies (China and Mexico) and developing economies (Thailand, Indonesia, Malaysia, Viet Nam, the Philippines and others). Our focus is on emerging economies and developing economies as financing issues are more challenging in those economies.

4.4.5.1 Emerging APEC Economies

(1) China

China has maintained its number one position on renewable energy investment for sometime[43]. The Chinese domestic renewable energy industry has been developed with the strong guidance and engagement of the Chinese government[56]. In the 12th Five-Year Plan, running from 2011 to 2015, a target was introduced to generate 15% of primary energy from renewable sources by 2015. The financing model is typically government oriented. To date, the renewable expansion has been financed by an electricity surcharge, raising funds from electricity consumers to support renewable energy projects.

The main stakeholders consist of the central government, developers (mainly state-owned energy companies), wind turbine manufacturers, local governments, banks, and capital markets. State-owned enterprises (including The Top 5 Power Generation Groups and their subsidiaries, other central stated-owned enterprises, provincial and municipal state-owned enterprises, are the main bodies to exploit the wind and solar power market, which respectively accounted for 80% of the cumulative wind power installed capacity in 2011. Meanwhile, joint exploitation bodies accounted for 6.7% of newly installed capacity in 2011, while private enterprises, foreign-funded enterprises and Sino-foreign joint ventures enterprises respectively accounted for 3.2%.

The renewable energy projects have generally been financed on the balance sheet of one of the big generation companies, and the amount of non-recourse project finance is limited 62 (Norton Rose

[52] Sitorus, Suzanty, Randy Rakhmadi, Alke Haesra, and Muhammad Ery Wijaya. "Energizing Renewables in Indonesia: Optimizing Public Finance Levers to Drive Private Investment." Climate Policy Initiative: Jakarta, Indonesia (2018).
[53] IESR, 2018, Igniting a rapid deployment of renewable energy in Indonesia: Lessons Learned from Three Countries, Institute for Essential Services Reform, November 2018, Jakarta, Indonesia.
[54] https://www.wfw.com/wp-content/uploads/2018/08/WFWBriefing-Renewable-energy-Philippines.pdf
[55] https://www.nortonrosefulbright.com/en-me/knowledge/publications/71562ac3/renewable-energy-snapshot-Viet Nam
[56] Z. Ming et al. / Renewable and Sustainable Energy Reviews 31 (2014) 23–3728

Fulbright, 2010). This contrasts with other geographical markets where independent ownership and non-recourse project finance are common and regular. A number of government schemes have helped to provide credit to enable companies to invest on their balance sheets as well as to fund investment in manufacturing capacity. Most notably, in 2010, the Government of China extended US$36 billion in loan guarantees to renewable energy companies[57].

There are three main sources of funding for wind power projects and solar photovoltaic power projects in China: enterprise investment capital (own capital and stock market), bank loans, bonds, and central government investment subsidies. The bank is the main financing channel. A key enabler of renewable energy projects in China has been the availability of relatively low-cost financing from a number of state-owned banks, including the China Development Bank[58]. The largest developers in China, including Longyuan, Datang Renewable Power, Huaneng and Guangdong Nuclear, and the major wind and solar companies have received billions of dollars of credit. According to Pingkuo, 2019[59], although bank investment still occupies a large proportion in China's renewables industry investment structure, the share of private capital investment increases year on year from 14.1% to 30.2% between 2012 and 2015. Private capital in the Chinese renewable energy market brings great incentives if the entire industry can select some promising sub-industries in the renewables sector and choose some appropriate operation modes[60].

China has been in the process of restructuring its renewable energy market, shifting from high-speed capacity growth and dependence on direct financial support through uncapped FITs to deployment of high-quality technologies and systems through auctions and subsidy-free deployment to reduce costs and improve overall performance[61]. Going by different sources, domestic finance (public finance) will continue to play a key role; however, the main focus for the Chinese government has been on the grid parity, as it tried to encourage more private players to participate and also reduce the subsidies as now renewables such as solar PV and wind should be competing on their own merits and rather than be subsidized[62].

(2) Mexico

As far as financing is a concern, the renewable energy market in Mexico has made good progress compared to the developing APEC economies. Renewable energy projects in Mexico, just like in other parts of the world, mostly rely on traditional financing methods such as syndicated loans and non-recourse project finance debt, low-cost loans from development banks or multilateral lending institutions, and financing from private equity funds and institutional investors, or export credit agencies. A newer instrument, called "green bonds", has been gaining popularity, and the potential in that area is huge. A trend is quite visible when looking at the finance deals for renewable energy projects in Mexico. The local government-owned development banks have been helping hundreds of megawatts of wind and solar capacity get built. The National Bank of Foreign Trade (Bancomext), Nacional Financiera SNC (Nafin) and the National Bank for Public Works and Services (Banobras) took part in a number of project financing deals in the past years. The North American Development Bank (Nadbank) also helped a number of projects. Nafin is already an issuer of "Climate Bond Certified" green bonds. It has also been supported by the European Investment Bank (EIB), with which it signed a Memorandum of Understanding (MoU) in March

[57] Tan, Xiaomei, Yingzhen Zhao, Clifford Polycarp, and Jianwen Bai. "China's overseas investments in the wind and solar industries: trends and drivers." World Resources Institute Working Paper (2013).
[58] https://www.iisd.org/system/files/publications/public_finance_renewable_energy_china.pdf
[59] Liu, Pingkuo, and Penghao Chu. "Renewables finance and investment: how to improve industry with private capital in China." Journal of Modern Power Systems and Clean Energy 7, no. 6 (2019): 1385-1398.
[60] Renewables finance and investment: how to improve industry with private capital in China Pingkuo LIU1, Penghao CHU1, J. Mod. Power Syst. Clean Energy (2019) 7(6):1385–1398 https://doi.org/10.1007/s40565-018-0465-6
[61] REN21. 2020. Renewables 2020 Global Status Report, (Paris: REN21 Secretariat)
[62] https://www.cnbc.com/2019/11/04/china-does-not-need-foreign-help-in-renewable-energy-wood-mackenzie.html

2017 for the two institutions to work more closely together to support economic development priorities in Mexico (MIREC Report).

Mexico's $500 million CTF investment plan is helping to overcome institutional, regulatory, and cost barriers to large-scale deployment of low carbon technologies. By strategically placing CTF concessional financing to offset upfront costs and risks, Mexico aims to demonstrate the viability and expand private investment in geothermal and solar power, among other areas[63]. Local players, including financial institutions, utilities, and corporations, put around US$915 million into Mexican clean energy assets in 2012.

On March 26, Japan International Cooperation Agency (JICA) signed a loan agreement for a maximum amount of US$100 million with Infraestructura Energética Nova, S.A.B.de C.V. (IEnova), a Mexican energy company. The loan is part of the facility arranged by the International Finance Corporation (IFC) to finance IEnova's solar power generation portfolio. Both IFC and the North American Development Bank (NADB) committed loans to IEnova of US$100 million each in November 2019.

A funding mechanism was set up under the auspices of the fund for the Energy Transition and Sustainable Electricity Use (LAERFTE), which invests in studies that aim to further the objectives of LAERFTE. The fund is destined for research institutions and excludes private companies. It offers resources of US$538 million and is expected to be a fundamental player in helping Mexico reach its targets. Furthermore, the Mexican development bank, NAFINSA, is committed to supporting the government's renewable energy ambitions, and it financed 50% of the capital for Aura Solar I, the first large-scale PV plant in Mexico.

Canadian Solar Inc closed the financing for the 126 MW Tastiota solar project located in the Mexican state of Sonora[64]. The solar power company has arranged a non-recourse financing package with Japan's Sumitomo Mitsui Banking Corporation (SMBC), securing a US$67 million (EUR 57m) senior loan, a US$ 15 million letter of credit facility, and a US$ 2 million value-added-tax (VAT) facility covering construction and operation. The Tastiota Solar Park started commercial operations in end of 2020.

4.4.5.2 Developing APEC Economies

Due to the agreement and international commitment to reducing global emissions, most developing economies have embarked on a renewable energy transformation. However, many of them lack the sufficient financial means to achieve this, particularly domestic source of finance is limited. Both domestic and international sources of finance play a role in renewable energy project financing. Developers of the renewable energy projects include IPPs (domestic, foreign, joint venture), domestic utilities and energy companies, local cooperatives. However, some economies have imposed upper limits on the share of ownership by foreign companies, such as Viet Nam, the Philippines.[65]

Funds from the governments, both in the market development stage and for investment, are limited. International sources include development finance from various foreign governments of industrialised economies (US, Canada, European economies, and Japan) are available at the earlier stages of market development as grants and later stage as cheap lending. Export credit financing from the industrialised economies makes a source of borrowing. Also, international and regional development banks like World Bank and other organization like International Finance Corporation, Asian Development Bank, ADB, and Green Climate Fund play important roles to facilitate private finance both in the form of equity and debt. Local and regional commercial banks also play roles

[63] https://www.climateinvestmentfunds.org/country/mexico
[64] https://renewablesnow.com/news/canadian-solar-secures-funds-for-126-mwp-project-in-mexico-716291
[65] https://www.wfw.com/wp-content/uploads/2018/08/WFWBriefing-Renewable-energy-Philippines.pdf

but may not be substantially due to resource limitations. While, quite often, local financial institutions are more comfortable with the standard PPA, they lack experience with project finance, have limited financing capacity, and are unable to provide US dollar funding. World Bank, Asian Development Bank also play roles to tap private capital, acting as guarantors helping reduce risk.

The role of private sector, both local and international, engagement has been recognized in all economies. Developing APEC economies have used public and concessional resources available from international sources to attain the aid of the private sector, even though this does not fully address the different challenges or the risk that the private sector experiences.[66]

(1) Viet Nam

Through its first USD-based FIT for ground-mounted solar PV projects in 2017, Viet Nam was able to attract significant development activity and foreign investments in the solar energy sector.[67] On April 6th, 2020, Phase 2 of the solar FIT (and wind asl well) was approved by the Viet Namese government, ensuring another favourable 20-year PPA for new utility-scale PV projects connected until the end of 2020. It is expected that after the expiration of the FIT, Viet Name is likely to will transition to a competitive bidding scheme for solar projects in order to reduce the cost of solar electricity generation. In Viet Nam, renewable energy projects have been mostly developed by the IPPs; however, state owned utility EVN has also put on capacity. Here are examples of financial sourcing of the two IPPs.

- TTC Energy Development Investment JSC, owned (90%) by Gulf Energy Development Public Company Limited (GED), one of the leading energy producers in Thailand, and the TTC Group, a leading Viet Namese conglomerate, has commissioned a 50 MW solar PV power plant in Tay Ninh province in Viet NNam[68]. The Asian Development Bank has signed a $37.8 million loan deal[69], composed of an $11.3 million A loan and a B loan[70]of up to $18.9 million. The B loan is funded by Bangkok Bank PCL, Siam Commercial Bank PCL, and Standard Chartered Bank (Thai) PCL with ADB as lender of record. An additional $7.6 million loan was provided by Leading Asia's Private Infrastructure Fund, which is supported by the Japan International Cooperation Agency.
- The Asian Development Bank (ADB) and Phu Yen TTP Joint Stock Company (Phu Yen JSC)[71] have signed a $186 million loan to develop a 257 MW solar power plant in Hoa Hoi, Phu Yen Province, Viet Nam. The financing comprises a $27.9 million A loan funded by ADB, a $148.8 million syndicated loan (B loan) funded by commercial banks with ADB as lender of record, and a $9.3 million loan from Leading Asia's Private Infrastructure Fund (LEAP). Participating commercial banks include Bangkok Bank, Kasikorn Bank, Kiatnakin Bank, Industrial and Commercial Bank of China, and Standard Chartered Bank.

(2) The Philippines

According to the paper of Barroco et al. (2019) that examined a novel dataset of 120 new power plants with detailed project-level data in the Philippines, power companies financed the bulk of capacity (70%) and the majority of the renewable projects (52%). Financial, supplier and industrial companies financed 14%, 8% and 6% of the total capacity, respectively. Developers accounted for

66 Donastorg, A., S. Renukappa, and S. Suresh. "Financing renewable energy projects in developing countries: a critical review." In IOP Conference Series: Earth and Environmental Science, vol. 83, no. 1, p. 012012. IOP Publishing, 2017.

67 https://www.fs-finance.com/the-rise-of-the-banh-mi-how-Viet Nam-became-the-renewable-energy-powerhouse-of-southeast-asia/

68 https://www.allenovery.com/en-gb/global/news-and-insights/publications/banking-solar-in-Viet Nam--a-look-at-the-next-wave-of-renewable-power-projects-in-Viet Nam

69 https://www.vir.com.vn/unlock-long-term-financing-for-solar-power-in-Viet Nam-73242.html

70 B Loans are funded by commercial banks and other eligible financial institutions with ADB acting as lender of record.

71 https://solarbusinesshub.com/2020/10/10/adb-provides-186-million-green-loan-for-257-mw-solar-pv-project-in-Viet Nam-one-of-the-largest-in-southeast-asia/

a meagre 1% of the capacity but 12% of projects, since they focused on small projects. Local investors accounted for 77% of the capacity and 73% of the projects. Foreign and local investors project financed 71% and 60% of their capacity but 23% and 33% of their projects. Around 70-80% of the projects were corporate financed. Publicly listed companies deployed 77% of the capacity and 52% of the projects.

Foreign funds have been made available to the government and the banking system (both public and private) from the foreign governments and Development Financing Organisations like World Bank[72]. The European Union and the Japanese government were among the major donors/lenders, along with the World Bank and its sister company, the International Finance Corporation (IFC). The World Bank recently approved a US$44 million guarantee to cover REC loans from commercial banks for renewable energy investments. By providing a US$44 million guarantee, the World Bank said this would lower the risk of commercial bank lending to the Ecs (Electric Cooperatives) and small IPPs, thereby enabling the latter to access commercial bank financing for renewable energy projects. The renewable energy projects that are expected to be supported by the World Bank guarantee would be mini-hydro and solar PV projects. The Philippine government has thus far not issued any bond to finance the development of renewable energy[73].

For smaller projects, the EU program, Access to Sustainable Energy Programme (ASEP), consists of a €60 million grant aimed to provide 100,000 Filipino households with access to electricity through the Department of Energy (DOE). The program calls for at least 20 MW of clean, grid-tied Solar PV Plants (six to 10 plants of 2-3 MW capacity each). Other foreign funds were lent through two major government banks, Land Bank and the Development Bank of the Philippines, and two private commercial banks. Funds for the latter, Banco de Oro (BDO), Bank of the Philippine Islands (BPI) and its affiliate BPI Globe BanKO, come from the IFC. On the domestic front, the Pag-IBIG Fund can lend its members up to PhP130,000 for a solar rooftop installation (maximum capacity of 1kW) as part of its housing loan services. This may be for new housing or as home improvement. The loan is payable in 20 to 25 years.

The Land Bank of the Philippines has several lending windows for different renewable energy users. REWARD, Renewable Energy for Wiser and Accelerated Resources Development, gives financial assistance (ten years maximum) to entities that will engage in renewable energy projects in support of the domestic government's call to develop alternative energy sources. Eligible borrowers include sole proprietorship, partnerships, corporations (at least 60% Filipino owned), cooperatives, local government authorities, as well as non-government organizations with the legal personality to borrow.

The Development Bank of the Philippines (DBP) has an Environmental Development Project (EDP) program, which is financed by the Japanese government. EDP supports various renewable energy initiatives of private corporations/enterprises, renewable energy service companies, qualified third parties for energy projects, private utility operators, LGUs, NGOs, rural electric cooperatives (REC), and participating financial institutions. The term of the loan can have a maximum maturity of 15 years. The equity requirement (share in the total project cost) for private companies is at least 20%, while for LGUs, RECs and NGOs, a minimum equity of 10% of the total project cost is required.

In addition, the DBP has a lending facility. Eligible borrowers are private corporations and financial institutions, rural electric cooperatives, local government units, and government owned and controlled corporations (40 billion Php). Two of the financing programs of the DBP are the Financing Utilities for Sustainable Energy Development (FUSED) Program and the Green

[72] Fortaleza, W., Diokno M. T., Ong T. A., Bordamonte, J., 2016. Geing TheRE Geing through the humps and red lights that hinder the advance of green energy, the Friedrich-Ebert-Stiftung – Philippine Office, 2016.

[73] https://library.fes.de/pdf-files/bueros/philippinen/13975.pdf

Financing Program[74]. The term for the loan is 15 years maximum inclusive of up to 5 years grace period of the principal.

(3) Indonesia

Although some measures to develop renewables have been introduced since early 2000, the Indonesian renewables sector has yet to fully take off. Some challenges such as policy uncertainty, market barriers, financing barriers, and low renewables manufacturing capacity have been contributing to the sluggish development of renewables in Indonesia[75]. In 2017, Indonesia only added 242 MW of renewable energy, the lowest since 2011 (ISER, 2018). Renewable's investment in Indonesia was US$1.3 billion in 2017, decreasing by 17% compared to the $1.57 billion in the previous year. The slowing development of renewables in Indonesia was caused by several factors such as regulatory and policy uncertainty, market barriers, financing barriers, and undeveloped local. The regulatory uncertainty increased the perceived risk to investors, resulting in investors to wait and see until the next regulations on renewables provide better investment climate. The last pricing structure which caps the renewables prices at 85% of BPP is deemed as the main market barrier to obtain funding for new projects[76]. The disregard of subsidies, price interventions, and externalities of coal also creates unlevel playing field for renewables. The increasing demand from multinational companies to use renewables-based electricity in Indonesia most of the time has to compete with PLN's interest to keep the domestic grid under its sole control.

PLN, the state electricity company, estimated that the total investments needed to reach renewable energy targets is IDR 2000 trillion, or equivalent to US$154 billion (PLN, 2016)[77]. For power generation alone, investment needs amount to IDR 1,400 trillion, or an average of IDR 140 trillion per year. To meet this target, the Government of Indonesia needs to attract other sources of finance, particularly from the private actors. Very low-price level makes the project not bankable. Also, PLN's lack of experience in managing variable renewable energy generation as part of the power mix is seen as a challenge by some stakeholders[78].

Between 2012 and 2016, public finance provided by the Government of Indonesia to support clean energy development amounted to at least IDR 12.4 trillion (US$954 million)[79]. Tracked the government funding between 2012 and 2016 amounted to at least IDR 2.5 trillion per year on average (US$192 million). The amount, directly and indirectly, was successful in the deployment of 2,140 MW of renewable energy projects across Indonesia. Of that additional power capacity, about 1,240 MW benefitted from guaranteed instruments provided by the government.

Small-scale green energy projects were the most difficult to fund[80]. The National Development Planning Agency's (Bappenas) Center of Private Investment (PINA) division is tasked with searching for alternative funding sources for various infrastructure projects outside the state budget. The high cost of financing and the low power purchase agreement (PPA) tariffs are serious concerns and roadblocks to renewable energy development in the economy, which is why the government

[74] https://www.dbp.ph/developmental-banking/infrastructure-and-logistics/financing-utilities-for-sustainable-energy-development-fused/

[75] IESR, 2018, Igniting a rapid deployment of renewable energy in Indonesia: Lessons Learned from Three Countries, Institute for Essential Services Reform, November 2018, Jakarta, Indonesia.

[76] IESR, 2018, Igniting a rapid deployment of renewable energy in Indonesia: Lessons Learned from Three Countries, Institute for Essential Services Reform, November 2018, Jakarta, Indonesia.

[77] https://climatepolicyinitiative.org/wp-content/uploads/2018/11/Energizing-Renewables-in-Indonesia-Optimizing-Public-Finance-Levers.pdf

[78] ADB 2019, Renewable Energy Financing Schemes for Indonesia, Asian Development Bank, November 2019, Manila, Philippines.

[79] https://www.climatepolicyinitiative.org/publication/energizing-renewables-in-indonesia-optimizing-public-finance-levers-to-drive-private-investment/

[80] https://www.thejakartapost.com/news/2019/02/07/indonesian-institutions-struggle-to-get-funding-for-green-energy-projects.html

intends to provide financial incentives for renewable energy developers via an Energy Resilience Fund (ERF)[81].

Blended finance is defined as public/philanthropic funds to mobilize multiples of additional private capital[82]. For Indonesia, where the renewable energy prjoects still face a multitude of barriers and risks, blended finance is an important tool to unlock private investment[83].

4.4.6 Financing Challenges and Recommendations on Mobilizing Capital for RE Development

(1) High cost of capital

Compared to conventional power generation sources such as coal, renewable energy is characterized by a relatively high initial investment and low variable costs. Since a much greater share of the cost of energy is determined by the initial investment, higher financing costs have a disproportionate impact on renewable energy project development.

Although the costs of renewable energy technologies have decreased in recent years, the size and capacity have been increasing. This gives rise to considerable CAPEX funding requirements for these projects, of which a sizable debt consideration would usually be required. Project developers are utilizing equity. When accessing equity finance from for-profit funds such as commercial private equity funds, entrepreneurs observed that financiers expect high returns on investments as some of them consider renewable energy investments to be high risk. Some local banks still discern renewable projects as high-risk projects and charge high-interest rates (for example, more than 10% in Indonesia). High-interest rates of loans, further reducing the returns of typically capital-intensive renewable energy investments; high collateral requirements and absence of project finance makes it difficult to raise debt financing for renewable energy investments.

To address the issue, capacity building of the local banks and other financing institutions on renewable energy project financing is recommended to bring down the financing costs and meet the financial gap. The related economies need to exploit funds at home and abroad, public as well as private sources of funds.

(2) Renewable Energy Fund

The creation of financing instruments is needed to ensure low-cost financing for more renewable energy projects. Lessons learned from Germany, China, and other economies help shed some light on how to the renewables projects and drive the rapid development of renewable energy in their power markets. While Germany and China use surcharges to fund renewables, India came out with an idea to impose a tax on its coal production and import to support renewables.

Slower renewable energy progress in APEC economies like Indonesia may formulate new approaches by collecting funds from related sources into the Renewable Energy Fund (REF), which can be used to support and stimulate the development of renewable energy.

(3) Financing Instruments

As the cost of debt capital in the developing APEC economies is high by a couple of percentage points than in the developed economies, interest subsidy could be an effective instrument to bring

[81] https://www.adb.org/sites/default/files/publication/541531/renewable-energy-financing-indonesia.pdf

[82] Tonkonogy, Bella, Jessica Brown, Valerio Micale, Xueying Wang, and Alex Clark. "Blended Finance in Clean Energy: Experiences and Opportunities." Retrieved from Climate Policy Initiative: Available from: https://climatepolicyinitiative. Org/wp-content/uploads/2018/01/Blended-Finance-in-Clean-Energy-Experiences-and-Opportunities. pdf (2018).

[83] Sitorus S., Rakhmadi R., Haesra A., Muhammad E. W., (2018), Energizing Renewables in Indonesia: Optimizing Public Finance Levers to Drive Private Investment, Climate Policy Initiative, November 2018. https://www.climatepolicyinitiative.org/wp-content/uploads/2018/11/Energizing-Renewables-in-Indonesia-Optimizing-Public-Finance-Levers.pdf.

down the cost of financing[84]. An interest subsidy is an attractive policy as it directly addresses the issue of lacking availability of low cost, long-term debt with a relatively low capital outlay by the government. The green bond is among other instruments that could be used to tap the needed capital for the investment in renewable energy projects. Some economies in the region, such as Indonesia and Mexico, have already experienced issuing green bonds, which can be applied in other economies.

4.5 Business Environment

The situation for renewable energy investment varies across the APEC economies. They are at the different development stage, and as can be seen from the discussion below. Some policies and regulations in favour of renewable energy development have been in place in major economies in the region. According to Viet Nam's Clean Energy Association (VCEA), Viet Nam has approximately 30 investors, both domestic and foreign enterprises, establishing new solar power projects with the capacity of 20 MW to over 300 MW in some localities. The information mentioned evidently proves that the market in renewable energy is indeed thriving, thus encouraging investors to focus on Viet Nam's energy sector in this area. In contrast, key barriers for renewable energy developer in Indonesia exist, and some of which include:

- Power purchase prices are too low to allow developers to recover their investments and make reasonable profits from the projects, especially since the introduction of Regulations 12/2017 and 50/2017 capped power purchase prices at 85% of the local average generation cost (PPP);
- Frequent changes to policy, regulatory delays, and patchy implementation of government policy by PLN all play a role in further undermining investor confidence and increasing perceived project development risk by the developers and investors.

To provide more long-term certainty for foreign and private investors in Mexico, the government has taken some measures like:

- The formation of a generation capacity market, designed to ensure capacity adequacy through the remuneration of the fixed costs that are not covered by the energy market (OECD/IEA, 2016);
- The establishment of Clean Energy Certificates (CEC) that will be bought and sold at prices based on the supply and demand. Firms that generate clean energy will earn CECs, and the final users will buy them from the producers. The CEC's get issued for each MWh of clean energy generated (Vietor, 2017). This increases the income revenue for clean energy producers. The annual quota obligation for electricity consumption from clean sources for 2018 is 5% (IEA, 2017). In 2022 it was 13.9% (SENER, 2018).
- Provision for long-term contracts and auctions, locking in prices for generators of clean energy (for example, for a period of 15 years), capacity (15 years) and Clean Energy Certificates (20 years) (OECD/IEA, 2016).

Although the framework could provide important incentives to promote clean energy, renewable energy developers still face challenges. Mexico's power grid has been in poor condition, owing to years of underinvestment by CFE, and power lines throughout the economy need to be upgraded and expanded. This is a particular challenge for renewable energy developers because most of the economy's wind and solar resources are in remote areas, far from the population and energy demand centers. In addition, although costs for wind and solar have declined precipitously in recent years, renewables in Mexico continue to face steep competition from cheap natural gas imports from the United States. Finally, the local communities have opposed developers' plans to construct

[84] Shrimali, Gireesh. "Renewable Energy in India: Solutions to the Financing Challenge." (2018).

renewable energy generation and transmission projects, much as other energies, transport, and extractive industries projects all over the world have faced similar local oppositions.

4.5.1 Business Model

Suitable business models for investments in renewable energy project are needed to provide policy makers and investors with alternative methods for deploying new technologies or applying well-established technologies and practices in new settings[85]. The most appropriate business model for a given project will depend on local conditions, the financial and regulatory environment, and the institutional framework and support mechanisms that are in place. Business models can be broadly categorized as follows:

- Ownership models, which focus on financing and risk mitigation concerns;
- Service models, which focus on providing specified services and highlight different methods of operation and maintenance.

The type of business model chosen depends largely on the scale of the project and its investment costs. The business model required for a residential or community rural electrification solar PV project is very different from that for a 200 MW utility-scale project designed to supply the domestic power grid. The ownership business models address the technical complexity, economies of scale, capital costs, and funding challenges of renewable energy and energy efficiency projects. For medium- to large-scale or grid-connected renewable energy projects, the most appropriate ownership business model that is frequently a public–private partnership (PPP), implemented as a form of:

- Build–own–operate–transfer (BOOT);
- Build-own-operate (BOO);
- Build-own-transfer (BOT);
- Multiparty ownership.

4.5.2 The Public–Private Partnership

A PPP involves a contract between a public sector authority and a private party, in which the private party provides a public service (e.g., electricity supply) and assumes a substantial amount of the financial, technical, and operating requirements. In exchange, they get the right to earn certain revenue over a specified period. The main purpose of a PPP is to allocate the tasks and risks to those parties best able to manage them, notably to the private sector partners.

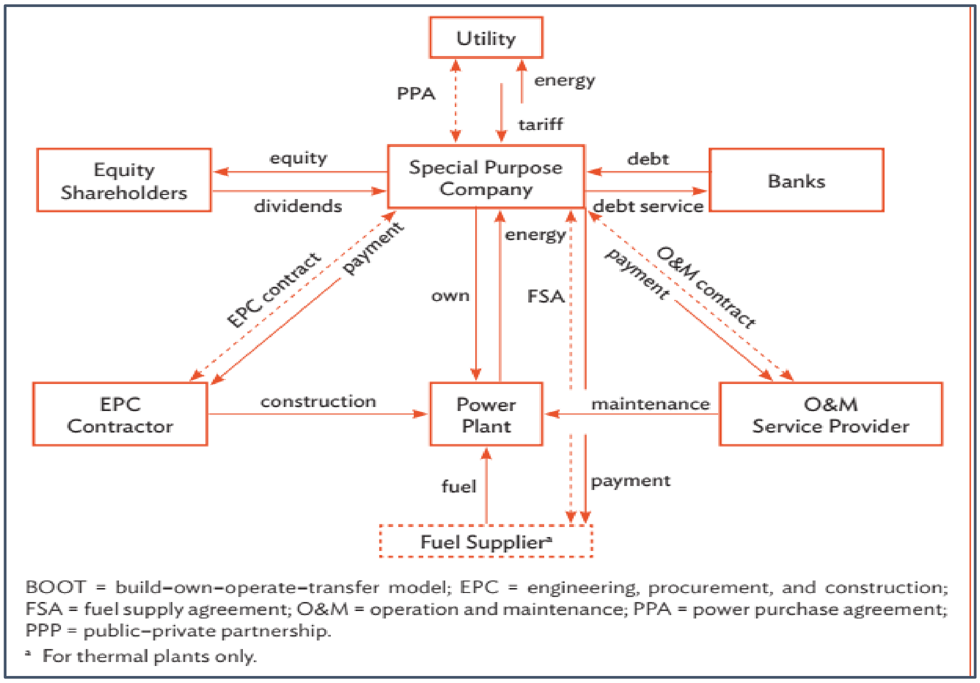
Depending on how the PPP contract is structured, the cost of using the service can be borne exclusively by the users of the service (no taxpayer or public participation) or the government, or by both in some blend of these opposite approaches. Government contributions to a PPP may also be in kind, for example, the transfer of assets or land. Common PPP models were mentioned in the previous section.

PPP schemes typically involve the creation of a special-purpose company (SPC) or special purpose vehicle (SPV) to develop, build, maintain, and operate the asset (project) for a contracted period of time. The SPC or SPV enters into a contract with the government and subcontractors to build the facility and then operates and maintains it. The SPC/SPV is the central administrative and operating entity handling all contracts for funding with equity and debt investors. It also manages the construction and operation and maintenance (O&M) contracts, as well as the billing of end-users. This type of business model is suitable for both conventional and renewable energy projects. An

[85] ADB, 2015, Business models to realize the potential of renewable energy and energy efficiency in the Greater Mekong Subregion. Mandaluyong City, Philippines: Asian Development Bank, 2015..

example of a possible PPP–BOOT business model for a power plant project is shown in Figure 4.36.

The Indonesian government also applies the Build, Own, Operate, and Transfer (BOOT) scheme to all renewables but the municipal waste-to-energy. This scheme requires the IPPs to transfer their power plant assets to PLN once their PPAs expire, meaning that there is no contract renewal for IPPs. The scheme has raised objections from some developers as the costs associated with asset transfer (e.g., land acquisition) cannot be covered by the renewables tariffs of 85% of BPP. Under the PPA scheme (85% of BPP), most developers find difficulties in finding funding for renewables projects.[86]



Note: Fuel supplier and FSA does not apply.
Source: ADB, 2015

Figure 4.36 PPP-BOOT Model for Renewable Power Project

While thermal power projects such as coal or natural gas are not subject to foreign ownership restrictions, renewable projects such as solar and wind are subject to such restrictions as they are considered to utilise a domestic resource. Foreign ownership of a company developing a renewable energy project in the Philippines is limited to 40%[87]. There are also similar restrictions on the foreign ownership of land. To resolve this issue, foreign investors can implement appropriate structuring arrangements with local partners. However, they should be mindful of compliance with the economy's anti-dummy laws in respect of foreign holdings which target artificial ownership. However, some economies have been loosening the related restriction. Viet Nam, for example, has allowed foreign investors to own up to 100% of the equity in renewable energy projects.[88]

4.5.3 The Cooperative Model

The cooperative business model provides a mechanism for governments and NGOs to support renewable energy projects at the local level. For example, an NGO or government could assist in financing such projects through up-front investment grants or interest-free loans to a user

[86] https://www.readkong.com/page/alternating-currents-indonesian-power-industry-survey-2018-7031263
[87] https://www.wfw.com/wp-content/uploads/2018/08/WFWBriefing-Renewable-energy-Philippines.pdf
[88] https://www.nortonrosefulbright.com/en-me/knowledge/publications/71562ac3/renewable-energy-snapshot-Viet Nam

cooperative, allowing the system to be installed and reducing user charges. Electric cooperatives (EC) play a key role in providing renewable energy to marginalized and remote communities not profiting from private sector interest. Cooperatives are, in many situations, more cost-effective and efficient in providing services to local electricity consumers since their direct accountability to their customer base makes them more responsive to the concerns and needs of local communities and encourages a system of self-regulation.

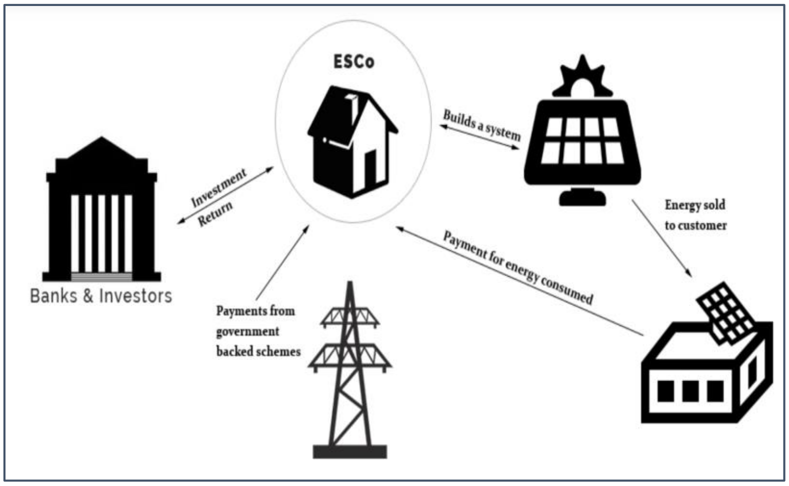
Romblon Electric Cooperative (ROMELCO) is one of the most active EC in deploying renewable energy development in the Philippines[89]. ROMELCO is situated in Romblon Island and supplies a population of more than 23,000. ROMELCO's latest low-carbon energy development project is on Cobrador Island. It has a total land area of 2.6 km ^{2}and a population of around 1000 people or 239 households. Before 2016, electricity was provided to the community by a diesel generator (15 kW peak capacity) for only about eight hours per day. In 2016, ROMELCO, together with the Asian Development Bank (ADB), the Korea Energy Agency (KEA) and NEA implemented a joint project on Cobrador Island, leading to the installation of a solar-battery-diesel hybrid system in August of the same year. The hybrid system consists of a solar PV capacity of 30 kW, a battery (lithium-ion) capacity of 200 kWh and a diesel backup generator of 15 kW. The hybrid system improved the reliability of electricity supply (w24 hours), affordability (50% tariff reduction) and environmental soundness (RE share up to 90% per day).

In Indonesia, irst energy cooperative, named Kopetindo, was established in February 2018.[90] Initiated by the Indonesian Renewable Energy Societies (METI), Kopetindo has a noble vision to maximize Indonesia's renewable energy potential through local community empowerment and participation. It claims to provide various services that include surveying the potential of renewable energy, coaching, and funding the installation of renewable energy-based electricity generation projects, such as bioenergy, wind, and solar PV. This marks a positive step to the establishment of energy cooperatives in Indonesia.

4.5.4 The RESCO Model

The ESCO Model, as shown in Figure 4.37, is one of the models followed by Solar Energy Corporation of India (SECI) for solar rooftop installation. Here, the entire system is owned by the developer. The responsibility of O&M for the system lifetime (25 years) is also with the developer. Rooftop owners may consume the electricity generated, for which they have to pay a pre-decided tariff monthly. Excess generation may be exported to the power grid, subject to the availability of requisite regulations. In this case, the developers are selected through tariff-based reverse bidding process.

[89] Bertheaua. P, Dionisioc J., Jüttea C., and Aquinoc C. ,(2019), Challenges for implementing renewable energy in a cooperative-driven off-grid system in the Philippines, Environmental Innovation and Societal Transitions, March 2019.
[90] https://aseanenergy.org/energy-cooperatives-option-for-pushing-indonesias-energy-transition/



Source: https://amplussolar.com/resco-solar

Figure 4.37 Illustration of the RESCO Model

4.6 Investment Condition

4.6.1 Existing Policies

Effective policy support is among the keys to the uptake of renewable energy. Policy frameworks could continue to evolve in response to changes in renewable energy technologies and market conditions. Over the period, much of the advancement in renewable technology development and deployment has been greatly achieved, thanks to effective government policies, and relevant policies continue to be important to overcome economic, technical, and institutional barriers[91]. Table 4.39 lists the policies that have been in place in the APEC economies.

Policy support for renewable energy development can be categorized as direct and indirect policy[92]. Direct policies, such as mandates or financial incentives, explicitly target at the increased deployment of renewable energy and enabling technologies. Indirect policies support effective operating conditions and the integration of renewable energy and enabling technologies into existing infrastructure, including power systems and electricity market.

Table 4.39 Renewable Policy Framework in Selected APEC Economies

		Chile	Mexico	Indonesia	Philippine:	Vietnam	China	Australia	Japan	USA	ROK
	Renewable energy targets	√	√	√	√	√	√	√	√	√	√
Regulatory policies	Feed-in tariff	NA		√	√	√	√	√	√	√	
	Electric utility quota obligation/RPS	√	√	√	√	√	√	√		√	√
	Net metering/net billing	√			√	√		√		√	√
	Transport obligation		√	√	√	√	√	√		√	√
	Tradable REC	NA						√	√	√	√
	Tendering	√	√	√	√	√	√	√	√	√	
Fiscal incentives and											
public financing	Capital subsidy, grant, or rebate	√	√	√	√		√				√
	Investment or production tax credits	√	√	√	√	√	√			√	√
	Reductions in sales, energy, VAT or othe	√	√	√	√	√	√		√	√	√
	Energy production payment				√		√				√
	Public investment, loans or grants	√	√	√	√	√	√	√	√	√	√

Source: Natureportfolio[93]

As discussed in the previous section, renewable energy target is among the primary means of expressing commitment to renewable energy growth and, at the same time, sending a positive signal

[91] REN21. 2020. Renewables 2020 Global Status Report, (Paris: REN21 Secretariat)

[92] REN21. 2020. Renewables 2020 Global Status Report, (Paris: REN21 Secretariat)

[93] https://www.nature.com/articles/d42473-018-00330-7#:~:text=Determined%20to%20make%20up%20lost,is%20serious%20about%20energy%20transition.

to market players[94]. Although targets on their own are generally insufficient to stimulate investment in renewable energy projects, they may be converted into action through the adoption and implementation of complementary policies. As from Table 4.16 in the early section, all major economies in the region have domestic or regional targets on renewable energy for the power sector. The economies with sub-domestic targets include Australia and the United Sates. It has been noted that Korea has revised its target from 7% to 20% by 2030.[95]

The suite of renewable energy policies being deployed has evolved in response to changes in technologies and markets, as well as the evolving needs and realities of different jurisdictions in the region. In relatively more mature markets where large shares of renewables have been installed, decision-makers are adapting policy to support the technical and market integration of renewable energy and addressing the impacts of further larger or rising shares of variable renewable electricity (VRE), including small-scale distributed generation, into the power system.

In relatively less mature renewable energy markets and some developing and emerging economies in the region, the policies have remained focused on dealing with increasing renewable energy capacity and generation to meet basic energy demand, promote job creation and energy security, and provide increased access for the residents to modern energy services. It issues also need to be addressed to engage private sector investment given its scale and other characteristics, renewable energy policy can exist across all levels of governance, including international and regional; domestic, state, and provincial; and municipal governments. In jurisdictions with regulated power systems, domestic and sub-domestic public utility commissions (also called energy commissions or energy regulators in some circumstances) develop policies that apply to regulated utilities.

Policy mechanisms that promote large-scale, centralized renewable power include renewable portfolio standards (RPS) and other quota obligations, feed-in policies (tariffs and premiums), renewable power tenders and auctions, financial incentives (for example, grants, rebates, and tax credits) and more recently community choice aggregation programmes[96]. Feed-in policies have been used to promote both large-scale, centralized renewable energy and decentralized renewables. Economies also have been making an attempt to shift away from feed-in policies and towards mechanisms such as auctions and tenders. In December 2019, Viet Nam announced plans to switch from FITs for large-scale solar PV to a new auction mechanism. However, in April 2020, Viet Nam decided to allow solar PV projects that would commence commercial operation before the end of 2020 to continue participating in the FIT programme, while all other projects would transition to an auction mechanism in 2021. China has been in the process of restructuring its renewable energy market, namely shifting from high-speed capacity growth and dependence on direct financial support through uncapped FITs to deployment of high-quality technologies and systems through auctions and subsidy-free deployment to reduce costs and improve overall performance[97]. The newly elected government of Mexico cancelled the fourth renewable energy auction early in 2019. Financial incentives play a role in spurring investment in the manufacture and installation of renewable technologies. In the United States, the production tax credit for wind power was extended through 2020, a year longer than anticipated. The government of Indonesia provided fiscal incentives for clean energy development through income tax incentives and exemptions from import duties and the value-added tax. The government of Indonesia has been looking at new

[94] IEA, "Policies", https://www.iea.org/topics/renewables/policies, viewed 21 October 2019

[95] https://www.nature.com/articles/d42473-018-00330-7#:~:text=Determined%20to%20make%20up%20lost,is%20serious%20about%20energy%20transition.

[96] Community Renewable Energy Arrangement: Through community energy arrangements, residents, businesses and others within a r elatively small geographic area initiate, develop, operate, own, invest in and/or directly benefit from a renewable energy project. Co mmunities vary in size and shape (for example, schools, neighborhoods, city governments, etc.), and projects vary in technology, siz e, structure, governance, funding and motivation. Policy plays a crucial role in permitting or fostering the deployment of community renewable energy projects. FIT schemes, net metering and VNM, and policies dedicated to supporting community energy arrangem ents all have the potential to incentivise community renewable energy initiatives.

[97] REN21. 2020. Renewables 2020 Global Status Report, (Paris: REN21 Secretariat)

financing and incentive models to increase the deployment of clean and efficient technologies[98]. The high cost of financing and the low power purchase agreement (PPA) tariffs has been among serious concerns and roadblocks to renewable energy development, which is why the government intended to provide financial incentives for renewable energy developers via an Energy Resilience Fund (ERF)[99]. Schemes suggested by the ADB include (i) viability gap funding, (ii) project development funding, and (iii) credit enhancement funding. In addition to Feed-in-Tariff, Viet Nam provides the following supports[100]:

- Import duty exemption on equipment: There is an exemption from import duty regarding goods imported to construct or form fixed assets, such as raw materials, manufactured materials, and other components;
- Corporate income tax exemption and reduction: Income from new investment projects for renewable energy production can be subject to corporate income tax at the rate of 10% for the first 15 years.
- Land-related incentives: Investors may be entitled to exemption from the land use fee that would usually apply for 11 years or, in cases in which the investment project is in a region facing extreme socioeconomic difficulties, 15 years. In addition, during the capital construction period of a project, investors are entitled to exemption from land rents and water surface rents.

Under the Mexican tax code, companies investing in renewable energy generation equipment can deduct up to 100% of their total investment during the first taxable year[101]. In the Philippines, renewable energy project developers can have exemptions from income tax for seven years, followed by a discounted income-tax rate of only 10% (compared with the standard income-tax rate of 35%) [102].

The rapid rise of distributed renewable generation, which is typically dispersed and small-scale, presents new opportunities and challenges for investment. For individual consumers and businesses, opportunities include the ability to install their own renewable energy systems to generate their own electricity, reducing the need to rely on the grid. The reasons for self-generation vary from place to place but can include increased reliability and reduced electricity purchase costs. Distributed renewable energy generation also may provide grid flexibility services and the ability to mitigate challenges arising from grid constraints during the peak demand period. Challenges associated with renewable distributed generation relate to grid integration and operations and the need to mitigate the impacts of adding new renewable generation to existing transmission and distribution grids. Policies and regulations that advance the deployment of distributed renewable technologies and increase renewable generation include solar mandates, feed-in pricing and net metering (and virtual net metering), as well as the measures that support community aggregation (such as solar community policies) and public utility commission policies that target utility activities and investments (for example, grid modernization). Many small-scale residential and commercial installations can benefit from net metering policies, which compensate the power system owners for surplus electricity fed into the power grid.

In 2019, the US state of California implemented a new solar mandate that took effect in 2020, making it the first state in the economy to make rooftop solar PV mandatory for most new houses. Just as feed-in policies that incentivize large-scale renewable generation, these policies also encourage small-scale, renewable distributed electricity generation. In 2019, Japan continued to

[98] ADB 2019, Renewable Energy Financing Schemes for Indonesia, Asian Development Bank, November 2019, Manila, Philippines.
[99] ADB 2019, Renewable Energy Financing Schemes for Indonesia, Asian Development Bank, November 2019, Manila, Philippines.
[100] Nguyen, T. C., A. T. Chuc, and L. N. Dang. 2018. Green Finance in Viet Nam: Barriers and Solutions. ADBI Working Paper 886. T okyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/green-finance-viet-nam-barriers-and-solutions.
[101] https://www.thedialogue.org/wp-content/uploads/2018/05/mexico_renewable_energy_future_0.pdf
[102] PwC, 2018, The next frontier for infrastructure investments: Renewable Energy in Asia-Pacific, PricewaterHouse Cooper, Singapore

offer a FIT for small-scale renewable generation (including geothermal and biomass), although Japan replaced its FIT programme for large-scale solar and wind power with a wholesale tender system.

The financial incentives also play a role in spurring investment in distributed renewable energy generation. In some regulated power markets, the point of market entry for distributed renewable energy generation is through procurement of electricity by utilities. In markets regulated by public utility commissions, these commissions may enact policy related to utility investments in distributed renewable generation[103]. For example, in 2019 public utility commissions in Canada and the United States enacted a range of policies requiring utilities to consider distributed renewable energy generation in their investment plans, as well as to incentivize utilities to take advantage of renewable (and other) distributed generation to reduce the customer costs for electricity services.

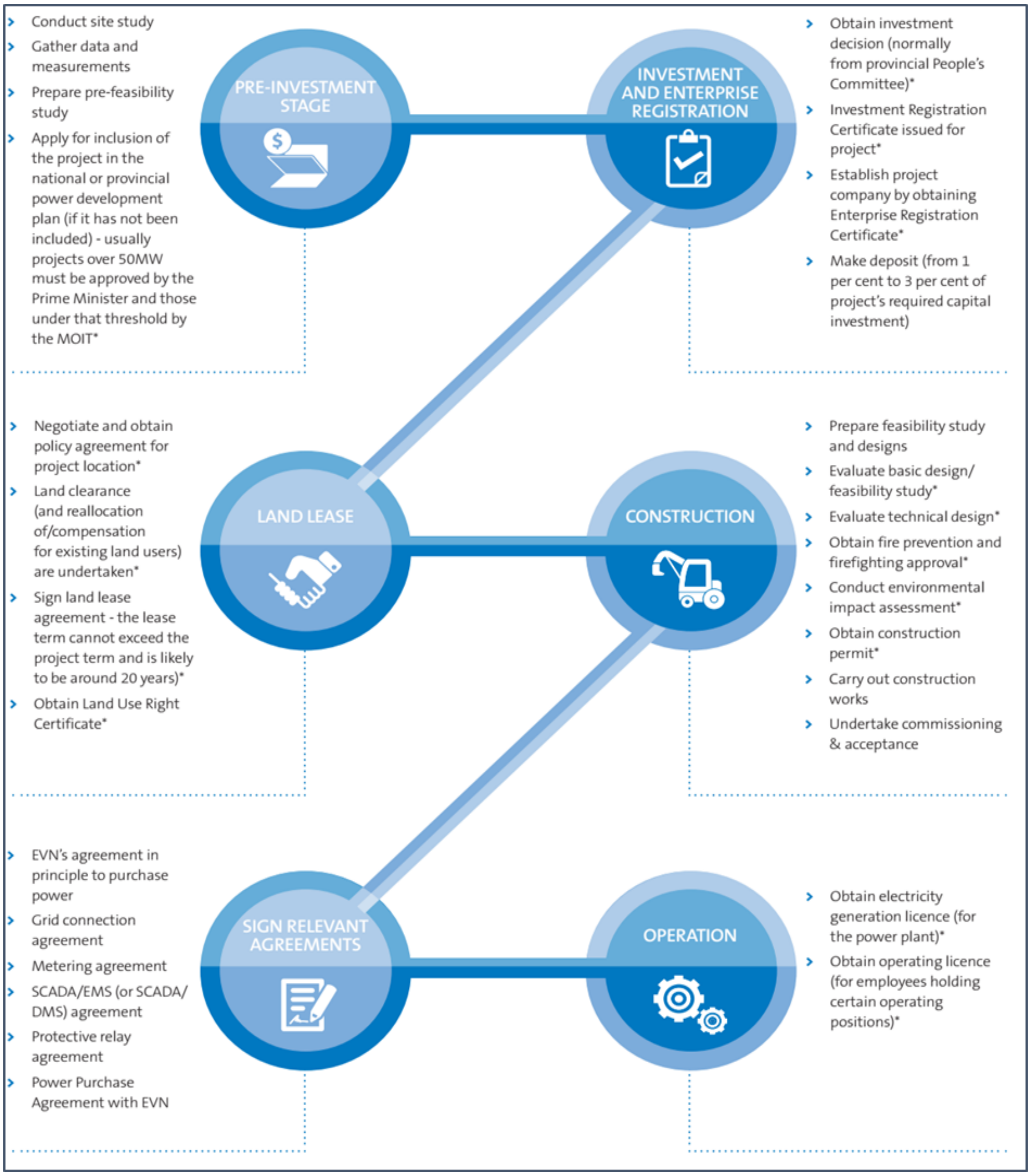
4.6.2 Licensing and Permit

Implementation of renewable power projects needs approval and permits at various stages of project development. Lengthy procurement process due to onerous licenses and permits required is reported in Asia Pacific region[104]. Investors often found a gap between policy and the reality of implementation, particularly during the early development and permitting phase. A common complaint was that the permitting procedures for renewable energy projects are complex and lengthy[105]. Approvals are required from a multitude of government agencies, each having its own timelines and milestones. In the Philippines, permits are required from all levels of Government (i.e. from the barangay, municipal, provincial, regional, and departmental authorities), which can give rise to variations in timing and application requirements and can appear to be a repetitive process. In light of this, investors may want to consider reviewing their internal and external staffing arrangements to ensure there is sufficient workforce in place to deal with multiple permit applications. In addition, permitting is complicated in the Philippines because most areas with geothermal potential are protected as environmentally critical under the existing law. However, the Philippine Department of Energy has attempted to simplify the permitting process, so there may be positive changes on this going forward.[106] A challenging permitting process and a lack of investors willing to absorb the development risk that is endemic to the industry[107]. Permitting challenges along with the threat of legal action has deterred some potential investors. The following are some of the principal consents and licenses required of a foreign investor for renewable energy projects in Viet Nam:

- Principal Approval;
- Investment Registration Certificate;
- Enterprise Registration Certificate;
- Power Purchase Agreement;
- Business License (for investors importing, exporting and distributing);
- Electricity activity license;
- Approval of Environmental Impact Assessment Report;
- Construction permits;
- Land use right certificate.

Complicated approval and licensing process for renewable power project in Viet Nam is illustrated in Figure 4.38.

[103] REN21. 2020. Renewables 2020 Global Status Report, (Paris: REN21 Secretariat)
[104] PwC, 2018, The next frontier for infrastructure investments: Renewable Energy in Asia-Pacific, PricewaterHouse Cooper, Singapore
[105] https://www.wfw.com/wp-content/uploads/2018/08/WFWBriefing-Renewable-energy-Philippines.pdf
[106] https://www.wfw.com/wp-content/uploads/2018/08/WFWBriefing-Renewable-energy-Philippines.pdf
[107] REN21. 2020. Renewables 2020 Global Status Report, (Paris: REN21 Secretariat)



Source: https://www.allens.com.au/globalassets/pdfs/insights/asia/Viet Nam-renewableenergy-170817.pdf

Figure 4.38 Permitting and licensing process for renewable energy project in Viet Nam

Energy projects in Mexico have often faced resistance from local communities. Much of the land is collectively owned, meaning developers must consult with dozens or even hundreds of people before beginning a project. This process often lead to long, expensive legal battles and processes. The government should clarify the consultation process, take a stronger role in mediation and encourage projects in which local communities share ownership, benefit from the energy produced and are incorporated into the supply chain[108]. To increase public and private investments, the

[108] https://ieefa.org/op-ed-mexico-is-poised-for-a-renewable-energy-revolution/

Mexican government has also reduced the number of days required from licensing, permitting and constructing a renewable energy project from 620 to 465 on average[109].

In summary, policy makers can support renewable energy investment through centralizing review and permitting of projects. Streamlined permitting involves limiting the number of agencies engaged in reducing the burden on the developers to contact and receive permits from many different agencies. Further, to support streamlined permitting and approvals, fully informing and integrating local communities into renewable energy project, such as wind and solar PV, development decision-making processes is critical, including these conducted at the regional or domestic levels.

4.6.3 Procurement Model

Feed-In-Tariff (FiT) is the most common Direct Support Policy in the world and has been preferred by the investors in both developed and developing economies, including these in the APEC region (Table 4.40). A FiT is a renewable energy project procurement mechanism that offers guaranteed grid access and guaranteed energy payment over a long-term contract to all developers within a set of conditions such as eligible technologies, project sizes, and locations. Through FiT mechanisms, the government buys the energy from renewable energy projects through a power purchase agreement at a fixed price throughout the term of these projects to cover the costs of project installation, operating expenses (including interest costs) and a reasonable equity return[110]. FiTs are more appropriate when the costs of renewables are substantially higher than non-renewable technologies, and at the initial stage of the market development process as level of risks remain unknown is high for the investors. Feed-in-tariffs (FiTs) offer premium prices as an incentive for increasing private sector investments[111]. Revenue certainty of FiT is a major driver of financing and a lender's requirement. Across the regions, FIT with long-term power purchase agreement has played an important role in increasing renewable investment by ensuring definite revenue in accessing finance.

Table 4.40 Procurement System in Selected APEC Economies

Economies	Solar	Wind
Japan	Auction	Feed-in-Tariff
Philippines	Competitive selection process (Auction planned in 2020)	Competitive selection process (Auction planned in 2020)
Australia	Wholesale market	Wholesale market
Indonesia	Bilateral (agreement with PLN)	Bilateral (agreement with PLN)
Thailand	Competitive bidding (tariff cap defined)	Competitive bidding (tariff cap defined)
Viet Nam	Feed-in-Tariff (Auction planned for 2021)	Feed-in-Tariff (Auction planned for 2021)
Chinese Taipei	Feed-in-Tariff	Feed-in-Tariff
Korea	Auction	Auction
Mexico	Auction	Auction
Peru	Auction	Auction
Chile	Auction	Auction

Source: PwC 2018; Javier et al., 2018

[109] IEA 2017. Energy policies beyond IEA countries. Retrieved on April 4, from https://www.iea.org/publications/freepublications/publication/EnergyPoliciesBeyondIEACountriesMexi co2017.pdf
[110] https://www.pwc.com/sg/en/publications/assets/renewable-energy-in-asia-pacific-2018.pdf
[111] https://www.marketlinks.org/resources/analysis-renewable-energy-auctions-six-countries

In recent years, costs have become competitive or lower for electricity from renewable energy than non-renewable sources. As a result, there has been a trend away from FiTs toward auctions, especially reverse auctions, to stimulate competition for more efficient price recovery, driving down capital and operating costs. A well-designed auction system needs to ensure that sufficient competition and transparency are present. The auctions should be conducted by an independent regulator of energy sector. With transparency, auctions can broaden private sector participation in the development and financing of electric power generation capacity. As a result, they can help reduce the costs of renewable energy development to domestic and sub-domestic governments and utility companies and attract the interest of large-scale investors and other sources of financing. The majority of Asia-Pacific economies have moved to some form of the competitive selection process for renewable energy technologies, especially for utility-scale solar PV and wind power projects. Japan's first auction for contracts to provide solar electricity pushed electricity prices down by nearly a quarter from a previous system. The lowest accepted price for solar PV projects was 17.2 yen/kWh in November 2017, down from 24 yen/kWh in the year through March 2017 for the projects approved under Japan's Ministry of Economy, Trade and Industry (METI) FiT programme. METI has set a target for solar electricity tariffs to reach 14 yen/kWh by 2020 and 7 yen/kWh by 2030.

According to Javier et al. (2018)[112], the Governments of Mexico and Peru have successfully attracted experienced private sector investors and developers through renewable energy reverse auctions. These economies have obtained additional renewable electricity capacity at lower contracted prices in each succeeding auction as technologies have improved, manufacturing and supply costs have declined due to economies of scale, and experience with such investments in the economies has increased. However, it should be noted that the low bid prices in tendering processes do not necessarily reflect the overall costs of technology. For example, prices depend on resource availability and local labour costs, while tendering conditions might include the provision of grid connection to developers, land availability and other requirements[113].

Mexico held three technology-neutral energy auctions between March 2016 and November 2017. These three auctions resulted in contracts of 1780 MW of firmed installed capacity (76% natural gas, 12% wind, 11% solar and 1% geothermal). The first and second auctions were only open to the generation companies, the Comisión Federal de Electricidad (CFE). Ceiling prices in the first auction were too low, and no qualifying bids for the firm capacity were received. The ceiling price for the firm capacity was approximately 172 times higher in the second auction. Mexico's third auction differed from the previous two. First, it was open to private off-takers in addition to the CFE. Second, the GoM established a clearinghouse to execute separate contracts with the developers and off-takers. The clearinghouse also managed the contractual obligations of all parties by requiring financial guarantees for performance and payment obligations.

While more and more economies are moving to reverse auction for large utility-scale projects, they are using feed-in policies to incentivize small-scale, renewable distributed generation. Such efforts have involved households, small- and medium-sized businesses, energy co-operatives and municipalities. In 2019, Japan continued to offer a FiT for small-scale renewable generation projects (including also geothermal and biomass), although the economy replaced its FiT programme for large-scale solar and wind power with a wholesale tender system. Viet Nam continued its 20-year FiT for rooftop solar PV at $0.0935/kWh until 2021.

The APEC economies without reverse auction include Viet Nam, the Philippines, and Indonesia. However, Viet Nam has announced to move to reverse auction in 2021. Since economies like Viet Nam and the Philippines did not hold renewable energy auctions yet, the experiences in other

[112] Javier Molina; Nadia Scharen-Guivel; and Eric Hyman. 2018. Analysis of Renewable Energy Auctions in Six Countries. Washington, DC: Crown Agents USA, and Abt Associates, Prepared for the U.S. Agency for International Development.

[113] REN21. 2020. Renewables 2020 Global Status Report, (Paris: REN21 Secretariat)

economies can help the government decision-makers, energy project developers, financial institutions, and investors, and industrial or commercial users design and implement them successfully. In some economies, auctions have been combined, or used in parallel with FiTs in policy hybrids, whereby FiTs are used for smaller-scale projects and auctions used for larger-scale procurement.

In its early stage of renewable energy development, China used auctions to determine the price level of FiT. In 2003, the first renewable auctions were conducted for onshore wind projects. The prices revealed in these auctions were used to set a fixed FiT introduced in 2009. The utility-scale solar PV projects were auctioned in 2009 and 2010 before China established a unified FiT in 2011. As part of China's transition to a renewable energy market without direct policy support and subsidy by 2021, a bidding scheme was launched to select solar PV projects for FiT support as well as those for "grid-parity" (Grid parity in China refers to market-driven with no FiT support but with priority off-taking), and by July the government approved 22.8 GW and 14.8 GW of capacity respectively.

4.6.4 International Support

Developing and emerging economies face a two-fold energy challenge in the 21st century: meeting the needs of millions of people who still lack access to basic, modern energy services while simultaneously participating in a global transition to clean, low-carbon energy systems. In addition, they have to fulfil other basic needs of their citizens like clean water, education and health; therefore, they are hard-pressed with limited resources. To build a renewable energy market with financial support needed, the economies need to formulate the right business environment, putting appropriate policies, institutions, and legal framework. They need to create clear and consistent policies, which should be innovated and implemented effectively in developed economies. However, they also need to be adapted under local conditions in developing economies. Increasingly, the challenge is not just to establish targets and policies, but to get the details right, and put them into action.

Economies need engineers to install these new sets of technologies and maintain them. Furthermore, as the share of intermittent renewable energy resources increase, grid integration becomes a key issue dealing with grid stability and system flexibility. Grid management is another important issue. Strong support from developed economies and international/regional development organisations, NGOs, and the technology leaders is needed on capacity building, knowledge sharing and technology transfer. For example, in Viet Nam, sustainable energy has been a focal sector of EU-Viet Nam cooperation for the period of 2014-2020.[114] Through its technical cooperation and policy dialogue, the EU has significantly contributed to the development of the legal, policy and technical frameworks to attract private investors in the renewable energy market in Viet Nam.

Elia Grid International, a Belgium transmission system operator (TSO), has led three projects, including power system studies, recommendations and capacity building in Viet Nam[115].GIZ, through the EU, supported a project helping electric cooperatives in the Philippines at off-grid sites with diesel power systems on how to combine them the system with renewable energy supply to reduce carbon emissions and lower their operating and maintenance costs.[116]

In Indonesia, the Ministry of Energy has partnered with the International Energy Agency (IEA) to accelerate the uptake of renewable energy in the economy. The ministry and IEA partner with utility PT Perusahaan Listrik Negara (PLN Persero) designed and implemented a flagship scheme

[114] https://ec.europa.eu/international-partnerships/where-we-work/Viet Nam_en

[115] https://www.eliagrid-int.com/elia-grid-international-active-in-Viet Nam-with-three-projects-to-support-renewable-integration/

[116] The same project shared with electric cooperatives serving off-grid sites with diesel power systems how to operate the systems more efficiently, and how to combine them with renewable energy systems to further reduce carbon emissions and their operating and maintenance costs.

to encourage private investment in renewable projects, and develop strategies to enhance renewable integration with power grids.[117]

The International Renewable Energy Agency (IRENA) provides services like sharing information on renewable energy issues (resource potential, technical, economic, planning, financing, grid integration, and distributed generation etc.) to developing economies, including APEC economies. Global Environment Facility, in collaboration with UNDP (United Nation Development Programme), ran a programme between 2002-2007 on Capacity Building to Remove Barriers to Renewable Energy Development in the Philippines (GEF, 2011). Main objectives of the programme include:

- Strengthening the capacity of relevant Government of the Philippines (GOP) agencies to formulate, enact and implement sound renewable energy policies;
- Enhancement of renewable energy data banking and provisions of information on renewable energy for targeted audiences to build functional markets;
- Enhancement of coordination among organization concerned with renewable energy development;
- Assisting the market penetration of renewable energy in remote off-grid communities through the provision of incentives, and innovative financing and delivery and operation mechanisms;
- Improvement of the quality of and knowledge and skills on renewable energy technologies and systems.

The International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety of the German Government assists partner economies in switching to a sustainable, low-carbon economy.[118] IKI's partners receive support in the form of knowledge transfer, technology cooperation, policy advice and investment measures, enabling them to develop and implement appropriate methods and instruments that can be used to advance transformational processes. Within the framework of the IKI, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has commissioned the Renewables Academy (RENAC) to design and manage the following capacity building programmes, which include:

- Transfer Renewable Energy and Efficiency (TREE);
- Capacity Building on Integration of Large Amounts of Renewable Energy in Electricity Grids (ReGrid);
- Capacity Development on Renewable Energy and Grid Integration (CapREG) thematic studies.

While there is evidence of the support from the international community, however, as the complexity on technical, policy, planning and operation, and business and market related issues of renewable energy grow, international community needs to keep supporting these developing economies.

4.6.5 Barrier and Recommendation on Improving Business Condition

Although many APEC economies have made good progress on laying a business environment for renewable energy projects, there are barriers that have prevented growth in renewable investment in the region. In the following sections, we list some main barriers and provide recommendations for improvement to tackle the challenges.

[117] https://www.powerengineeringint.com/renewables/iea-to-help-indonesia-to-accelerate-the-energy-transition/

[118] https://www.international-climate-initiative.com/fileadmin/Dokumente/landingpages/EW05_Renewable_Energy_Capacity_Building.pdf

(1) Permit and Approval

Investors often find there is a gap between policy and the reality of implementation, particularly during the early development and permitting phase. A common complaint is that the permitting procedures for renewable energy projects are complex and lengthy. Approvals are required from a multitude of government agencies, each having its own timelines and milestones.

These needs simplifying and standardizing approval process. The Obama administration had undertaken a process of fast-tracking permits for renewable energy projects on federal lands, allowing renewable energy projects to be undertaken much more rapidly[119]. As another example, in a recent move, India Government has exempted solar PV power projects from environmental clearance[120].

(2) Policy Uncertainties

A range of policies drives renewable energy development in all economies. Unclear, unstable, and short-sighted policies cause challenges to the developers, investors and financiers. Revenue certainty is among the major drivers of financing and a lender's requirement and FiT with a long-term power purchase agreement playing an important role by ensuring definite revenue flows in accessing finance.

Viet Nam's first FiT program on solar projects was in force from 1 June 2017 to 30 June 2019. After the uncertain period of 10 months, the second FiT program was announced on April 7, 2020. Those solar PV project developers only qualified for the new rates if they put their projects into commercial operation by 31 December 2020. Unfortunately for the regulators, developers, investors and financiers to Viet Nam's solar power sector, the window of availability for the new solar PV FiTs is short; only those solar power projects which had already been approved before 23 November of the previous year can continue in development with the assurance that they can obtain a power purchase agreement (PPA) with a FiT.[121] On the other hand, India and Germany, two strong renewable energy markets, have offered the FiT program for a much longer period bringing some stability. The German FiT program ran over the period 2000-2016, although amendment on price took place matching the falling cost of the renewable energy technologies. Utility in Viet Nam is responsible for Power Purchase Agreement and pays for energy delivered. There is no take-or-pay obligation or minimum purchase guarantee. EVN can curtail generation with no financial penalty. Mexico cancelled its fourth renewable energy auction early in 2019 because of administrative changes in the entities involved.

Low FiT in Indonesia does not make renewable projects bankable, therefore, it defeats the very purpose of the FIT program. FiT should be calculated based on the levelized cost of electricity (LCOE) produced from renewable energy resources, instead of current use of the percentage of the Cost of Generation or the Indonesian acronym, BPP.

In addition, the policy has to be updated in response to market evolvement and development. Germany, for example, started with fixed price incentives determined by the government, known as FiT. As the installed solar PV capacity exceeded the initial plan, the FiT is reduced accordingly. In 2017, the EEG, which is the main regulation that governs the FiT was amended. With this new amendment, the FiT scheme had been changed into an auction system as the renewables prices have become more competitive.

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[119] Cozzi, P., 2012, Assessing Reverse Auctions as a Policy Tool for Renewable Energy Deployment, Number 007, ENERGY, CLIMATE, AND INNOVATION Program, THE FLETCHER SCHOOL TUFTS UNIVERSITY, May 2012

[120] https://www.livemint.com/Politics/QW4cJ9yjhmvUtOZCPyOt3J/Govt-eases-environment-clearance-rules-for-solar-projects.html

[121] https://www.allenovery.com/en-gb/global/news-and-insights/publications/new-developments-for-Viet Nam-renewable-energy

(3) Land Issue

Renewable project developers in some economies face land acquisition issues. For example, energy projects in Mexico also often face resistance from local communities. Much of the land is collectively owned in Mexico, meaning the developers must consult with dozens or even hundreds of people before beginning a project. This process often leads to long, expensive legal battles. The government of India makes land available to the successful bidders for setting up solar park projects[122], therefore also eliminating the time required on acquiring land-related permits and approval.

(4) Grid Connectivity & Stability

As discussed in the previous section, grid connection and stability is an issue that could greatly vary in severity among different jurisdictions. Renewable energy developers consider grid connection and grid stability as an important factor for project viability (e.g., securing grid connection, dealing with inadequate grid infrastructure and distance of the project from and to the power grid)[123]. Lessons from China indicate that the failure to manage the grid will lead to high level of renewables curtailments.

The economy's power grid is owned by the utility in its own economy, for example, EVN in Viet Nam. The transmission and distribution network will require a significant upgrade to absorb renewable electricity. Developers are responsible for power transmission, and grid connection costs up to the designated point of interconnection. With the growth in renewables, there have been grid-related technical issues which have resulted in the curtailment of solar and wind power in certain instances. In addition, particularly for larger-scale projects, there is often a mismatch between the timing that utility needs to obtain approval for and develop the necessary grid infrastructure to support the project and the investor's own desired project timetable. This is a particular challenge for renewable energy developers because most of the economy's wind and solar resources are in remote areas far from population centers, such as in Mexico and Chile.

Finally, in some economies, local communities have opposed developers' plans to construct renewable energy generation and transmission projects, such as in Mexico. There are likely opportunities to include and leverage private sector and international donors' expertise in the area of renewable energy grid integration, smart grids, and battery storage and flexibility enhancement. Encouraging private sector participation in in grid connection and capacity augmentation is among positive steps, while investors need to be incentivized to do so, including through appropriate compensation and making things like the licensing process and land access easier.

4.7 Distributed Energy Utilization

4.7.1 Distributed Energy Development Plan

Selected relevant plans and program on distributed energy development in some APEC economies are summarised as below.

(1) China

One of the key drives behind the development of distributed energy and micro-grid system in China is to make full use of renewable energy to meet the diversified demand of energy, maximize the utilisation of distributed energy resources, and improve efficiency of the energy systems. Since 2011, China has issued a series of industrial policies and developed relevant programs to foster the

[122] https://www.newindianexpress.com/business/2019/mar/13/govt-modifies-rules-to-help-solar-parks-get-land-1950447.html

[123] PwC, 2018, The next frontier for infrastructure investments: Renewable Energy in Asia-Pacific, PricewaterHouse Cooper, Singapore

development of distributed energy based smart energy micro-grid system, and some of which are summarised as below:

- **Energy Production and Consumption Revolution Strategy (2016-2030) or the Energy Revolution Strategy (ERS):** issued in December 2016 jointly by the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA). The purpose of the strategy is to build a smart energy network and strengthen smart grid construction, effectively integration of gas pipelines, heating pipelines and power grids; promoting the interconnection of multiple energy flows and the transformation of different energy forms; establishing coordinated source network for energy storage, and build up the multi-energy integrated networks;
- **Notice on the First Batch of Multi-Energy System Integrated Demonstration Project:** issued by the National Energy Administration in January 2017, along with the announcement of the first batch of integrated multi-energy system demonstration projects. Among them, there are 17 user-side integrated multi-energy systems and six power-side integrated multi-energy systems;
- **Implementation of Integration of Source Network, Load and Storage:** issued in August 2020 by the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA). The goal is to improve the level of clean energy utilization and power system operation efficiency, and better guide the planning and development of the power supply base and the coordination and interaction of energy sources, energy delivery network and load centres. Priorities were given to the efficient use of clean energy resources, improving the performance of the regulatory frameworks of electricity and coal supply, effective configuration of relevant energy storage facilities, promoting the flexible demand-side response. Also, it is beneficial to give full play to the advantages of new and renewable energy resources, realize the large-scale renewable energy, optimize energy system structure, relieve the resources constraints, promote sustainable development of the energy field and protect ecological environment. The measures were laid out for breaking the barriers between various fields, coordinating the development, and scientific allocation of resources, achieving the goal of coordinated development of sources, network, load and storage, improving the utilization rate of clean energy.

(2) Japan

In the "Energy Master Planning and Design", issued by the Japanese Government, the goal of developing and popularizing the use of distributed energy fuel cells, cogeneration, solar power generation, wind power, biomass energy and waste power generation was comprehensively outlined. Among them, the goal of cogeneration is to install additional 10 GW by 2020. Cogeneration and solar photovoltaic dominate Japan's distributed generation landscape, with a total installed capacity of roughly 36 GW, accounting for 13.4% of the economy's total installed power capacity. Among them, 6,319 commercial distributed generation projects are primarily used in hospitals, restaurants, public leisure, and entertainment facilities. There are 7,473 industrial distributed generation projects, with the majority of them being used in the chemical, manufacturing, steel, and other industries.

According to Japan's Ministry of Economy, Trade and Industry (METI), installed cogeneration capacity in Japan is expected to reach 16.3 GW by 2030, nearly doubling the capacity of 2006. According to the World Alliance for Decentralized Energy's (WADE) prediction of Japan's energy supply and demand, distributed generation would account for 20% of total electricity generation in Japan by 2030.

Based on the fact of increased number of occasions of the domestic energy shortages, Japan has launched research program on smart energy micro-grid, mainly focusing on the development of energy supply, pollution reduction, and meeting the electricity needs for users. Renewable energy resources such as wind power and solar power, according to the Japanese government, are expected to play an increasingly vital role in the economy's energy structure. However, due to renewable energy power's volatility and predictivity level, microgrid can help achieve the energy supply and demand balance by controlling renewable energy output and storage capacity, matching the load fluctuations. Smart microgrids with energy storage devices can help deal with the intermittent nature of energy supply from renewable energy resources. From the perspective of a large power grid, the microgrid potentially can be equivalent to a constant load with no influence on power flow distribution.

The Japanese microgrid research attaches special importance to energy storage and control. The microgrid in Japan adopts a control system, by which the distributed power supply in the network is managed and dispatched in a uniform manner by the top-level energy management system, ensuring the grid's transient power balance and limiting the impact on the main network. The concept of the Flexible Reliability and Intelligent Electrical Energy Delivery System (FRIENDS) was proposed by certain Japanese academics, which allows rapid and efficient control over the flexible AC transmission system components to optimize the distribution network and meet consumers' various power quality criteria. Furthermore, in order to be more environmentally friendly, and to increase the efficiency of energy system, the concept is also coupled with the proposed cogeneration design at relevant sites.

(3) Viet Nam

The Government of Viet Nam advocates energy access and energy security by setting up different schemes of electricity prices for residential, industrial and agricultural users. This help consumers with low income with electricity access. The government had also achieved the plans and actions for rural electrification to cover the entire population with electricity services by 2020. To access modem energy, off-grid investments had been directed to remote rural areas and isolated islands to develop microgrid systems for distributed electricity supply. Viet Nam has further continued to support the building of distributed power systems and micro-grids from the aspects of technical feasibility and financial viability to support electricity access and great reliability for electricity supply for the remaining population, which has been in line with the goals of improving grid resilience, constructing a stronger power supply system, and improving power supply quality for the users across the economy.

(4) Other economies

In the United States, according to the "Distributed Generation 2020 Agenda", distributed generation become a model of efficient use of fossil energy in commercial buildings, promoting economic growth and improving residents' quality of life while reducing pollutants emissions through distributed clean energy resources utilization.

Energy access issue exists in Indonesia. The majority of families without electricity are located on isolated islands and/or remote areas. Extending the main network is difficult. It has been advocated that full access to electricity can be achieved through distributed energy sources, and relevant policies and programs have been developed.

4.7.2 Policy for Distributed Generation

Various policies have been in place to support distributed energy development among the APEC economies, which took the local energy resources, social and economic background into the consideration of specific economy. A brief summary of some relevant policies is given as below for selected economies in the region.

(1) Canada

The "Pan-Canadian Framework on Clean Growth and Climate Change" presented as a policy framework, aiming to make Canada a global hub for green growth and innovation for clean technology R&D and demonstration projects in three Canadian sectors: energy, mining, and forestry. The framework covers five areas that focus on the environmental challenges and economic opportunities of operating Canada's natural resources. The framework aims at reducing greenhouse gas and air pollution emissions; improving waste management; producing and using of advanced materials and biological products; efficient production and use of energy. Distributed renewable energy is among the important sources for reliable and clean energy supply.

(2) Chile

Chilean President Sebastián Piñera announced the 2012-2030 energy development strategy, which outlines the economic, sustainable, healthy, and environmental principles for energy development in Chile. While fossil fuels will continue to be an important component of Chile's energy in the future, the focus will be on improving the environmental standards of electric power generation, making it a clean, safe and affordable.

(3) China

In China, an important policy document related to the distributed energy development is the notice from the National Development and Reform Commission (NDRC) in 2016 stated that Beijing, among 12 provinces, Tianjin and Hebei provinces continued to be included in the reform pilots for transmission and distribution charging mechanism, which resulted in a more flexible feed-in tariff range for electricity generation, gradually moving to separation of retailing from transmission and distribution business, clarifying the difference between the costs of electricity transmission and distribution, and the profits of the network companies.

According to the NDRC notice, Solar PV Feed-in Tariff Policy Related Matters in 2020 (NDRC2020, No. 511), 0.05 yuan/ kWh will be the subsidy standard for industrial and commercial distributed solar PV power generation projects that adopts the principle of "self-generation and self-use, with surplus fed into the power grid". The on-grid tariff for the projects in the industrial and commercial sectors, following the mode of "full grid feed-in", will be the same as the centralised solar PV power plant. Subsidies for household solar PV power generation will be cut. This results in a 0.08 yuan/kWh adjustment to the total subsidy level for household distributed solar PV power generation in 2020. The on-grid electricity price will remain unchanged for solar PV poverty alleviation projects, including the project at villages, that comply with regulations in China on solar PV poverty alleviation project management.

(4) Japan

Japan has formulated relevant laws and preferential policies to ensure the development of distributed electricity generation projects, allowing distributed generation systems to be connected to the power grid with conditions. The government supports distributed energy through the preferential environmental protection funds. Some preferential policies include:

- In some cases, urban distributed generation units are eligible for a tax break or exemption from taxation. Low-interest loans (2.3 % per annum) are available for 40-70% of the total investment; District heating facilities are exempt from special land tenure tax and utility tax, project cost, fixed asset tax, depreciation asset tax, etc;
- Financing distributed generation systems by banks and financial institutions have been encouraged. In addition, because district heating systems require significant investment, Japan's financial institutions have implemented long-term low-interest rates for the related projects;

- The Electricity Utilities Act was amended in order to allow non-utility energy suppliers to sell electricity to high-demand customers, a business that was previously dominated by power companies before the deregulation. It has been required that the buildings over 30,000 m^2 must also be integrated into the urban distributed energy systems.

(5) Korea

In 2017, the Korean Government announced the "2030 Renewable Energy Plan", which focuses on the development of renewable energy. The plan aims to increase the share of electricity generated from renewable energy from 7% in 2017 to 20% in 2030, and the installed capacity from 11.3 GW in 2017 to 58.5 GW in 2030, with the majority of the growth coming from solar and wind power. The plan calls for the development of distributed energy.

(6) Mexico

The Government subsidises renewable electricity generation. Energy from renewable resources is subsidized when plants need to run in full capacity, and the grid is compensated when supply exceeds demand and the plants do not run in full capacity. Mexico's energy control center, CENACE, set a reference price for the government to adjust subsidies based on forecasts of electricity supply and demand, as well as average marginal electricity prices.

(7) New Zealand

Energy security is among the key goals of the New Zealand Energy Strategy 2011-2021, which calls for 90% of New Zealand's electricity to come from renewable resources by 2025. Since signing the Paris Agreement, in 2005, New Zealand pledged a 30% reduction in greenhouse gas emissions by 2030, and the 100% renewable energy generation target reached by 2035. Distributed energy resources have been expected playing an important role on path of energy transition.

(8) Papua New Guinea

Papua New Guinea plans to generate 100 % of its electricity from clean energy sources by 2050 while reducing greenhouse gas emissions by 90 % compared to 1990. As part of its 15-year Electricity Development Plan 2014-2028, the government has proposed a series of policies to encourage the development of renewable energy. Mini-grid based distributed energy systems are among the suitable solutions for the remote and rural community’s energy access.

(9) Peru

As part of its electrification plan, the Peruvian government plans to install about 260,000 solar panels by 2021 in various areas with no electricity access. A budget of $526 million was spent by the government on more than ten power generation and transmission projects. To promote electric and hybrid vehicle use, the Ministry of Energy and Mining set a regulatory framework. Peru plans to have 15% of its energy mix coming from renewable resources by 2030. As part of its efforts to narrow the gaps between urban and rural areas, the government plans to achieve 100% electricity coverage by 2021.

(10) Chinese Taipei

The authority on economic affairs in Chinese Taipei announced that the whole sale price of renewable energy in 2019 has been significantly reduced, by more than 10 %. These include offshore wind power and photovoltaic power. Compared to the international average of 4.25 %, the average rate of photovoltaic power has been reduced by 10.17 %, which was unfavourable for the local photovoltaic industry and developers. With the improved legislation and policy framework and market condition, in the first half of 2018, the amount of photovoltaic electricity fed into the grid in Chinese Taipei reached a record high of 470 MW, nearly two years after the introduction of the Amendment for Electric Power Law. The cumulative installed capacity reached 2.24GW.

(11) The United States

Renewable energy technologies and projects that meet certain criteria can be subsidized through incentives offered by the federal government in terms of tax credits, grants, and loan program measures. These federal tax incentives, or credits, for qualifying renewable energy projects or equipment include the Renewable Electricity Production Tax Credit (PTC), the Residential Energy Credit, and the Modified Accelerated Cost-Recovery System (MACRS). Several government agencies, including the Department of Agriculture, the Department of Energy, and the Department of the Interior, may offer grant and loan programs. These financial incentives supporting or subsidizing the installation of renewable energy equipment have been made available in most states.

(12) Southeast Asian economies

Many Asian economies have achieved universal energy access. Due to the geographic constraints, however, a small number of isolated islands and remote rural areas in the APEC region have yet to be electrified. For energy access, governments of the related economies should implement the right policies and incentives, including feed-in tariffs, tax breaks, and financial subsidies, to ensure energy supply. Isolated islands and rural areas are located far from the economic centers, with transportation and power grid extension proving difficult. To help achieve the goal of 100% energy access, the development of distributed energy adapted to local conditions is critical to addressing the "last mile" of energy access in rural and remote areas. Solar home systems or small power grids could be developed with the help of international capital, and government, international financial support, and community participation should be combined to maximize the efficiency of each major player.

Table 4.41 Plan and Incentive Policy for Distributed Energy in APEC economies

Economies	Plans and incentives at the domestic level for distributed generation and microgrids
Canada	A Pan-Canadian Framework for Clean Growth and Climate Change was developed, a Cabinet Committee on Energy developed guidelines for comprehensive community energy solutions, and the government initiated a variety of important research topics related to integrated energy systems and technologies.
Chile	Chile's energy development strategy 2012-2030 proposes that the basic principles of energy development in Chile are economy, sustainability, health and environmental protection and that fossil fuel power generation will remain an indispensable and important part of future energy in Chile. However, the focus will be on improving environmental standards to make it clean, safe and economic with more renewable energy.
China	Make full use of renewable energy to meet the diversified demand of future energy, maximize the utilization of distributed energy, and improve energy efficiency. The goals include: • Comprehensively building integrated internet and intelligent energy network; • Strengthening the construction of smart power grid, effectively connecting oil and gas pipelines, heating pipelines and other network; • Promoting the interconnection of various energy flows and the transformation of different energy forms; • Establishing the integrated energy systems with multiple energy resources, energy network, energy storage facilities.
Indonesia	At present, most households without access to electricity are located in isolated islands and remote areas. It is difficult to extend the main distribution network. Distributed energy offers the solution toward full energy access
Japan	Cogeneration capacity in Japan is expected to reach 16.3 GW by 2030, and distributed generation will account for 20 % of total power generation. Through the top-level energy management system, the distributed power supply is managed and dispatched through a control structure to maintain the transient power balance of the grid and limit its impact on the main power grid. Policy measures include: • Urban distributed generation units could qualify for tax breaks or exemptions from paying taxes; • Encourage banks and consortia to invest in and finance distributed generation systems; • The Electricity Utility Law was revised as part of a series of deregulation measures in power sector to allow non-utility suppliers to sell electricity to large consumers.
Korea	The 2030 Renewable Energy Plan was announced to focus on the development of renewable energy.
Mexico	Mexico's government subsidizes renewable power generation when demand exceeds supply (when the plant operates at its full capacity).
New Zealand	New Zealand Energy Strategy 2011-2021 aims to reduce greenhouse gas emissions to 30% of 2005 levels by 2030, and achieve 100% renewable energy generation by 2035.
Papua New Guinea	In the 15-year Electricity Development Plan of 2014-2018, further emphasis is placed on the promotion of renewable energy, and distributed energy.

Economies	Plans and incentives at the domestic level for distributed generation and microgrids
Peru	More than ten power generation and transmission projects to be completed with expected of $526 million by 2021, including the installation of about 260,000 solar PV plants.
Chinese Taipei	New regulatory frameworks have been introduced, including the amendments to the Electricity Industry Law, the Energy Development Agenda and the revised Regulations on the Development of Renewable Energy.
The United States	By 2020, distributed generation will be the model for efficient energy use in commercial buildings.
Viet Nam	• Plans for rural electrification that will provide electricity to the entire population by 2020; • Off-grid investments to be made in remote rural areas and isolated islands to form microgrids composed of distributed energy to obtain modern energy; • Further promote the construction of distributed power supply and micro-grid from the aspects of technical feasibility and fund operability and solve the problem of power access for the last 1% of the population.
The Philippines	According to its tourism resources, those with more economic development potential should attract foreign capital or social capital to solve the electricity problem. In contrast, those with lower potential should be mainly invested by the government and actively apply for international assistance to solve the electricity problem of isolate islands and these remote rural areas.

The Philippines has reached about 95% of the electricity rate with 100% in urban areas. The Philippines' Island is among the weakest points. The Philippines' islands with high tourism potential could attract foreign capital or social capital to solve their electricity problems. In contrast, those with low tourism potential should be primarily invested by the government and should actively seek international assistance to solve the problems of their electricity access.

Table 4.41 is a summary of the plan and incentive policies for distributed generation in selected APEC economies.

4.7.3 Technical Standard for Distributed Generation and Microgrid

Distributed energy and microgrid technologies are characterized by small installed capacities, large quantities, multiple mesh points, multiple types of power supply, and access to medium and low voltage distribution networks. General requirements, such as power quality, power control, voltage and frequency response, grid connection and synchronization, as well as safety and protection are included in the related technical standards of distributed generation and microgrid technologies. There are two levels in terms of distributed power and microgrid standards, namely international and domestic. In terms of international standards, the most widely recognized standards are IEC and IEEE standards (as shown in Table 4.42), such as IEEE 1547 series standards and IEC 62786 standards.

Table 4.42 IEC and IEEE Distributed Power Supply and Microgrid Related Standards

Standard Name	Application	Content
IEC/TS 62786-2017	Distributed power supply	Planning, design, operation, and connection of distributed power
IEC 62257-9-2	Microgrid	Microgrids and hybrid energy systems in remote areas
IEC 62898-1	Microgrid	Guidelines for microgrid planning and design
IEC 62898-2	Microgrid	Microgrid operation and control
IEEE 2030.7	Microgrid	Microgrid controller function
IEEE 2030.8	Microgrid	Microgrid controller test
IEEE 2030.9	Microgrid	Microgrid planning and design
IEEE 2030.10	Microgrid	DC microgrid
IEEE 1547-2003	Distributed power supply	Distributed power generation and power system interconnection
IEEE 1547.1-2005	Distributed power supply	Distributed power grid-connected equipment testing
IEEE 1547.2-2008	Distributed power supply	Distributed power grid application guide
IEEE 1547.3-2008	Distributed power supply	Distributed power monitoring and control
IEEE 1547.4-2011	Distributed power supply	Distributed power supply design, operation, and integration guide
IEEE 1547.6-2011	Distributed power supply	Distributed power supply and power system interconnection
IEEE 1547.7-2013	Distributed power supply	The impact of distributed power access
IEEE 1547-2018	Distributed power supply	Distributed power grid-connected technical standards

Source: 1. Global Energy Internet Development Cooperation Organization: "Global Energy Internet Standard System Research", 2018; 2. IEC, https://www.iec.ch/; 3. IEEE, https://standards.ieee. org/.

- **IEEE 1547 series of standards:** developed by the American Institute of Electrical and Electronic Engineers (AIEE), they apply to the distributed resources of all power generation technologies, including grid control, testing, data and information communication, islanding, power quality, etc. The earliest began in 2003, and relevant standards have been continuously and improved, such as IEEE 1547.1-2005, IEEE 1547.2-2008, IEEE 1547.3-2008, IEEE 1547.4-2011, IEEE 1547.6-2011, IEEE 1547.7-2013 and, IEEE 1547-2018.

- **IEC 62786 standard:** the standard was formulated by the technical Committee of IEC TC8, which includes 11 APEC economies, namely Australia, Canada, China, the United States, Russia, New Zealand, Mexico, Korea, Japan, and Indonesia, which all are full members of the committee. The IEC 62786 standard defines the criteria and technical requirements for connecting distributed power sources to distribution networks. It is applicable to the planning, designing, operation and grid connection of distributed power sources. The contents of the standards include general requirements, connection scheme, normal operating range, active-frequency response, power quality, interface protection and monitoring, etc.

In terms of individual standards, some APEC member economies have released grid connection standards for specific forms of the distributed power supply based on the characteristics of their local power grids and specific regulations on technical requirements, controlled islanding (islanding), protection, and other aspects of grid connection.

Diversity of the APEC economies is reflected by the different standards for distributed power supply and microgrids due to the difference in technical level and development status. Taking Canada and China as example, in terms of active power control, reactive power control, frequency response, low and high ride through ability, and other aspects, Canada's C22.2 NO.257 and C22.3 NO.9 standards differ significantly from China's GB/T 33593-2017 and GB/33592-2017 standards[124].

Table 4.43 Comparison between International Standards and APEC Economic Standards

Genres	Standard name	Application scope	Technical requirements				
			Active power control	**Reactive power control**	**Frequency response**	**Low Voltage Ride Through (LVRT)**	**High Voltage Ride Through (HVRT)**
International Standard	IEEE 1547-2018	• Distributed power supply applicable to all generation technologies, including grid-connected control, testing, data and information and communication, islanding, power quality and other contents	√	√	√	√	√
Individual economies ‘standard	Canada C22.2 NO.257, C22.3 NO.9	• C22.2NO.257 is suitable for the grid-connection requirements of the converter based distributed power supply accessing the power grid with the voltage level below 0.6kV; • C22.3NO.9 is suitable for distributed power supply with voltage level below 50 kV and capacity less than 10MW.	×	Above 30kW is required	×	Not required, but allowed	×

[124]何国庆,王伟胜,刘纯,张悦,梁志峰,孙文文,李光辉.分布式电源并网技术标准研究[J].中国电力,2020,53(04):1-12+176.

	China GB/T 33593-2017, GB/33592-2017	• GB/T 33593-2017 and GB/T 33592-2017 are suitable for distributed power supply connected to the power grid through 35kV and below voltage levels.	Medium voltage required; low voltage not required	Medium voltage required; low voltage not required	Medium voltage required; low voltage not required	Medium voltage required; low voltage not required	×

4.7.4 Consumer Affordability

Distributed power supply and micro-grid installation costs are declining rapidly over the years. In APEC economies, installation, and maintenance costs for distributed power supplies and microgrids are declining, due to falling prices for solar photovoltaic panels, wind turbines and other related equipment. As shown in Table 4.44, for both residential and commercial solar PV installations, Japanese, Australian, Korean, Thailand, Malaysia, China, and others have all been experiencing cost duction from 2016 to mid-2019. Prices for household distributed photovoltaic (DPV) systems fell by 34.9% in China and 17.4% in California compared to 2016, while in other places in the United States, they fell by 12.9%; it was 19.3% in Japan, 23.47% in Australia, and 23.78% in Korea, respectively. The costs in Thailand fell by 4.47%, while Malaysia dropped by 37.1%. Malaysia saw the biggest reduction in commercial distributed PV, with a 37.5% drop, while China saw the smallest drop, with 12.3%.

The installed capacity of distributed power and microgrid have been growing rapidly, and over the past a few years, the installed capacity of distributed photovoltaic and small wind power has reached a certain scale in addition to the natural gas cooling, heating, and power triplet (CCHP) in some economies.

Table 4.44 Costs of Distributed PV in Selected APEC Economies

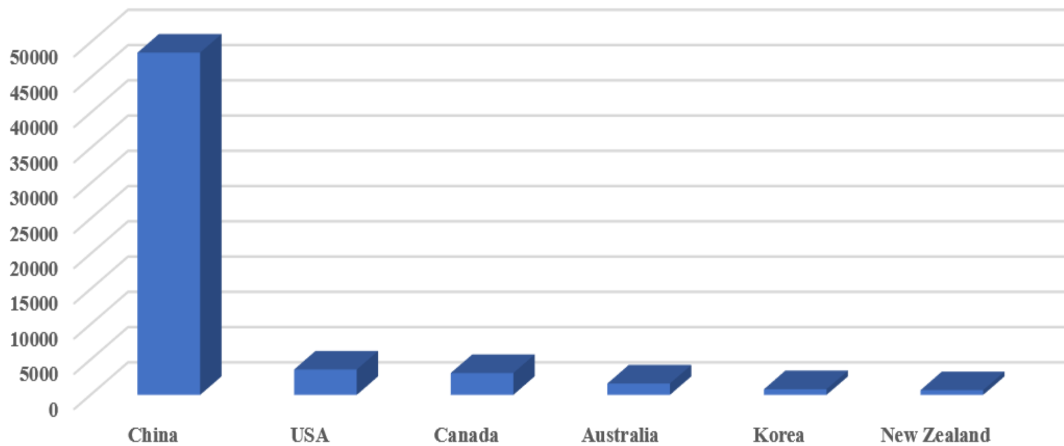
Unit: $/kWh						
Genres	**Economies**		**2016**	**2017**	**2018**	**2019**
Household use	China		0.103	0.096	0.079	0.067
	U. S.	California	0.207	0.187	0.179	0.171
		Other states	0.178	0.162	0.157	0.155
	Japan		0.202	0.188	0.169	0.163
	Australia		0.098	0.089	0.082	0.075
	Korea		0.164	0.141	0.130	0.125
	Thailand		0.179	0.159	0.137	0.171
	Malaysia		0.151	0.127	0.109	0.095
Industrial use	China		0.089	0.086	0.082	0.078
	U. S.	California	0.157	0.150	0.138	0.134
		New York State	0.213	0.189	0.181	0.171
	Japan		0.169	0.164	0.153	0.147
	Australia		0.097	0.086	0.082	0.078
	Korea		--	0.137	0.125	0.115
	Thailand		--	--	--	--
	Malaysia		0.128	0.099	0.087	0.080

Source: IRENA, Renewable Power generation costs in 2019.

It has been expected that distributed power and microgrid systems are expected to maintain a high growth rate, reaching average 15.9 % annually between 2019 and 2028. By 2030, distributed generation would account for 10 % of the world's total electricity generation.[125] The APEC economies place a high priority on the development of distributed power generation systems. Distributed energy has been identified as an economically viable clean energy solution by the US Environmental Protection Agency (EPA). In 2016, a total of 82.5 GW of distributed energy was installed in the United States, including combined heat and power generation (co-generation) and tri-generation capacity. APEC region's small-sized solar PV and small wind power projects connected to the distribution network have also experienced rapid growth, thanks to a decrease in

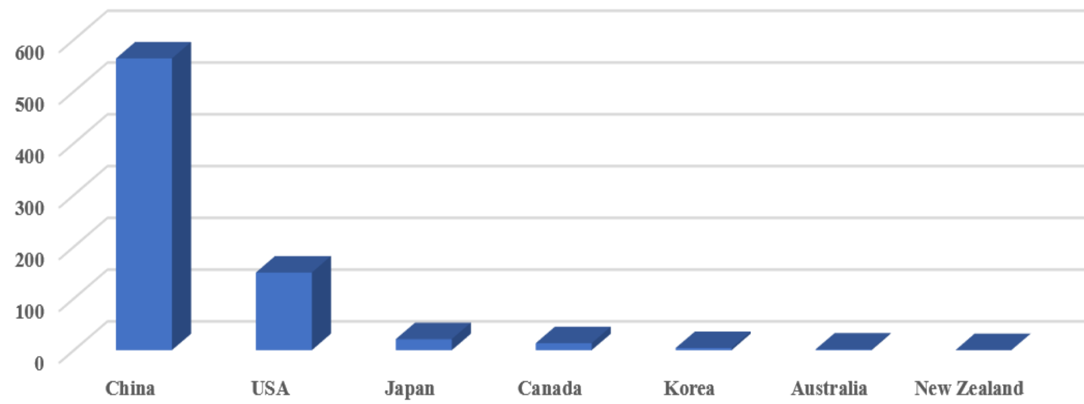
[125] Navigant research, http://www.navigantresearch.com/.

installation costs and a subsidy mechanism for electricity prices that encourages their usages. In the United States, the installed capacity of distributed solar PV reached 32 GW in 2018, and in China, it reached 50.61 GW. Small-sized wind power capacity reached 563.57MW[126].



Source: Statista, https://www.statista.com/

Figure 4.39 Distributed Solar PV Installed Capacity in Selected APEC Economies (2018)



Source: Statista, https://www.statista.com/

Figure 4.40 Installed Capacity of Small Wind Power in Some APEC Economies (2018)

Distributed power supplies and microgrid systems have been increasingly valued as important ways to solve power supply problems and improve energy access in remote areas. Some of the less developed areas of some APEC economies have not yet achieved universal access to electricity, and end users' demand for electricity and power supply quality cannot be effectively guaranteed, such as millions of people without electricity access in Indonesia, the Philippines, etc. (as shown in Table 4.45). More detailed discussions are given in the next Chapter of the report.

[126] Statista, https://www.statista.com/.

Table 4.45 Population Without Electricity in Selected APEC Economies (2018)

Economies	Share of population with access to electricity (2018)	Number of people without electricity (2018) (Unit: millions)
Viet Nam	>95%	<1
Indonesia	98%	5
The Philippines	>95%	5
Peru	>95%	1

Source: REN21, Renewables 2020 Global Status Report

In remote mountainous areas and where grid extension is inadequate, distributed power and microgrid systems are ideal solutions for power supply (such as islands, remote mountains, etc.). Due to technological advances and significant cost reductions in stand-alone and mini-grid systems, supported by enterprises, government departments, and financial institutions, over the past ten years, off-grid distributed power and microgrid systems have become highly effective in terms of addressing power accessibility. In 2017, 3.334 million people in Peru, Viet Nam, Thailand, the Philippines, Papua New Guinea, Malaysia and Indonesia were supplied with electricity, of which 700,000 people were dependent on small hydropower, 199.4 million with PV lighting (<11W), 20.7 million with mini solar system (>11W), and 43.3 million had access to the solar PV based mini-grid systems.

Table 4.46 Population of Off-grid Distributed Power Supply and Microgrid in APEC (2017)

Unit: Thousand

Economies	Mini hydropower	PV lighting (< 11 w)	Home PV Systems (11-50W)	Home PV Systems （>50W)	PV based mini-grid system
Peru	0	79	116	15	9
Viet Nam	380	--	--	1	--
Thailand	19	--	--	--	--
The Philippines	73	323	28	--	--
Papua New Guinea	--	958	34	--	--
Malaysia	1	--	--	--	3
Indonesia	227	634	0	13	421
Total	700	1994	178	29	433

Source: IRENA，Off-grid Renewable Energy Statistics 2019

4.7.5 Policy Support for Low-income and Remote Area Customer

Currently, renewable energy development is still largely dependent on policy support in many parts of the region. The installed capacity of renewable electricity generation has continued to rise, and policies to support renewable energy continue to evolve as the scale of renewable energy utilisation increases. Increasing the application of renewable energy and provision of energy services to the low-income population, particularly these resided in isolated islands and the remote rural areas is an important mean of achieving Sustainable Development Goals (SDGs), ensuring affordable, reliable, and sustainable access to modern energy for all. The relevant policies need to be more flexible and tend to be implemented in tandem with other measures. Relevant legislation should allow more private sector participation in producing, distributing and selling renewable energy electricity. The pricing mechanisms, license procedures for project development and plant operation should send right signals for the utilisation of distributed energy resources.

Renewable based off-grid and microgrid systems offer the solutions for the rural and remote areas. ASEAN member economies have introduced various support policies and incentives in order to promote regional renewable energy development. As shown in Table 4.41, the support mechanisms include setting renewable energy targets, introducing feed-in tariff policies (FiT), self-consumption programme, competitive bidding (auction), tax incentives, preferential loans, capital subsidies and tradable renewable (green) energy certificates.

The government and international aid funds are among the sources of funding for renewable electricity projects. In the region, a number of economies have implemented relevant fiscal policies, international financial approvals, and a variety of tax policies and other policies for solar household systems and micro-grid equipment, such as tax and fees exemptions, investment cost reduction, aiming at addressing the issue of energy access in rural and remote areas through distributed renewable energy resources.

It needs to be emphasized that for the isolated islands and remote rural areas, with limited access of electricity, the government financial support for the development of renewable energy is crucial. Instead of relying on large-sized and centralized electricity supply, the distributed power supply systems can be directly oriented toward the users and supply electricity on the spot according to the specific demands and needs. The development of distributed energy resources, adapted to local social and economic conditions, will help solve the issue of energy access for these “in the last mile" in the APEC region.

Chapter 5: Renewable Energy to Support Energy Access

5.1 Energy Access and Development in the Region

Energy is of vital importance for the sustainable development of an economy. Empirical research shows that ensuring universal access to affordable and reliable modern energy services can boost economic growth, reduce poverty, and improve well-being, while also promoting human development, supporting health, education, employment, and women's empowerment ([127,128]).

As part of the United Nations Sustainable Development Agenda, all economies have established 17 ambitious sustainable development policy goals to end poverty, protect the environment, promote gender equality, and ensure prosperity[129,130,131]). Sustainable Development Goal 7 (SDG7) aims to ensure access to affordable, dependable, sustainable, and modern energy for all by 2030. This includes expanding access to electricity, enhancing clean cooking fuels, lowering energy subsidies and reducing air pollution. Furthermore, energy is one of the main issues related to the achievements of most of the other SDGs as well, which is associated with 125 (74%) of the 169 SDG targets, making it critical for all societies to recognize the critical interconnections between energy and the broader development agenda.

Toward the SDG7, various efforts have been made in developing economies, and progress of energy access has been achieved globally. However, it is still a challenge for some economies, and there are still about 770 million people worldwide with no access to electricity by 2019.[132]

In the APEC region, many developing economies have achieved tremendous progress in electrification, bringing electricity to large swaths of the population, if not the entire population, particularly these in rural areas. Since 1990, various economies have progressed impressively toward electrification, reflected by increased share of the total population that gained access to modern energy services. China, Viet Nam, Thailand, and Chile are among the good examples in this regard. Relevant policies and programs developed implemented in these economies offer references and learning opportunities for others.

Figure 5.41 shows domestic average electricity access in selected APEC economies, and Figure 5.42 shows the situation of electricity access in rural areas. In the region, Papua New Guinea (PNG), Peru, Indonesia, and the Philippines are among these in the region that have yet to fully tackle the problem of energy access. The average electrification rate of these economies is 59%, 95%, 98%, and 95%, respectively, where Papua New Guinea has particularly less access to modern energy, especially the population in rural areas.

[127] McCollum, D., L. Gomez Echeverri, K. Riahi, and S. Parkinson. "Sdg7: Ensure access to affordable, reliable, sustainable and mode rn energy for all." (2017): 127-173. Retrieved from: http://pure.iiasa.ac.at/id/eprint/14621/1/SDGs-interactions-7-clean-energy.pdf. Accessed 15 August 2021

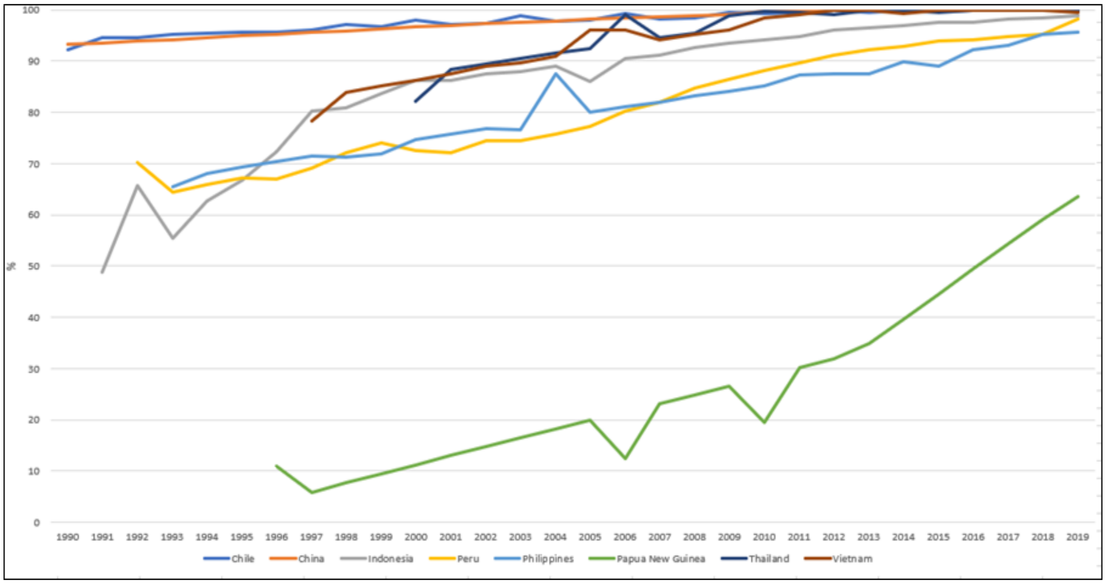
[128] Nerini, Francesco Fuso, Julia Tomei, Long Seng To, Iwona Bisaga, Priti Parikh, Mairi Black, Aiduan Borrion et al. "Mapping syner gies and trade-offs between energy and the Sustainable Development Goals." Nature Energy 3, no. 1 (2018): 10-15. Retrieved from: https://discovery.ucl.ac.uk/id/eprint/10037715/3/Tomei_Manuscript%20-%20Energy%20and%20the%20SDGs_final.pdf. Accessed 15 August 2021

[129] Aglanu, Leslie Mawuli. "Powering up Sub-Sahara Africa's renewable energy revolution through diffusion." (2018).

[130] https://openknowledge.worldbank.org/bitstream/handle/10986/33191/Sustainability-Review-2019.pdf?sequence=1&isAllowed=y

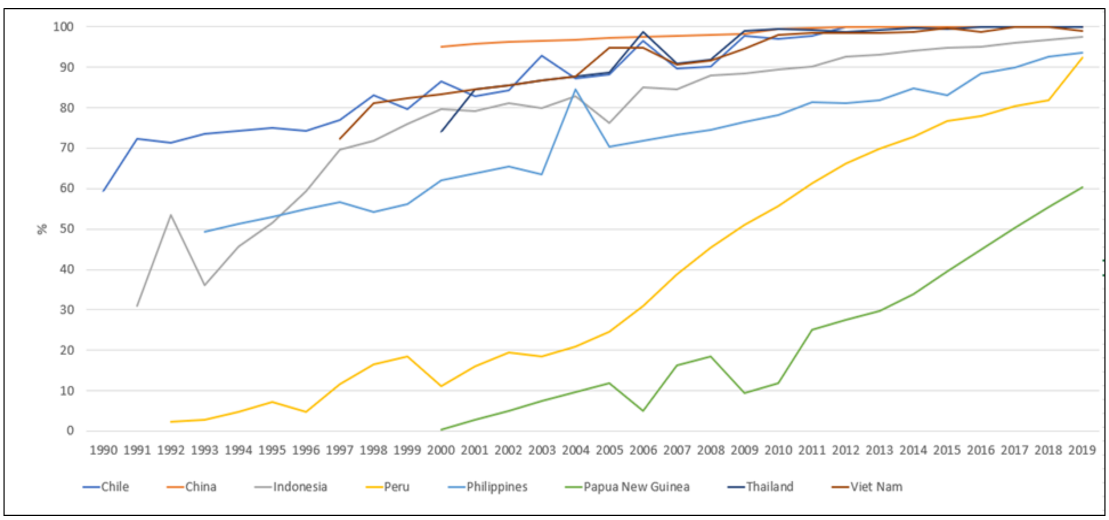
[131] https://www.iea.org/reports/sustainable-recovery

[132] IEA, 2019. https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity



Source: World Bank, Tracking SDG

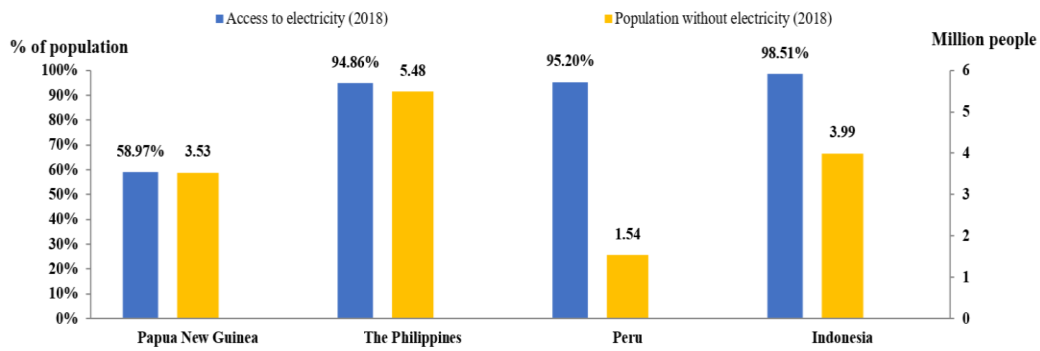
Figure 5.41 Domestic Average Electricity Access in Selected APEC Economies (1990-2018)



Source: World Bank, Tracking SDG

Figure 5.42 Electricity Access in Rural Areas in Selected APEC Economies (1990-2018)

The four APEC economies, namely Papua New Guinea, the Philippines, Peru, and Indonesia has a combined population of 14.54 million without electricity access. (Figure 5.43). Papua New Guinea still has the lowest rate of electricity access of 58.97 %. While in the Philippines, although 94.86% of the population has access to electricity, other 5.48 million people still have no access. In Peru, electricity is available to 95.20% of the population, with 1.54 million people living without electricity access. As for Indonesia, electricity is available to 98.51% of the population, while the other 3.99 million people are still without access to electricity.



Source: World Bank https://data.worldbank.org/indicator

Figure 5.43 The Access to Electricity of Selected APEC Economies (2018)

On the other hand, while comparing the results with the statistics given on power consumption per capita, it can be observed that out of the 21 APEC economies Papua New Guinea, the Philippines, Peru, and Indonesia have the lowest electricity consumption per capita, with 471, 740, 1475, and 843kWh/capita, respectively.

In the following sections, the situation and challenges in Papua New Guinee, Peru and in Southeast Asia are examined, and solutions are explored, with policy recommendations are drawn to rise electricity access for these in rural and remote areas in the related economies.

5.2 Papua New Guinea

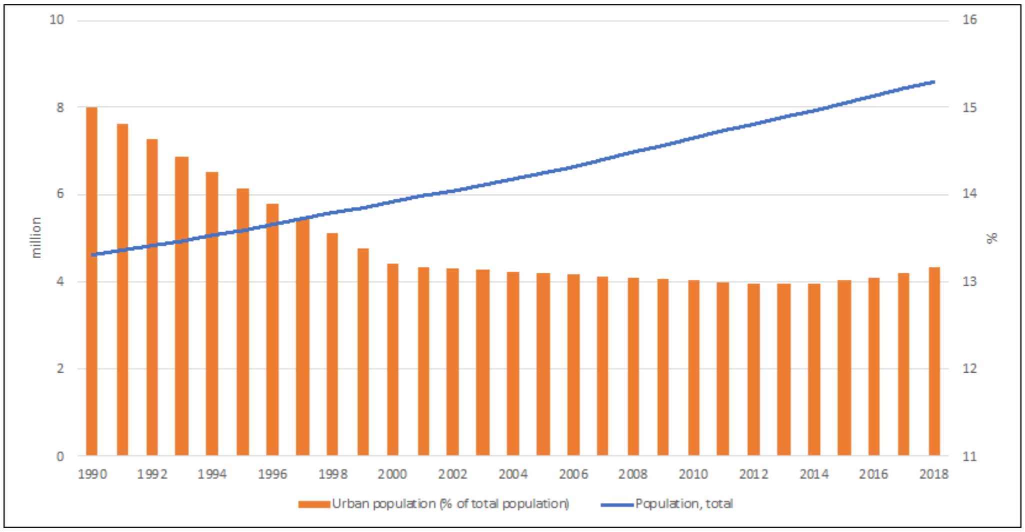
5.2.1 Social and Economic Background

Papua New Guinea (PNG) is the largest Pacific Island economy with surface areas of 462 841 km[133]. The Coral Sea and Australia are south of PNG, the Solomon Islands and Nauru are located to the east, while the Federated States of Micronesia are to the north. PNG is composed of a group of islands, including the eastern part of the island of New Guinea, the second-largest island in the world. Indonesia occupies the western half of New Guinea Island and borders PNG to the west. PNG has an estimated population of 8.79 million[134,135,] representing over 800 cultural groups widely spread over the economy's fertile highlands, rivers and island coasts.

(1) Demography

Figure 5.44 illustrates the population growth and demographic structure of PNG in a recent couple of decades. PNG has a long tradition as an agricultural society, and up to 85 % of the population engages in agriculture, forestry and fisheries. A small urban population, less than 15% of the domestic population is involved in a formal economic sector that focuses mainly on exporting natural resources. The vast majority of the rural population are dispersed in the rural areas live by subsistence and semi-subsistence agriculture. The economy remains highly exclusive and up to 37.5 % of the population lives below the domestic poverty line.[136]

[133] WBD, 2018. https://data.worldbank.org/indicator/AG.SRF.TOTL.K2?locations=PG
[134] WBD, 2020. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=PG
[135] Census population (2011) 7.275 million; Population estimate 8.788 million (2018) based on average 3.1% growth rate. ADB statistics state 2017 population 8.75 million: www.adb.org/publications/basic-statistics-2018
[136] Ibid ADB basic statistics. https://www.adb.org/countries/papua-new-guinea/poverty



Source: World Bank

Figure 5.44 PNG Population and Urbanization Process

(2) Economy

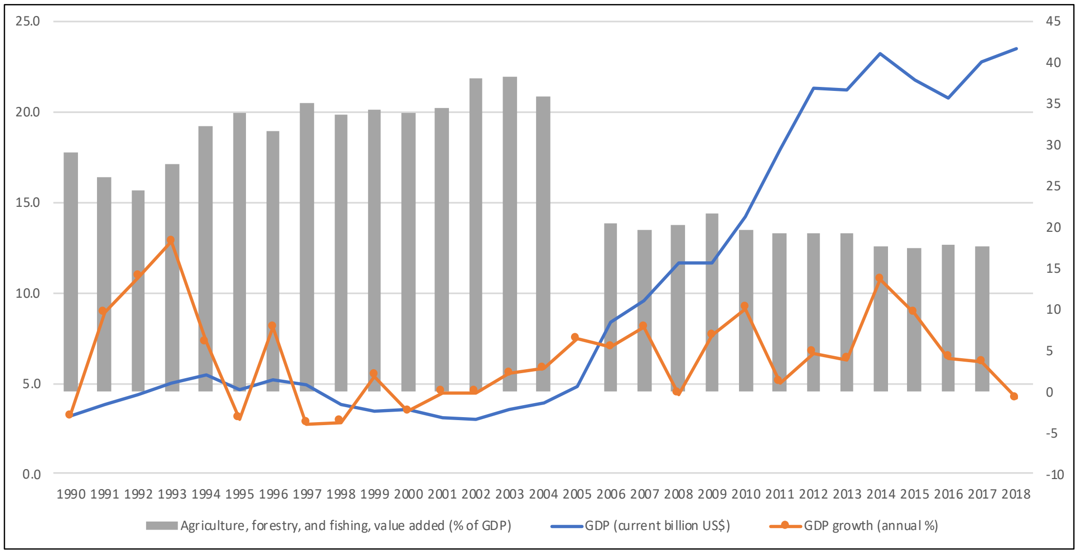
The economy of PNG is relatively small and much export oriented. The economy of PNG is primarily dominated by labour-intensive agriculture and capital-intensive extraction of oil and gas, and mineral resources, including gold, copper, silver, and iron ore. Mining and petrochemicals now account for over 25% of PNG's GDP. Mineral products, including oil, gas, liquid natural gas, gold, and copper, account for roughly 84% of all exports, with agriculture, forestry, and marine products contributing the other 16%. [137]

The economy has continued to face significant challenges in making economic growth more inclusive and sustainable. Many service deliveries such as health, education, transport, energy, and water remain weak, particularly in rural areas. The economy decreased by at least 2.9% in 2020, largely due to the impacts of the COVID-19 pandemic.[138] Challenging geography coupled with weak transportation, energy and telecommunications infrastructure, ethnic diversity and political instability, among others, have always hindered the broader utilisation of the economy's natural wealth for the benefit of its population.

(3) Governance

The Government of PNG is a member of the Commonwealth of Nations and is a constitutional parliamentary democracy. Executive powers lie with the Prime Minister who is elected by Members of Parliament (MPs). There is a strong emphasis on key leaders and personalities, not necessarily on political parties. MPs are more concerned with delivering goods and services to their constituents. This tendency of MPs to lean toward the dispensing of largesse to the people has historically worked against implementing long-term policies in the domestic interest.[139] However, starting in 2002, PNG has been able to achieve relative political stability and has had significant progress in the areas of economic management and policy development.[140] This coincided with a supportive external environment, which helped reverse the economic recession experienced in the late 1980s and early 1990s.[141] Figure 5.45 shows the economic growth and the contribution from the agricultural, forest and fishing sectors.

[137] WBD, 2020. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=PG
[138] ADB Member Fact Sheet, 2020. https://www.adb.org/sites/default/files/publication/27788/png-2020.pdf
[139] ADB Country Strategy and Programme, Papua New Guinea (CSP PNG), June 2006, p.4
[140] Ibid. p.4
[141] ADB Country Economic Review, Papua New Guinea, June 2000, p.5

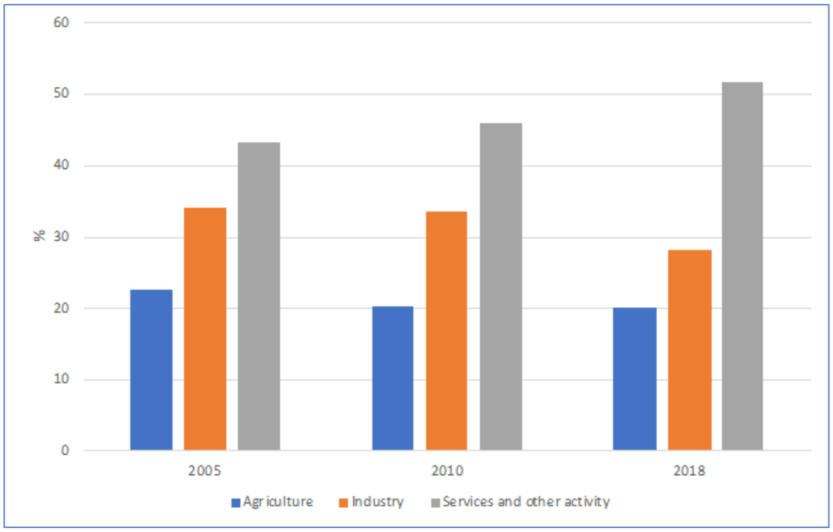


Source: World Bank

Figure 5.45 Economic Growth in PNG

Over the recent decades, economic expanded from 2007 to 2008, with over 6% growth rate. With the decline in prices of copper and oil[142], two of PNG's major exports, the economy's growth tapered in 2009 to 3.9 %, but the economy has remained in the longest period of economic growth since its independence in 1975[143].

The structure of GDP is illustrated in Figure 5.46, and Figure 5.47 shows GPD per capita in PNG and selected APEC economies.

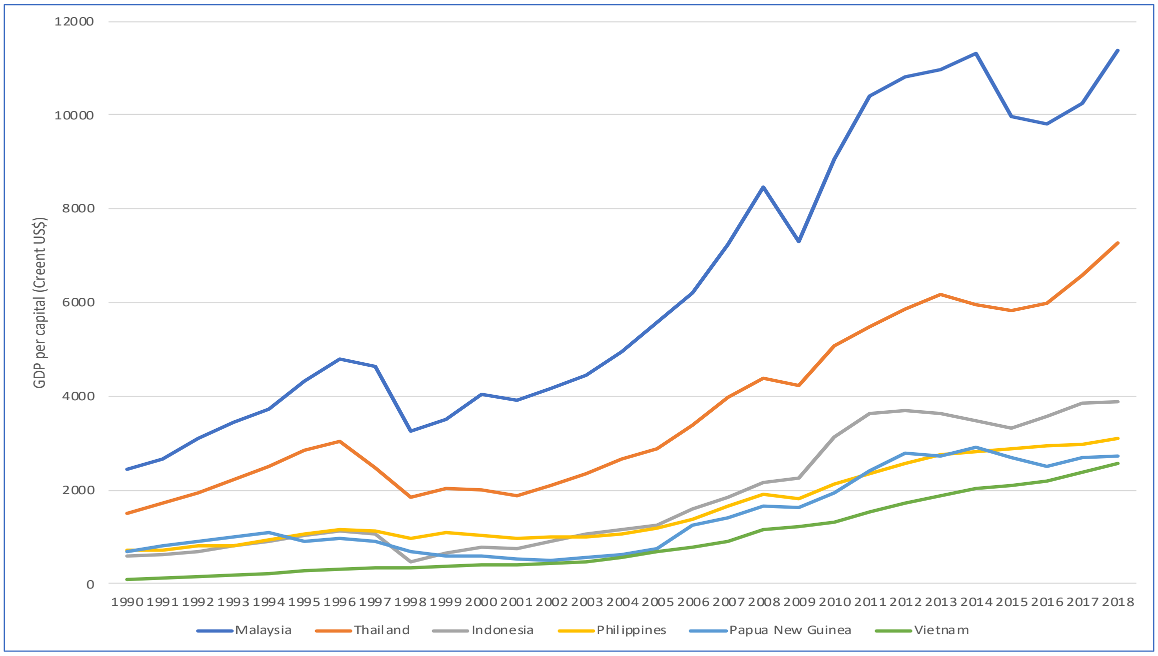


Source: World Bank

[142] World Bank Country Brief, Papua New Guinea, May 2010: http://web.worldbank.orq/WBSITE/EXTERNAL/COUNTRIES/EAST ASIAPACIFICEXT/PAPUANEWGUINEAEXTN/O,,contentMDK:20174825~menuPK:333775~pagePK:1497618~piPK:217854 ~theSitePK:333767,00.html

[143] Ibid (WB).

Figure 5.46 Economy Structure of PNG

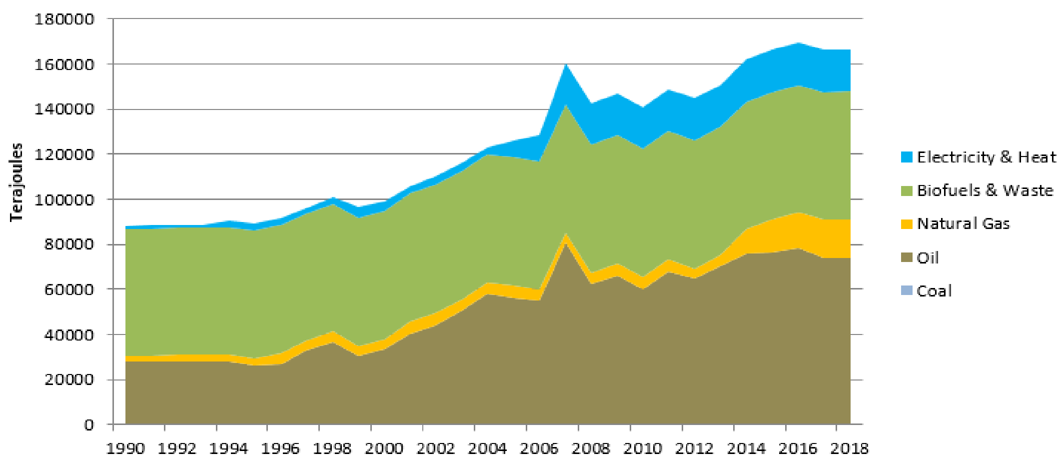


Source: World Bank

Figure 5.47 GDP per Capita of Selected APEC Economies (current US$)

5.2.2 Energy Supply and Consumption

The energy sector of Papua New Guinea is high carbon extensive. According to UN statistics[144], in 2018, crude oil maintained the largest share in the total supply accounting for 44.5%, and gas was the second-largest fuel source with 10.3% in 2018. The remaining share was attributed to other energy sources such as biofuels & waste, electricity, and heat, as Figure 5.48 depicts.

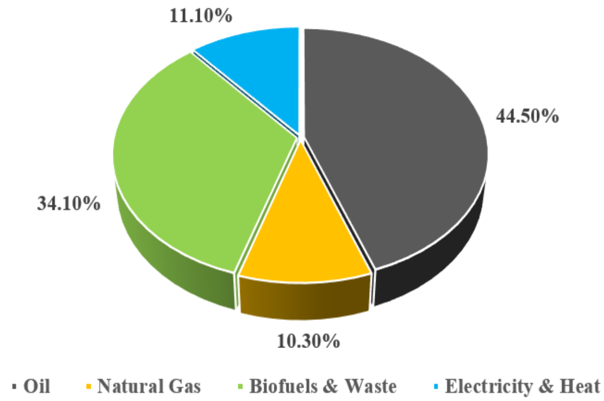


Source: UN Statistics

Figure 5.48 Energy Supply by Fuels in PNG (1990-2018)

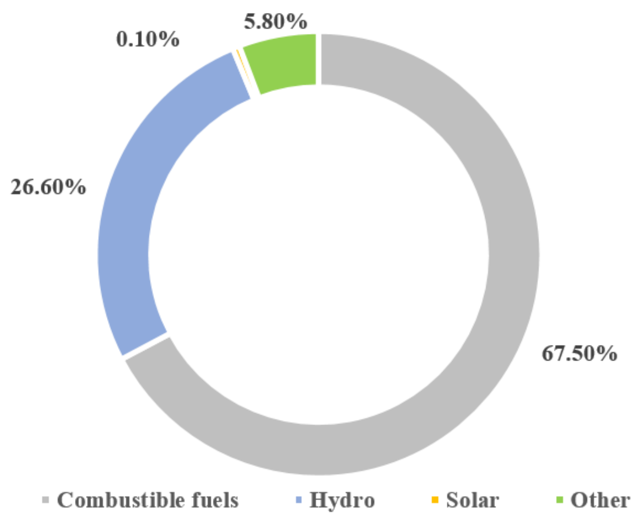
[144] https://unstats.un.org/unsd/energystats/dataPortal/

Besides fossil fuels, the economy is blessed with abundant renewable energy resources. However, there lack of comprehensive studies in the renewable energy sector to utilizing these resources to expand electricity accessibility is a challenging task[145]. Figure 5.49 and Figure 5.50, respectively, shows the structure of energy supply and installed electricity generation of PNG in 2018.



Source: UN Statistics

Figure 5.49 Total Energy Supply by Fuels (2018)



Source: UN Statistics

Figure 5.50 Share of Net Installed Electricity Capacity by Source (2018)

PNG's mountainous terrain and geographically dispersed rural population, and lack of economic activities compounds challenges to developing rural infrastructure in the economy. On average, electricity access is at about 13% domestic wide in 2018, while in many rural areas, it stands at about 7%-8% or even lower according to international development agencies such as ADB and World Bank. One of the key problems in relation to the development of rural electricity infrastructure in Papua New Guinea is its mountainous landforms, scattered and relatively sparse rural populations, and a lack of economic activity. Papua New Guinea has the lowest per capita electricity consumption in the APEC region, on average, with 499 kWh per annum in 2018. A comparison of annual electricity consumption per capita of the selected APEC economies in Soutehast Asia and PNG is presented in Table 5.47.

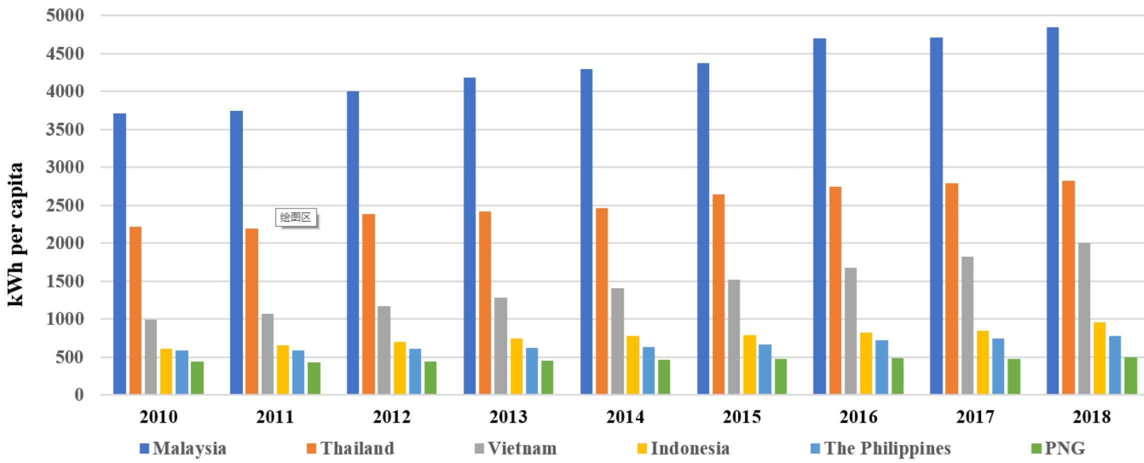
[145] Rawali, Manu, Anna Bruce, Atul Raturi, Brian Spak, and Iain MacGill. "Electricity Access Challenges and Opportunities in Papua New Guinea.

Table 5.47 Annual Electricity Consumption per Capita (kWh)

Economies	2010	2011	2012	2013	2014	2015	2016	2017	2018
Malaysia	3705	3747	4003	4177	4297	4376	4694	4710	4848
Thailand	2218	2198	2378	2421	2457	2640	2742	2783	2823
Viet Nam	986	1065	1174	1280	1401	1519	1681	1827	2006
Indonesia	612	652	700	745	779	785	826	843	957
The Philippines	588	587	609	623	630	664	715	740	775
PNG	439	434	437	451	461	479	482	471	499

Source: Population data source APEC statistics database: http://statistics.apec.org/; world and China's final electricity consumption data source IEA: https://www.iea.org/countries/china. Other economies final electricity consumption APEC Energy Database: https://www.egeda.ewg.apec.org/egeda/database_info/index.html

Figure 5.51 illustrates the per capita electricity consumption in the selected South East Asia economies. In 2018, Malaysia's electricity consumption hit the highest value among these economies, reaching 4848 kWh per capita, while Papua New Guinea showed the lowest electricity consumption in the region, standing for only 499 kWh per capita, reflecting the lack of electricity access in the economy.



Source: Population data source APEC statistics database: http://statistics.apec.org/; world and China's final electricity consumption data source IEA: https://www.iea.org/countries/china. Other economies final electricity consumption APEC Energy Database: https://www.egeda.ewg.apec.org/egeda/database_info/index.html

Figure 5.51 Electricity Consumption per Capita in Selected Economies (2010-2018)

5.2.3 The National Energy Development Plan

Energy has been embedded in the domestic development plans of various levels. The PNG Government has been pursuing the development of energy resources to guarantee the attainment of four key objectives, which include[146]:

- to ensure sustainable energy exports;
- to ensure cost reduction of energy per unit;
- to ensure a competitive international investment;

Table 5.48 summarizes the main key strategies and plans of the Papua New Guinea government and summarizes the energy-related components of these policy documents.

[146] Renagi, O. and Babarinde, J. A. (2017), Sustainable Energy Policy for Papua New Gduinea Incorporating Mandatory Environmental Impact Assessment (EIA), *Melanesian Journal of Geomatics and Property Studies,* Vol. 3, pp. 1-10.

Table 5.48 Key Strategies and Plans in PNG and Related Energy Components

Strategies and Plans	Scope	Main Energy Components
The PNG Vision 2050	A 40-year plan, with long terms vision and goals for PNG domestic	• Two of the "seven pillars" on the development plan are related to energy (natural resources and climate change and environmental sustainability); • Specified overall objective of the PNG energy policy is to ensure an affordable, competitive, sustainable, and reliable energy supply to meet domestic and provincial development needs at least cost, while protecting and conserving the environment; • Promoting the renewable energy resources for electricity generation and other development uses in which the government has set a target of 100% by 2050.
The PNG Development Strategic Plan (DSP) 2010-30	Follow-up the development blueprint set in the PNG vision 2050 for PNG to achieve a 'middle-income' economy status by the year 2030	• The DSP sets a target of 70% of electricity access by 2030, and also all towns and cities to be in the domestic grid which will feed off an electricity corridor, and most households have access to EasyPay (pre-paid power); • The DSP has prioritised the renewable resources including hydropower, solar, geothermal, wind and biomass; • On the path to 100% of electricity being sourced from renewables by 2050, the target of 50% has been set for PNG's electricity to be generated from renewable sources by 2030.
The Medium-Term Development Plan (MTDP)	MTDPs prioritise projects with appropriate funding to go with each activity that is correctly aligned to PNG Vision 2050. There are three MTDPs, namely MTDP1 (2010-2015), MTDP2 (2016-2017), and MTDP3 (2018-2022).	The MTDP 3 focuses on enabling economic growth through ongoing structural reforms and expanding the economy's infrastructure base. One of the Key Result Areas (KRA) of MTDP 3 is developing quality infrastructure and utilities. In the power sector, the goal is to improve infrastructure with sustainable and disaster-resilient quality to provide a more enabling environment for economy's growth and the improvement of service delivery. [147] Specific goals are set which include: • Increase household electrification rate from 17% to 33%; • Raise power generation by sustainable energy source from 4.4 to 11.25%. Strategies to achieve the goals include: • Increase electricity supply by extending the distribution power grid onto communities through National Electricity Supply Roll Out Plan (NEROP); • Increase the proportion of energy supply from the sustainable energy resource. Main investment areas include: • National Rural Electrification Roll Out Program aims at improving access to electricity in rural areas; • PNG Towns Electrification Investment Program is to improve and expand the reliable electricity supply in towns throughout the z; • Grid Development Program is to expand the network of electricity supply.

The following section summarizes Papua New Guinea's main energy and power sector development strategies and policies.

(1) Power Industry Policy

In response to the problems faced by the energy sector, the government of Papua New Guinea released the policy document, Electricity Industry Policy (EIP) in 2011. EIP is an ambitious power development document, including preparation of the National Electrification Promotion Plan (NEROP), the establishment of the Energy Bureau in charge of the power industry within the Ministry of Petroleum and Energy, and strengthening of its relevant policy implementation capabilities. The Power Industry Policy integrates the overall policy framework of power development, clarifies the development goals, and establishes key policy directives to address the three strategic goals for power development, which primarily include:

- Increase access to electricity services;
- Improve the reliability of electricity supply;
- Ensure the electricity affordability to consumers.

The Power Industry Policy reaffirms the domestic goal of achieving 70% electrification rate by 2030 and lists the key points of the power industry policy, including encouraging the private sector to participate in power development, supporting and speeding up rural electrification process.

(2) National Energy Policy

[147] The PNG Government. Infrastructure Goal and Strategies, Medium Term Development Plan III 2018-2022

As listed in Table 5.48, with the implementation of PNG Vision 2050, the overall goal of Papua New Guinea's energy policy is to meet the development needs of the economy and the province and protect the environment at the least cost. Specific energy policy aspects include guarantee the users have affordable prices, sufficient economic competitiveness, and the sustainability and reliability of power supply requirements. In this context, the Cabinet of the Papua New Guinea government approved the National Energy Policy (NEP) in February 2018. The purpose of this policy is to create a favourable environment and provide supports for the realization of the 2030 goals: by 2030, the proportion of PNG residents will increase to 70%, and by 2050, the proportion of using renewable clean energy will reach 100%.

The National Energy Policy is the economy's first domestic energy policy. Combined with the PNG Vision 2050, it proposes energy development strategies and policies consistent with legislative reforms and sets the following tasks and related development directions:

- Action plans necessary to promote and encourage more private sector investment in renewable energy development;
- Ensure that the government cabinet and parliament pass the Renewable Energy Law;
- Prepare and ensure that the government cabinet approves the Renewable Energy Policy;
- Develop Papua New Guinea's abundant renewable energy so that more renewable energy power can be used to supply power to the three power grids of Port Moresby, Ramu and Gazelle;
- Prepare Energy Efficiency and Energy Conservation Policy;
- Ensure that the Energy Efficiency and Energy Conservation Law is approved by the Cabinet and passed by the Parliament.

Renewable energy is among the key areas of the National Energy Policy. In order to make a corresponding contribution to the mitigation of climate change, the policy favours the use of renewable energy resources, but it is also noted that the policy does not exclude the usage of fossil fuels. Toward the policy implementation, with the support of the Asian Development Bank (ADB), the domestic energy policy has been focused on the development of hydropower, solar, wind, and geothermal. At the same time, Papua New Guinea Power Company Limited (PPL), with the support of the ADB, the New Zealand government and the World Bank, launched its electrification implementation plan to achieve the goals set by the Papua New Guinea Development Strategic Plan (DSP).

(3) National Electrification Plan

The development of the National Electrification Roll-out Plan (NEROP) was funded by the World Bank through the Energy Sector Development Project to support achieving the goals of the PNG Vision 2050. Under NEROP, the power sector expansion plan is outlined, including the Renewable Energy Plan to reach 100% renewable by 2050, focusing on geothermal and hydropower resources, and to a lesser degree on biomass, solar and wind. In addition, a small ocean energy facility is planned for 2022. NEROP recommends that PNG's power sector requires $1.7 billion to achieve the government's target of 70% electrification by 2030.

NEROP has given a stronger emphasis on power network development. With the grid extension, the beneficiary households will be identified within the vicinity of the main PNG Power's distribution grids, while the minimum supply kits will be installed in bush materials, semi-permanent and permanent houses. It is expected that the targeted 70% of electricity access will translate into better living conditions for both the rural and urban poor population, as well as offer new opportunities for business and education and help give more opportunities to people in getting better access to health, water, administrative and financial services. In addition, it has been expected to address the fragmentation issue in the energy sector. The plan calls for that all stakeholders including investors and the development partners and government work closely together.[148]

(4) Power Development Plan

In 2014, PNG Power Ltd PPL (PPL) developed the 15-year Power Development Plan, 15YPDP (2016-30), which provides a road map for priority power infrastructure, which was reviewed and updated in April 2019 to a 2019-2033 view.

The 15YPDP forms the basis road map for power infrastructure development, including generation, transmission and distribution. It aims to meet future economic growth and achieve the targets established under PNG Development Strategic Plan and Electricity Industry Policy. However, it has been noted that PPL's planning documents, primarily the 15 YPDP, are high-level documents, which does not have full technical, financial, economic, nor safeguards assessments.

(5) National Distribution Grid Expansion Plan

Reliable, grid connected power is crucial for economic development in small rural communities. Distribution grid expansion is vital for improving the lives of rural households and necessary to create income generating conditions and opportunities.

In May 2016, the PNG government developed a 15-year National Distribution Grid Expansion Plan (NDGXP) under ADB's support, which covers the technical, financial, and economic aspects of distribution expansion in PNG Power Ltd. centres.[149] The NDGXP details how the Government of PNG will expand the grid to rural communities around PNG Power's 34 provincial grids. It aims at enabling more people to benefit from access to grid electricity supply, including households, schools, clinics, as well as businesses in small communities.

5.2.4 Power Energy Sector in PNG

PNG has a total of 600 MW installed generation capacity by 2018. Around half of the electricity is generated through hydropower and one-third through diesel plants. The rest of the generation is contributed by gas and geothermal energy plants. PNG Power Limited (PPL), the domestic state-owned utility, manages generation, transmission, and distribution of about 320 MW, including three separate transmission grids, namely Port Moresby, Ramu and Gazelle. These grids serve only the main urban centres in the areas. There are private generation capacity and grids supplying the industrial sector and local communities. It is estimated that 280 MW is installed in the mining industry, which is one of the main drivers of PNG's economy, as captive power for self-consumption, in most cases, also servicing the immediate local communities. There are 19 geographically isolated MV/LV "mini" distribution power grids servicing provincial centres, though West New Britain province has a 66kV transmission line between Kimbe and Bialla to utilise hydropower resources.

(1) Stakeholders in Energy Sector

The government institutions related to the electricity sector and renewable energy development include:

- Energy Division (ED) of the Department of Petroleum and Energy (DPE): institution in charge of renewable energy and energy efficiency;
- Energy regulator: Independent Consumer and Competition Commission (ICCC);
- The Department of Public Enterprise is the delegated owner of all state-owned entities, including PPL. Its role is to increase investments, productivity and transformation of the state-owned enterprises (SOEs) to drive growth and industrialization through Kumul

[148] https://postcourier.com.pg/national-electrification-plan-near-completion/
[149] http://news.pngfacts.com/2016/04/adb-supports-png-to-increase-access-to.html

Consolidated Holdings Ltd (KCHL), which is a trustee owner and all-encompassing authority for all state-owned assets and enterprises;

- PNG Power Limited (PPL), Independent Power Producers (IPPs) and eventually NGO are energy service providers.

(2) PNG Power

PPL is a state-owned vertically integrated company created under the PNG Power Act 2002,[150] which is PNG's main power public utility that provides electricity to consumers, the sole operator in the power sector in the economy, yet there is a partial unbundling of its generation business. PPL operates under the utility operation procedure, Utilities Regulatory Authority Policies and Procedures. It has been granted the operation licences by the Independent Consumer and Competition Commission (ICCC) for the business of generation, transmission, distribution and retailing of electricity.

PPL operates three separate urban grids (isolated) and 19 other independent provincial systems. As shown in Figure 5.52, the three separate urban grids are Port Moresby System, Ramu System, and the Gazelle Peninsula System.

Source: PPL information manual

Figure 5.52 Locality Map of PNG Power Network

The Pacific Power Association (PPA) undertakes regular benchmarking studies of power utilities in the Pacific Island economies. In 1998, according to PPA, average network delivery losses were 22.3%, and distribution grid losses were 54.4%, which is the highest among the utilities in Pacific Island nations.

System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index are measures of annual hours and frequency of customers are un-served. According to PPA, in 2017, PPL's SAIDI was 13069.5 minutes[151], and SAIFI was 115.6.[152]

[150] There is a partial unbundling of PPL for power generation.
[151] Pacific Power Association (PPA). 1998. Pacific Power Benchmarking Summary Report: 2017 Fiscal Year. PPA. Suva, Fiji

The frequency and long duration of outages are very high and have seriously detrimental impacts on realising the economic benefits of current developments in the economy. In addition, distribution reliability measured by an average number of events of 100km distribution line is 546.32 event/100km in 1998. All these suggest PPL performed at the bottom among the utilities in the Pacific Island nations.[153]

(3) Other Players

In addition, about 100 small, rural mini-grids (C-Centres) are operated at the district level by local governments. Nearly all the mini grids are running on diesel, although some have hydro and solar power as well. Many of these mini-grids are not able to operate well.[154] A research revealed that among these 150-200 C-centres established in the 1980s for the purpose of electrifying rural areas, very few of them remain operational.[155]

From an operational point of view, PPL is a state-owned enterprise and is licensed under the electricity industry act to generate, transmit, distribute, and sell electricity in PNG. It also has the exclusive right to supply small customers (<10 MW) within 10 km of its network throughout PNG. PPL has plans to increase its own hydro capacity generation, and it is increasingly supporting hydro, biomass, and PV-Diesel hybrid IPPs. PPL, with the support of the ADB, planned to hybridize 20 provincial diesel mini grids with solar energy. There is support for IPPs, mini-grids and small-scale stand-alone RE projects, and more IPPs are expected to join, as solar hybridization of diesel mini-grids. Private Banks are financing small solar home system projects.[156] In addition to the public systems, as mentioned previously, privately owned systems supply electricity to their operations such as mines, plantations, and other industries, including a mine that uses PNG's sole operating geothermal power plant.

5.2.5 Challenges Faced by PPL

The isolated provincial centre grids in PNG are powered almost entirely on diesel, with WNB an exception, resulting in high electricity generation cost. This creates a disincentive for PPL to expand the grid further into rural areas. In addition, high network losses (technical, and non-technical including from theft, errors and tampering with meters), high household connection charges, lack of coordination and leadership in the power sector and weak governance and financial management and performance within PPL make it more challenging to implement the government's sector road map. There are a significant number of challenges that PNG has faced in the achievement of the PNG government development priorities. The provision of electricity from the power grid to vast areas of PNG would be among some of the most challenging efforts.

Ageing network assets and lack of maintenance cause poor reliability of power supply from the PPL network. PPL's asset maintenance approach is more reactionary than higher level strategic approach which is represented by planned, proactive or engineered predictive maintenance practices. The underlying issues include lack of strategic asset planning, effective implementation of O&M, and lack of supporting investment in system infrastructure and effective operational maintenance on the existing assets. This ultimately means higher social and economic costs are borne by the users.[157] Besides technical losses, non-technical losses, such as theft, also contribute to very high network losses of PPL. Substantial potential exist to invest in loss reduction initiatives,

[153] Pacific Power Association (PPA). 1999. Pacific Power Benchmarking Summary Report: 2018 Fiscal Year. PPA. Suva, Fiji
[154] Renewable energy opportunities and challenges in the Pacific Islands region: Papua New Guinea, IRENA, 2013, p. 3, https://www.irena.org/DocumentDownloads/Publications/Papua%20New%20Guinea.pdf
[155] The Lowy Institute. 2017. Infrastructure Challenge for Papua New Guinea. Sydney. http://interactives.lowyinstitute.org/publications/PNGin2017/png-in-2017-infrastructure-challenges-for-papua-new-guineas-future.html#thirteen.
[156] EU TAF. 2017. Stocktaking Mission to Analyze Private Sector Activities and the Funding Opportunities in Renewable Investments in the Pacific Region Program Identification and Formulation.
[157] MTDP 2011-2015, p.57.

improve the reliability of power supply, and reduce costs to energy consumers and add economic value to the community. In terms of PPL's operation, the challenges include[158]:

- Poor regulation and political interference have led to an inefficient allocation of economics resources;
- PPL's power centre and some businesses' capacitive power generation facilities mostly rely on imported petroleum fuels. The high costs of fuels has been another critical issue for energy supply in PNG;[159]
- Insufficient and ineffective asset management practice;
- Ongoing maintenance costs for grid power are high. The reliability of the power supply from PPL is generally low due to the terrain, rainfall, vandalism, poor road network etc;
- Insufficient and short-term capital budget allocations have undermined PPL's ability to increase capacity in the sector, with the private sector unable to develop needed capacity due to lack of long-term investment signals;
- Electricity tariff levels are below the cost of delivery, further undermining PPL's revenue and financial performance;
- High technical and non-technical losses of the network and revenue collection problems
- PPL's operational performance is weak. It is understood that PPL suffers losses of some 20%.[160] The deficits have also been worsened due to unable to collect electricity fees from its customers;
- Capacity and skill levels of personnel is inadequate in planning and asset management fields to provide a sound technical and financial base for investments;
- Landowner and political problems exist. Most lands in PNG are owned by traditional villages, and is known as "traditional lands." Project developers must thus negotiate with individual villages and villagers. This has been cumbersome because of disputes over who has authority over the land.

To address these challenges, a range of investment opportunities are needed, and these include:

- There is strong need for donor support directed at improving the performance of PPL;
- Get the revenue/cost matrix aligned so PPL can support loans and self-generate funds for development if not funded through government social obligations;
- Providing core funding for prioritised energy infrastructure investments, leveraging other government and IFA (ADB, WB, JICA, etc.) funding sources; it has been observed that good progress is already being made on these aspects, but the reluctance of the government to directly fund and/or provide leveraging facilities for private/public partnerships.

Under the current tariff scheme, a uniform energy tariff applies to all service areas covered by PPL depending on the consumer's category. Currently, the PPL's energy consumers are classified into four categories: industrial consumers, general supply consumers, domestic consumers and public lighting. General Supply and Domestic Consumers are further classified into Credit Metered and EasiPay.

The existing tariff structure involves the payment of minimum charge per month for domestic and general supply consumers in addition to the fixed charge per kWh on the total energy consumption. Industrial consumers are billed monthly with a fixed charge per kWh on all energy consumption with no minimum charge. Public lighting customers are billed annually. Annual charges are based on the installed streetlights. Electricity tariff levels are below the cost of delivery, undermining PPL's revenue.

[158] MFAT 2018 'Evaluation of New Zealand's Country Programme in PNG, Part IV, prepared by Adam Smith International.
[159] The diesel price in Wewak was 326 Torea per /litre in April 2019.
[160] PPA, Pacific Energy Investors Forum. 2018. https://www.ppa.org.fj/event/pacific-energy-investors-forum/

The PPL electricity tariff is regulated by the Independent Consumer and Competition (ICCC). An agreement between ICCC and PPL was signed in November 2013 and effective for five years from January 2013 to December 2017. A new contract agreement has been drafted and is being under review, which is planned to take effect in 2019. However, the 2013 tariffs were still in place when the assessment was conducted in October 2020.[161] The electricity tariff has been unchanged for the years. Under the contract agreement with the Energy Regulator, PPL has the option to implement quarterly tariff rate adjustments approved by ICCC due to fuel oils price fluctuations only[162]. Previously, there was an approved tariff adjustment but was never implemented due to political intervention.

5.2.9 International Development Partners

Asian Development Bank, World Bank, International Finance Corporation (IFC), European Union (EU) and the New Zealand government are among the main cooperation partners supporting the energy sector development in PNG.

(1) The World Bank Group

The World Bank's Energy Sector Development Project for PNG focuses on strengthening policy development and strategic framework for renewable energy and rural electrification and attracting investors for sustainable development of new hydropower generation capacity to supply the Port Moresby electricity grid. Amongst the projects, the World Bank provided technical assistance for preparation and planning for Port Moresby hydropower supply and supported the development of the PNG National Electrification Roll Out Plan (NEROP).

Working with the Department of Petroleum and Energy (Energy Division) and PNG Power Ltd, World Bank's Energy Sector Management Assistance Program (ESMAP) conducted Renewable Energy Resources Mapping in PNG, and GIS layers for the key solar and wind mapping outputs were produced. IFC and PPL have worked together to provide reliable power to remote centres that are not connected by the PPL's two main electricity grids, and identified ways to increase power generation through renewable energy resources.[163]

(2) ADB

ADB supported the development of the renewable application modules and provided technical assistances looking into gas-based power generation, power system planning, Port Moresby grid development, township electrification, institutional development of the power sector, review of electricity tariffs and policy of power sector policy development, and hydropower development including specific hydropower project site assessments and the Ramu-Port Moresby transmission interconnection. ADB processed loans supporting the construction of hydropower plants, including Divune and Upper Warangoi, and reinforcing the Ramu grid. ADB also supported the distribution grid extension for community development in rural areas, and assisted in the preparation of the PNG distribution network development plan.

(3) UNDP

The UN system's efforts have been mostly directed to environment and climate change, working with the government institutions, development partners and civil society. In PNG, the UN programs have three priority focus areas: institutional capacity building for sustainable natural resource management and biodiversity conservation; promotion of low carbon growth and climate-resilient development; and sustainable livelihoods and community empowerment for environmental governance.

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[161] PPL.2020. Electricity Tariff. http://www.pngpower.com.pg/electricity-tariffs, access on 7 October 2020.
[162] PPL. Clause 3.2(a)(i) of the Contract on Tariff Formulation.
[163] https://emtv.com.pg/png-power-signs-agreement-with-ifc/

UNDP's Facilitating Renewable Energy and Energy Efficiency Applications for Greenhouse Gas Emission Reduction (FREAGER) project demonstrates the use of community mini-grids, using hydro and solar resources for electricity generation to improve livelihoods in rural areas.[164]

(4) New Zealand Government

The New Zealand Government has been actively supporting energy sector development in PNG, aiming at expanding access to affordable, reliable, and clean energy. The New Zealand Government provides aids and technical assistance improving access to electricity from clean and renewable sources. These include Ramu 2 hydro project, supporting energy access in rural areas by extending the distribution network, and supporting pilot renewable generation and standalone mini-grid projects. The New Zealand Government assisted in geothermal policy development to the PNG government.

(5) Chinese Government

The Chinese government has increased its participation in energy sector development in PNG. Through a loan agreement between the PNG government and the Exim Bank of China, a 132kV transmission project, including 189 km transmission lines and four substations from Mount Hagen to Tari in Hela Province, was commissioned in July 2018.[165] With the completion of the project, independent power producers are able to connect to the existing Ramu grid. Chinese loans and companies have also been involved in generation projects, such as the 50 MW Edevu Hydropower plant to enhance the capacity of power supply to Port Moresby.

(6) PNG Electrification Partnership

In November 2018, PNG invited Australia, Japan, New Zealand and the United States to work together to support its enhanced connectivity, achieving its domestic electrification goal. The PNG Electrification Partnership is intended to focus on the importance of principles-based, sustainable infrastructure development that is transparent, non-discriminatory, environmentally responsible, promotes fair and open competition, and meets PNG's needs. It intended to adopt a strong focus on investments that provide employment and training opportunities for local contractors and communities.[166]

The planned investment is in new generation capacity and transmission and distribution lines to connect households, service providers and businesses to the grid. The focused areas also include improving institutional and regulatory frameworks of the power sector.

5.2.10 Options for Energy Access in Rural Areas

5.2.10.1Renewable Energy Resources

Cost reduction of renewable energy offers a great opportunity to raise energy access and bring electricity to more rural and remote communities. Table 5.49 shows PNG's advantage of abundant renewable energy resources, including hydro, solar and biomass. Renewable-based off-grid options offer the economy a solution for increased electrification in rural areas and could support value chains in the agriculture and fishery sectors.

[164] https://www.pg.undp.org/content/papua_new_guinea/en/home/presscenter/pressreleases/2020/promoting-renewable-energy-in-papua-new-guinea-.html
[165] Chinese Embassy in PNG 2018. http://pg.china-embassy.org/chn/xwdt/t1566991.htm
[166] https://www.pm.gov.au/media/papua-new-guinea-electrification-partnership

Table 5.49 Renewable Energy Resources in Papua New Guinea

Renewable Energy Resource	Resource Information and Development Status
Hydropower	PNG has abundant hydropower resources, including micro-hydropower systems that are ideal for rural areas. There is a scarcity of data in terms of hydrological surveys in most places to help calculate regional hydropower potentials, as well as location and technical characteristics of hydropower plants. Hence, there is a shortage of comprehensive and precise hydropower potential related information and statistics.
Solar power	PNG has abundant solar energy resources and receives a lot of sunlight throughout the year, making it viable for businesses and households to use solar energy. As part of a World Bank-funded initiative, ESMAP has completed renewable energy resources survey and assessment in PNG and made GIS maps of major solar resources available to the public. The PNG University of Technology and other indigenous research institutions have established and maintained solar energy resources databases.
Wind power	Wind resources in PNG are usually not as good as in certain other economies in the region. The ESMAP project has designed wind resources, including key layered online GIS wind maps. These can be obtained from the Global Wind Atlas website. The renewable energy resource assessment results made by the Technical University of Papua New Guinea focus primarily on solar energy but also provides technical resources information for hydro and wind energy assessment.
Geothermal power	PNG has yet to conduct a comprehensive and systematic geothermal evaluation, although surveys indicate that the north coast of New Britain, where at least seven geothermal sites exist, is the most promising area. Lihir in northern New Ireland has commercially exploited geothermal resource, which includes a 70MW geothermal power plant being in operation to supply electricity for the gold mining company.

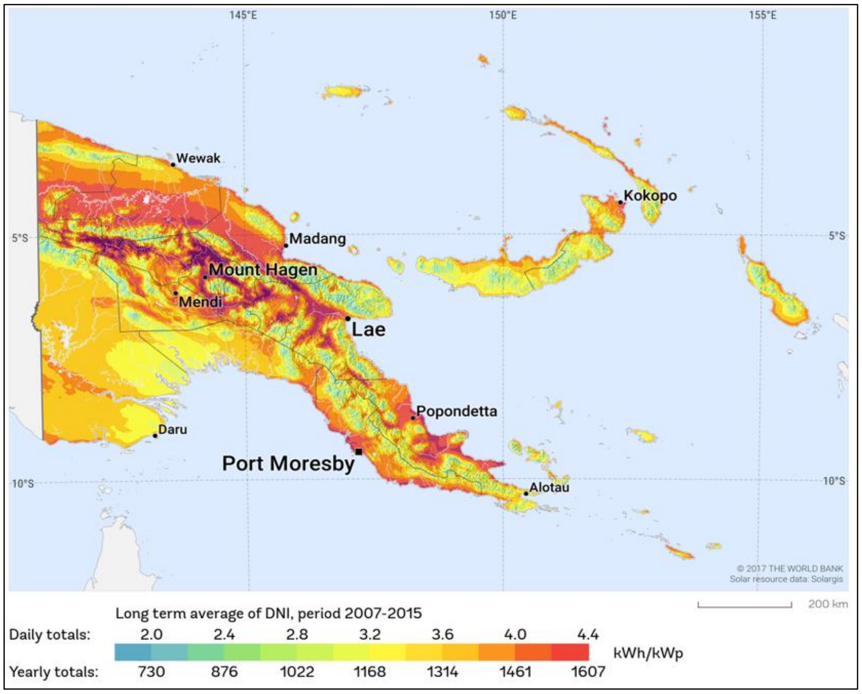
PNG is endowed with good hydropower potential[167], which also includes micro-and mini-hydro resources suitable for rural communities, with the large exploitable potential. However, it seems that there is limited hydrological survey data in the region to identify regional hydropower potential and project sites to harness the hydropower resources. Due to limited hydrological surveys, only approximate information on hydroelectric potential is available.

Solar energy is among the largest potential renewable energy sources across PNG. With a large proportion of sunshine days over the year, there is a great potential to harness solar resources to supply electricity for businesses and households. Average solar radiation reaches 3.59 kWh/kW, while the maximum reaches 4.33 kWh/kW as shown in Figure 5.53. As a World Bank-funded project, ESMAP has completed renewable energy mapping in PNG and has made GIS layers for the key solar mapping outputs available to the public. The maps and resources data can be downloaded from the site of Global Solar Atlas[168]. It is noted that domestic research institutions such as PNG University of Technology have also maintained a solar energy-related database.

Wind resources in PNG, in general not as good as these in some other economies. The ESMAP project has also mapped wind resources in PNG, which has made GIS layers for the key wind mapping outputs available online, and the relevant maps and posters can be downloaded from the site of Global Wind Atlas as well[169]. Locally, the PNG University of Technology has conducted renewable energy resources assessment, with a primary focus on solar resources, and technical resources for hydropower and wind energy assessment.

As indicated before, no systematic geothermal energy assessment has been carried out, but reconnaissance studies suggest that the most promising area is the northern coast of New Britain where there are at least seven geothermal sites for development. The only commercial geothermal development in PNG has been at Lihir, north of New Ireland, where there are up to 70 MW of capacity installed.

[167] IRENA. 2013. Pacific Lighthouses – Renewable Energy Opportunities and Challenges in the Pacific Islands Region: PNG.
[168] https://globalsolaratlas.info
[169] https://globalwindatlas.info

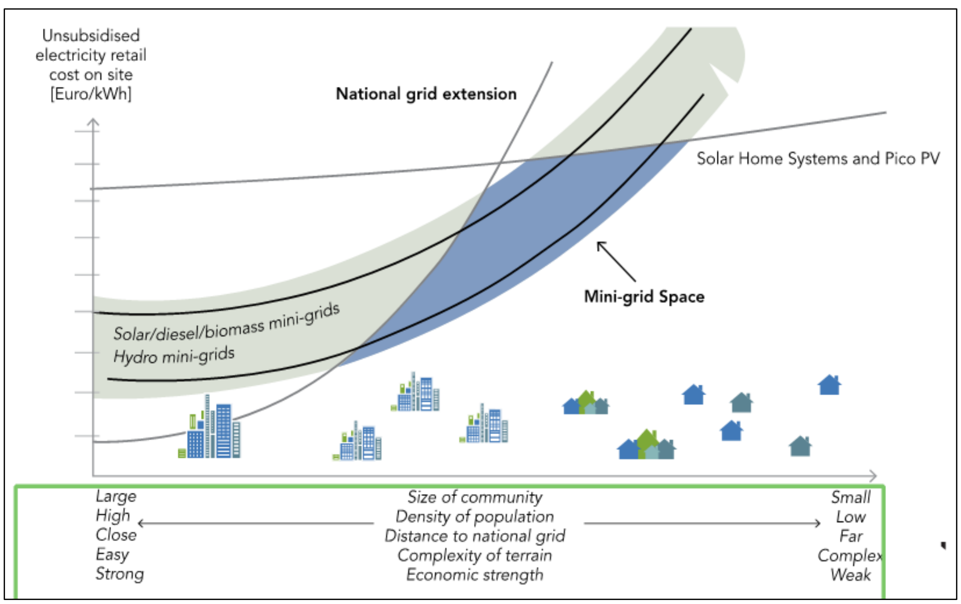


Source: https://globalsolaratlas.info

Figure 5.53 Solar Photovoltaic Power Potential in PNG

5.2.10.2Technology for Power Supply

Figure 5.54 shows application of distribution network extension, microgrid power supply, and home solar systems as the least cost technology options for increasing energy access in different situations.



Source: EUEI PDF, REN21

Figure 5.54 Technical Options for Rural Electrification

(1) Power from the grid

The experience in different economies, in the APEC region and beyond, have shown that traditional grid supply will be the predominant approach for supplying electricity to urban households. However, the costs of grid extension are usually higher for smaller customers in rural and remote areas. This is largely because (i) the relative weaker commitment of utilities to provide electricity access to rural customers; (ii) inadequate electrification planning for rural areas; (iii) high investment cost for providing electricity connection due to overrated technical specifications compared to the lower load level; (iv) inefficient procurement practices for rural electrification project in developing economies; (v) low population density which is related to the load level; and (vi) lack of financing options to make gird connection charges affordable for low income customers in rural areas. In addition, some exacerbating matters are various fees for inspection and application procedures, government taxes, mandatory security deposits, and connection charges. High upfront investment requires anticipated load growth to be materialized, or else there will be inadequate revenues to cover the capital costs.

The main challenges to expanding grid-based electrification and increase electricity access, therefore, are the lack of sufficient generation capacity, poor transmission and distribution infrastructure, the high cost of supply to rural and remote areas, the inability of low-income households to pay high connection charges, and the weak financial state of the utilities. In PNG, PPL's approach has been primarily focused on centralised generation capability expansion and transmission and distribution networks. With the findings of about US$1.7 billion from the PNG Electrification Partnership (PNG EP), PPL has now been working more progressively and on the detailed programs to achieve the electrification goal. The effective measures need to be in place to overcome the relevant challenges.

An integrated approach is expected to be taken for rural electrification and more electricity from the grid. With the domestic renewable energy policy under the development, expected policies to encourage more private sector's investment in power generation, and possible adjustment of the regulatory framework for the power sector in PNG.

Technically, as mentioned above, PNG has abundant solar resources, the resources across the region have been mapped, and data are now available to the public. Solar PV is among the options to hybridize the power generation at the existing PPL power centres to lower power generation cost. With the needed investigation and feasibility study, hydropower resources in the region also offer alternative sources for power supply supporting the network development and achieved regional electrification goal through gird expansion. The medium and/or large hydro project development could potentially offer the option to change the landscape of power supply and network in the economy.

(2) Off-grid option

The current domestic energy development strategies, including many international development partners' efforts, have been focused on network extension, connecting the customers to the grid. Inter-connecting of the existing grids has been among the primary focuses of PPL. A substantial barrier to household electricity access through distribution grid extension is the connection cost. It has been assessed that extending the distribution grid in the rural areas in PNG is not cost-effective, which is among the reasons that PPL sets the target of 70% grid coverage of the economy and the rest for off-grid solutions.

Off-grid solutions, such as solar home systems and mini-grid, provide the alternative for power distribution network extension as the first option to bring electricity to the rural and remote population. As off-grid solutions reduce cost, improve efficiency and reliability, the areas for which grid extensions make sense decreases, and people in outside urban areas would be better served by off-grid solutions. The use of renewable energy resources such as solar, micro-hydro, biomass could make real improvements in cost reduction and reliability for electricity supply, and at the same time reduce energy related carbon and pollutant emissions and provide energy services for rural households and local communities.

Solar PV mini-grids can also support income-generating uses of electricity, whereas solar home systems (SHSs) are mostly too small in capacity to support such applications. Solar PV mini-grid is a good solution for rural communities that lack access to the grid, as well as for coastal provinces with good solar resources. Furthermore, with the ongoing drops in the prices of solar PV cells and lithium-ion batteries, solar PV mini-grid systems in PNG could potentially save much money over time compared to the diesel generators that are now widely used. PNG does not have the experience to date with solar PV mini-grids or large grid-connected solar PV project. There are some relevant academic research activities conducted at The PNG University of Technology and NARI.

In PNG, micro- and mini-hydropower have the potential to provide power at a much lower cost over time than diesel generators, with no ongoing fuel expenses. Moreover, because the land issues and planning issues of micro and mini-hydro are much less complicated than those of large hydropower projects, they have the potential to be realised faster than the large hydro projects. At the moment, there are a very limited number of micro and mini-hydro projects in PNG.

(3) Mini-grid

Mini-grids have been emerging as one of key players for cost-effective and reliable electrification of rural and remote areas in many economies. Mini-grid has the unique advantage of flexibility and scale and, as such, can provide electricity to rural areas, likely at a cost close to that of grid electricity. Hybridization of mini-grid is increasingly popular, especially in the areas that have been powering the existing mini-grid with diesel. Moreover, improvements in energy storage system and cost reduction enable the use of renewables and decrease the share of diesel for power generation, which would mainly supply evening peaks. Furthermore, mini-grid can also contribute to the socio-economic development in the rural community. Besides providing basic energy services, such as lighting, basic appliances, and mobile phone charging, they can fuel productive and income generating activities such as pumping, milling, and processing.

It has been observed that in many circumstances, however, the tariff for electricity from mini-grids are higher than grid-based tariffs, particularly when the positive externality of alternative technologies are not accounted in the existing tariff scheme. The situation may limit the willingness-to-pay of households, therefore appropriate policy support and necessary subsidy to the mini-grid might be required.[170]

Besides technical configurations and feasibility, suitable business model of the micro- or mini-grid project need to be thoroughly investigated and properly structured in terms of operation, maintenance, and management in order to make the mini-grid project both technically and financially variable, so sustainable rollouts. High upfront investment requires anticipated load growth to be materialized, and promotion of productive usage of electricity, or else there will be inadequate revenues to cover the investment cost. In addition, other government support for mini-grid and off-grid electricity will be required, which include:

- A comprehensive policy and regulatory framework toward electrification;
- Provision of access to medium- and long-term finance;
- Effective institutions to facilitate the expansion of new forms of energy supply;

[170] PWC Global Power & Utilities. 2016. Electricity beyond the grid: Accelerating access to sustainable power for all. https://www.pwc. com/gx/en/energy-utilities-mining/pdf/electricity-beyond-grid.pdf

- Where needed, financial support either to households so that they can afford access or to productive usage of electricity to reduce the high initial cost of developing a new business model when delivering energy to previously unserved customers.[171]

(4) Community off-grid power supply and household solar system

Couple of technical options are available and feasible for small communities and household electricity supply.

- **Community off-grid power system:** it includes electricity supply for community usage such as health centres and churches and market. The system can provide power for indoor lighting, phone charging, fan cooling, refrigerator, TV, radio, and small water pumps. They can be used for rural and settlement housing, as well as rural schools, community centres, aid posts, and likely also agricultural centres in the rural areas.
- **Household solar system:** the solar home system (SHS) includes DC solar home systems, 12V, range from 3 W to 20W. The system could provide lighting & mobile phone charging for home users in rural areas. LED light bulbs provide light for rooms. USB output is used to charge mobile phones. The AC (220V) solar home systems have a capacity from 300W~1000W or higher. They consist of solar panel arrays, solar charge controller, battery and inverter. The systems can provide power for indoor lighting, phone charging, fan cooling, small refrigerator, TV, radio, and small water pumps.

Reliable clean water supply has been an issue in most rural areas. Much of the time has been spent by women fetching water for household needs. With the aid of solar-powered pumps, women can be freed for more productive activities and others. The discussions with solar industry stakeholders, including PNG Solar Energy Association (SEA), services and equipment suppliers, and private sector project developers, such as Origin Energy, showed that PNG has gradually developed experience with low voltage DC solar home systems, which could be used at a single household or building, and mostly also in the form of Plug-and-Play.

5.2.11 Achieving National Electrification Target

The discussions with the main stakeholders revealed that many reasons caused slow progress of electrification in PNG, and a range of constraints and barriers need to be alleviated and/or removed for the economy to pick up the pace of bringing electricity to most of its population, particularly these in the rural areas that power grids could not reach in medium terms or likely will never reach. Providing of affordable electricity to the broad community is PNG's domestic electrification goal. Determining what is affordable for electricity supply is a complex calculation, typically involving the interrelated dimensions: (i) affordability by consumers for connection fees and consumption costs; (ii) affordability by electricity service providers for operational and financial viability; and (iii) fiscal affordability of subsidies needed for sustainable supply and expansion of electricity access by the local and domestic government. The relevant factors are illustrated in Figure 5.55.

[171] Nygaard I. and T. Dafrallah. 2016. "Utility led rural electrification in Morocco: combining grid extension, mini-grids, and solar home systems." Wiley Interdisciplinary Reviews (WIREs) Energy and Environment 5(2): 155–168.

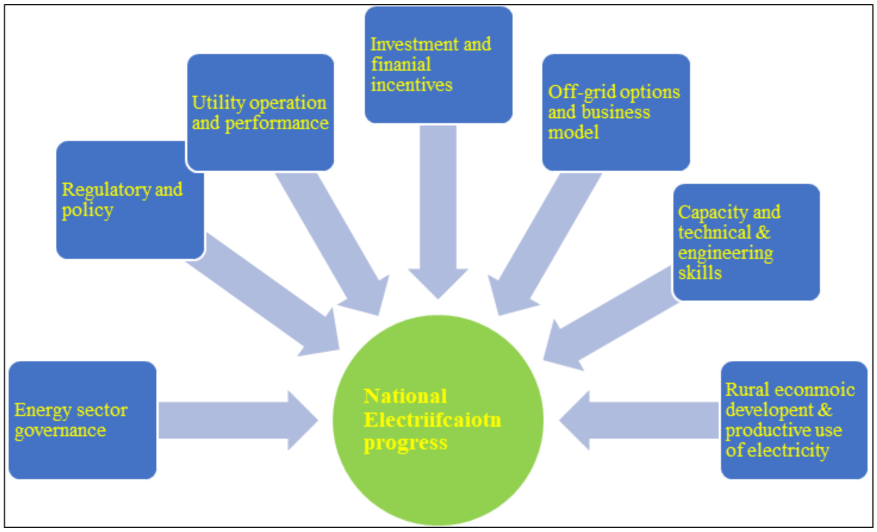


Figure 5.55 Factors Affecting the Progress of National Electrification

Key factors affecting the progress of National Electrification goal are listed in Table 5.50, and the approach to address the issues are discussed below. International best practices for successful grid-based implementation include sustained government commitment, dedicated institutions, and predictable financing mechanisms, realistic measures to ensure affordability and sustainability, and the electrification programs that fit into a broader vision of social and economic transformation.

Table 5.50 Factors Affecting the Progress of National Electrification

Dimension	Main challenges affecting the progress of electrification goal in PNG
Geographic, social, and economic condition	• Difficult terrain and sparse allocated rural population; • Lack of productive use of electricity; • The inability of low-income households to pay high connection charges.
Regulatory framework and governance of the power sector	• Weak sectorial level coordination and planning; • The economy's energy sector was developed through various Acts of Parliament, but its development was not coordinated properly for a period of 43 years since attainment of political Independence in 1975[172]; • Lack of effective governing body for the energy sector.
Utility operation and performance	• Poor transmission and distribution infrastructure; • Weak financial management capacity of PPL; • Weak operational capacity of PPL; • Obsolete system monitoring and network planning capacity; • Inadequate maintenance of current assets; • High network losses and poor reliability of power supply; • High costs of supply to rural and remote areas.
Investment environment	• Expensive diesel generation create a disincentive to expand distribution in rural areas; • Insufficient investments in power sector infrastructure.
Off-grid development	• Limited knowledge about off-grid renewable energy products among entrepreneurs and financial institutions; • Limited awareness about off-grid renewable energy solutions among communities; • Few private sector actors are working in off-grid areas.
Rural development plan	• Lack of rural energy development plan.
Capacity and skills	• Lack of sufficient renewable energy know-how; • Lack of technical and engineering expertise for power projects.

[172] Basil, S. H. (2018), March PNG Energy Policy, Port Moresby, Papua New Guinea.

The key hurdle appears to be creating an enabling environment for an energy access rollout, and how clean energy fits into the picture of domestic development plans, and how emerging and innovative service delivery models can accelerate progress on meeting the energy targets.

(1) Effectively policy and regulatory framework

Emphasis on appropriate policy measures is an essential requirement for continued innovation and scale-up, enabling a clear framework for regulation and legislation that facilitates the providers of effective and sustainable delivery models. Lack of policy will create uncertainty and risk that deter private investors.

In order to assist rural areas development, where the costs of providing electricity services are greater than in urban areas, the government could subsidize the difference between the actual costs and the charges allowed by the domestic tariff as a Community Service Obligation (CSO)[173]. CSO needs to be reviewed and updated to ensure its effectiveness.

Feed-in tariffs have been established in PNG but have not been implemented. There are no power purchase agreements (PPA) rules. PPAs of power generation projects have been negotiated on a case-by-case basis. The implementation of related regulations, however, needed to be reinforced for the project development.

As discussed, currently, there is a prohibition on power generation project by anyone other than PPL within 10 km of PPL power lines. Although self-generation is permitted, the generators must be owned by the facility owner. This acts as a disincentive for captive power projects, including captive power projects that are often owned by third parties who sell the electricity to the facility. Review and updating relevant regulatory frameworks are necessary.

(2) Functional and effective institutional set-up

Historically, PNG lacks an effective institution to oversight and coordinate relevant energy policies and plans. The establishment of an energy authority is a work in progress with the draft bill to be presented to the National Executive Council (NEC) to create a dedicated energy entity solely responsible for the development and implementation of National Energy Policy.[174]

The National Energy Authority (NEA) is the main government vehicle to coordinate in partnership with PNG Power Ltd (PPL) to expedite the harmonisation process for the application of relevant regulations to all government activities in electrification. It is expected that this process will facilitate the environment for accelerated use of renewable energy resources in the economy to generate electricity, with the medium-term objective of reducing electricity tariff.

(3) Policy support for renewable energy development

Calls for renewable energy innovations have been made to advance sustainable development to meet the ever-increasing demand for locally sourced energy. To achieve this, there is the need to diffuse modern renewable energy policy innovations, especially in developing economies where there are acute energy challenges.

Some significant improvements in the renewable energy sector, which are largely driven by policy support, include innovations in financing, falling prices and the use of renewables to advance technological developments. Therefore, the current paradigm of renewable energy research needs to be focused on the importance and contribution of renewable energy innovations to the development of green economies and their minimal impact on climate change.

[173] Community service obligations (CSOs) typically focus on either delivering core services to remote populations or providing services at a reduced cost to selected customer groups.
[174] https://www.thenational.com.pg/bill-to-establish-energy-authority-in-progress-kua/

The Renewable Energy Policy (REP) in PNG is based on the relevant work programs encapsulated in the PNG Vision 2050 Statement. The statement addresses possible sectoral and sub-programs to drive renewable energy development in PNG for all available renewable energy resources. The REP presents the approach to accelerate the development and utilisation of the renewable energy resources. The sectoral sub-programmes for each of the renewable energy resources, including an overview of the sub-sector, the roadmap and the relevant action plans addressing specific needs of the said sub-sector, have been developed to serve as guidelines to achieve the PNG Vision 2050 statement. Relevant development framework includes drafting of the Renewable Energy Law. In support of policy development, UNDP in PNG embarked on a project funded by GEF and with the Climate Change Development Authority (CCDA) as the executing agency. Further related efforts are necessary.

(4) Effectively power system planning

Power system planning will have to account for spill over effects. Clear grid expansion plans would be in parallel with suppliers of alternative off-grid options in order to effectively integrate the roles of the grid and off-grid solutions. International experience has shown that provisions and processes are also necessary for the circumstances where the domestic grid is extended to areas that have previously been provided with off-grid connections. Some of the key areas, in order to support effective system development planning, include:

- Demand forecasting, based on sound data, to aid investment decisions for grid extension;
- Analysis of the drivers of economic growth to inform energy demand forecasting;
- Development of least-cost investment plans for both generation and transmission;
- System planning capacity building and use of appropriate system planning tools.

(5) Formulation of rural energy development plan

Rural areas in PNG have been largely left behind in terms of electrification development. Without electricity access, rural communities and citizens suffer from lower levels of education due to a lack of quality, after-dark light, and lower levels of health service provision as medical supplies and medication cannot be refrigerated. Furthermore, agricultural productivity is also compromised given the traditional (versus electric) irrigation methods that must be used.[175] Currently, there lack of rural energy development plan in PNG. The need for support, however, is particularly high for rural electrification as it appears less attractive for the private sector investment than the domestic grid expansion projects at key PPL centers.

The current rural electrification projects are mainly funded by Members of the Parliament and largely involve the grid extension from the existing distribution network. There is a strong need for The Rural Electrification Policy (REP). The policy should provide specific requirements and initiatives to promote the use of renewable energy resources in rural areas and for agricultural value chains.

(6) Facilitating investment in electrification project

Progress towards PNG’s electrification objectives will require large-scale investment by both the public and private sectors. This includes investment in new generation capacity as well as transmission and distribution lines to connect households, service providers and businesses to the grid.

Under the National Electrification Roll-out Plan (NEROP), an estimated investment of some $1.4-1.7 billion could be required. The PNG Development Strategic Plan (PNGDSP) for the period to 2030 estimates that peak demand for electricity will increase to 1400 MW by 2030. The plan also targets making investments to upgrade and rehabilitate existing grid systems and reduce non-

[175] Duncan, Samantha. 2011. Papua New Guinea Energy Strategic Review.

technical losses in the system and aims to increase generation from hydropower and gas-based generation and phase out diesel power generation.

Meeting future needs of power access in PNG boils down to budgetary and fiscal realities. The typical utility-based, centralized approach to grid extension involves significant upfront investment in infrastructure to deliver the power required by customers, whose level of consumption will provide a payback for the utility over an acceptable timeframe. But the connection costs to remote areas, which demand less electricity, are much higher. Typically, these customers cannot afford high upfront costs, so payback can only be achieved over an extended period or is simply not feasible. Thus, innovative delivery mechanisms are required for sustainable electricity supply to remote areas.

It is critically important for the private sector to finance interventions, while incentives are needed to be in place for investors to earn returns on their investments. The need to balance return-on-investment with customer affordability has been increasingly recognized by emerging energy service delivery mechanisms. On the other hand, public sector support is necessary to offset upfront private investment costs in capital-intensive renewable energy project and to attract the private finance required for increased access to modern energy services. Continued efforts to improve institutional and regulatory frameworks are required in order to unlock private investment.

(7) Development of rural renewable energy application module

Besides the “plug-and-play” type of home solar kits, the renewable energy system module for agricultural and rural communities should be developed. These need to consider a resource, geographic location, population, and nature of energy use of the systems. The modules include household solar system, community solar energy system, and micro- or mini-grid. Household solar kits/systems are currently available in many townships in PNG, while the distribution of the products can be extended to the region. Feasibility studies can be organised on technical configurations and cost assessment of the modules, particularly community solar energy systems and micro- or mini-grid. Module developed in the area could be overlayed with the plan for local agricultural and fishery sector development and with projected demographic changes, so to generate an outline for the deployment of renewable energy system applications.

Until more recently, most off-grid electricity systems support has been based on funding allocations from public programs, but this approach is not sustainable. It is required that, increasingly, off-grid energy solutions need to be delated strategically with a set of factors that are opening space for business, notably, (i) thinking broader than energy; (ii) seeking a mix of public and private finance; (iii) combining investment with assistance; (iv) dealing with affordability issues in the context; (v) engaging with consumers, and (vi) providing after-sales service.

A range of international development organizations have been active in facilitating the establishment of suitable delivery modules. For example, the SHSs can be made affordable to households through a combination of consumer credit and decreasing subsidies. Mini-grids can supply grid-quality power to communities quickly. However, they must address challenges, including high upfront investment, regulatory uncertainties, tariff differential issues, the likely stranded assets problem, management and operations capabilities of the project, supply and demand mismatch, and the need for productive loads. As discussed, for the private sector to play an increasing role in financing mini-grid projects, there must be right incentives in place to allow investors to make returns on their investment.

(8) Ensure sustainability of rural electrification project

Experience in many other economies has shown that the off-grid solutions will not be sustained if relying purely on funds from international aids or development agencies. The innovative and tailor-made business model for each region is essential to ensure project effectiveness and sustainability.

Besides financial sustainability, and participation and involvement of community members in the project development and operation are important factors for a successful rural electrification program. There is a strong need to promote community participation and ownership of rual energy projects. As part of an integrated approach for rural electrification, the considerations need to give on the ability to scale up energy access beyond the project's life.

In this regard, public financing mechanisms could leverage private sector investment, overcome the challenges of lacking private financial instruments, facilitate high-capacity deployment, and mitigate related risks. These models include micro-credit and fee-for-service. Innovative business models, such as the pay-as-you-go (PAYG) model or the one-stop-shop model, have now been emerging as among the successful models leading off-grid energy access development.

(9) Support productive use of energy

Productive use of electricity services in rural areas, defined as agricultural and commercial, and industrial processing activities that require electricity services as direct inputs to the production of goods or provision of services.

It has been suggested that a proactive approach to facilitate the expansion of productive use of electricity include: (i) identification of the productive activities taking place in an energy project area and likely supporting activities; (ii) assessment of the potential contribution of electricity in the identified activities and sectors; (iii) technical and economic feasibility and the social viability studies of the identified activities; and (iv) a targeted promotional campaign to potential users about the gains from the use of electricity for a new production process involving various stakeholders (such as electricity service providers, equipment manufacturers, financial institutions, relevant local government institutions and community organizations). With access to modern energy, electricity can be provided for agricultural production for heating and cooling, mechanical power, lighting in a possibly cleaner and affordable manner along the value chain of agricultural sector, from production to post-harvest and storage, from transportation and distribution to handling and processing.

A range of off-grid renewable energy technologies can be used in agriculture value chains, including solar PV, solar thermal collectors for heating, small hydropower, and small wind power for mechanical power and/or for electricity generation. In addition, biogas with electricity and biomass gasifiers for heating and electricity are also among the solutions.[176]

In general, in PNG, there is a need to improve technical and management capability throughout the value chain of the energy sector, including application of these technologies, formulation relevant plan, and development of implementation program. The inadequate or lack of technical knowledge and skills need to be effectively addressed. Relevant trainings programs can be organised at different levels targeting different groups such as for provincial and district government officials on policies, implementation, and program management, for technicians on design and installation and maintenance of the systems, and end users/customers for usage.

(10) Technical assistance and capability building

It has been approved that the power network is among the centre for domestic electrification development. PPL's poor technical and financial performance and weak governance prevent them from effectively implementing related grid development and reinforcement and rural electrification programs. This also prevents them from providing adequate, reliable, and affordable electricity services to their customers and expanding electricity services to peri-urban and rural areas. Supports are needed to address improve the situation.

[176] IRENA. 2016. Renewable Energy Benefits: Decentralized Solutions in the Agro-food Chain.

Currently, there is insufficient information on hydro potential in PNG, including mini- or micro hydro power penitential which can provide power to rural communities. Necessary field investigations are needed to map the hydro potential across the economy and build up relevant databases to facilitate the exploitation of hydropower resources.

There is a lack of technical experience and engineering capability at local levels, which is the situation for both the provincial and the local government, as well as PPL. There is a small number of vendors selling basic solar PV products in provincial capital cities, and there are few in other town centres. For the products sold, the venders do not provide warrants. There are some private household solar PV installations in the towns but few renewable energy applications in the agriculture and fishery sectors in the region.[177] There is a need for technical assistance and training for technicians and relevant government officials, retailers and dealers.

Across the region in PNG, the solar business generally is still relatively new. Industry technical standards and an effective compliance procedure to certify the components of renewable energy systems in the market are needed. Technical standards appropriate for rural areas should be developed and enforced right from the start of the domestic electrification program.

The distribution network for components and relevant services of solar systems are needed. Necessary supports are needed to broad the distribution channel and business of renewable energy equipment and products in rural areas. The inadequate knowledge and skills have been among the leading causes of customer dissatisfaction and off-grid system failures. Relevant technical skills need to be improved through organised training programs and capacity-building initiatives, which include system maintenance.

5.2.12 Summary

Three main principles, that largely contributed to the rapid rural electrification progress, include a clear vision and a continuing political commitment to follow the plan; an institutional framework leveraging the strength of the utility and including domestic and international stakeholders; effective financing model that includes all stakeholders, namely international financial institutions.[178]

PNG is among the lowest in terms of rural electricity access, while outdated transmission and distribution infrastructures lead to frequent outages in urban centres. Providing reliable electricity accessible to a broad population can drive social and economic development and improve people's quality of living. In PNG, the low electrification coverage reflects a combination of high network cost due to the dispersion of the population and geographic characteristic, as well as low capacity to pay for most of the population.

As PNG's economy and population continue to grow, the government is collaborating with development partners and the private sector to scale up electrification rates and improve electricity services. A holistic approach is required to address the issues, which covers government policy, regulatory framework, fiscal measures, institutional setting and operations, the performance of power utilities, mobilising private sector actors, local communities' participation, and support of rural productive use of energy. Technically, the top-down approach of grid extension connecting more customers to the power network which is based mostly on large-sized centralised generation capacity, while at the same time, the bottom-up approach of off-grid solutions based on distributed renewable energy resources should be explored to accelerate the pace of rural electrification. Off-grid energy solutions include solar home systems (SHS) and larger solar PV installations, micro-

[177] During the field mission it was mentioned that some activities in the region provide solar off-grid lighting to households. https://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/cm-stories/papua-new-guinea-300-days-of-sunshine.

[178] Nygaard I. and T. Dafrallah. 2016. "Utility led rural electrification in Morocco: combining grid extension, mini-grids, and solar home systems." Wiley Interdisciplinary Reviews (WIREs) Energy and Environment 5(2): 155–168.

hydro plants, and solar pumps, which may provide power to meet rural household needs, as well as the delivery of electricity to productive or commercial activities such as agricultural produces processing, refrigeration, and commercial enterprises. Micro- and mini-grid can be deployed, with necessary energy storage capacity, to supply reliable and affordable electricity to a large number of the villagers and local communities.

PNG could draw from successful experiences on rural electrification in other APEC economies and these in other region, take necessary systematic approach for the governments, international development partners, the private sector, civil society organizations, and practitioners, working togethering, develop necessary and implement programs, and act up them to narrow the electricity access gap.

5.3 Peru

Electrification in Peru has progressed steadily in terms of the domestic population with electricity access, starting at a relatively low level of less than 70% in 1992, the population with electricity access reached 95% in 2018. Thanks for the continuous efforts by the domestic government, with the supports from various international development agencies, NGOs, the private sector and local communities. Electricity access in the rural areas has also been raised impressively from as low as 2% in 1992 to about 82% in 2018.[179]

Rural electrification in Peru has made progress particularly since the early 2000s. Recognizing the pressing needs to improving rural electrification in the economy, General Directorate of Rural Electrification of the Ministry of Energy and Mines (DGER - MINEM) made efforts to achieve universal access in terms of rural electricity coverage in accordance with the National Rural Electrification Plan. Still, the electricity access or electrification rate at an urban level shows a disproportional high with respect to the rural level. As shown in Figures 5.41 and 5.42, compared with other economies in the APEC region, rural electricity access still falls behind. This case study summarises the achievement made in Peru in terms of electrification progress and draws relevant experience from the local practices.

In Peru, access to energy, particularly in rural areas, is made problematical by various factors, mainly geographical, such as the distance between the various towns and villages located in the most remote and inaccessible areas, and the isolation of the population due to the absence of inadequacy of communication and transportation means. The lack of road infrastructures hindered private investment in projects connected with rural electrification. This is among the main reasons behind the government intervention.[180] The lack of access to electricity for Peru's rural population has been one of the causes of rural poverty. Combined with the shortage of other infrastructure services, lack of electricity restricts economic development and hinders improvements in living standards, contributing to a lower quality of life, poor medical care, poor education, and limited economic opportunities in the rural areas.

In 2006, the General Law of Rural Electrification (Law 28749) was enacted, which through the National Rural Electrification Plan and Cross-subsidies Policies to Electricity Rates, resulted in residential photovoltaic systems being considered Rural Electrical Services. The implementation of these policies and enforcement of the legislations supported the pace of rural electrification across the economy. Furthermore, in 2013, the 2013–2022 Universal Energy Access Plan was approved through Ministerial Resolution N °203-2013- MEM/ DM, whose objective is to close the gap of energy access by implementing projects that provide partial and total subsidy to Programmes

179 World Bank. World Bank Data.

180 EnDev Peru. Nrgising Development Project. 2018

for the Development of New Supplies in the Border, as well as for the Improvement of Rural Energy Use, which includes improved cookstoves and biodigesters.

5.3.1 Relevant Legislation and Energy Policy

Higher poverty rates in rural areas and the gap in quality of life between rural and urban areas highlight the importance of investing in basic infrastructure. The government made rural electrification a high priority, and it has sought out innovative approaches to achieving the goal. The National Government, led by the General Directorate of Rural Electrification of the Ministry of Energy and Mines (DGER-MINEM), in collaboration with regional governments (RG) and local governments (LG), has been making joint efforts to develop rural electrification projects.

(1) Regulations on Rural Electrification

Key legislations on rural electrification in Peru include:

- Law 28749 and its regulation set forth as their objective to establish the regulatory framework required for the promotion and sustainable development of electrification in rural areas in Peru;
- Regulation of Rural Electrification Law, enacted by Supreme Decree N ° 25-2007-EM contains a list of principles that govern rural electrification activities. According to those principles, rural electrification projects are qualified as being a domestic necessity and public welfare and, for their development, coordinated action among governmental institutions is required. Likewise, the importance of introducing renewable energy technology has been set forth to enhance rural electrification goals.

The measures outlined in the regulatory framework aimed to close the electrification gap in rural communities by enlarging the existent power grid and by building a distribution network that can allow rural communities to connect to a distribution company for obtaining grid electricity supply. In order to achieve such goals, the government invested in building a set of systems classified as Rural Electric Systems that include housing connections, distribution networks, transmission wires and generation plants. Once these facilities are built and developed by the government, they are transferred to the local distribution concessionaires to operate so they can deliver energy to those rural areas where such facilities have been created.

In addition, there are some provisions promoting the use of renewable energy technology for meeting rural electrification demand. According to these provisions, renewable energy projects will be encouraged in those places where it is not possible to enlarge the existent grid due to technical or economic constraints.

(2) National Energy Policy

The National Energy Policy (NEP) of Peru 2010-2040[181], establishes the domestic legal framework, with emphasis on the promotion and protection of private investment, minimizing social and environmental impacts and encouraging energy markets, as well as promoting energy efficiency and development of renewable energies at the local, regional and domestic level. NEP contains nine policy objectives, including the following objectives regarding renewable energy resources:

- **Objective 1**: To have a diversified energy matrix, with an emphasis on renewable sources and energy efficiency;
- **Objective 4**: To improve the efficiency of the use of energy and of the energy production chain;
- **Objective 6**: Develop an energy sector with minimal environmental impact and low carbon emissions within a framework of sustainable development.

[181] Política Energética Nacional del Perú 2010-2040.

MINEM's National Energy Plan 2014-2025 sets a target of 60% generation from renewable energy by 2025.[182]

5.3.2 Renewable Energy Development

(1) National Renewable Energy Plan

Although Peruvian Law mandates a National Renewable Energy Plan under Legislative Decree 1002, which was passed in 2009, a plan has yet to be published when the study was conducted. A National Renewable Energy Plan however is needed to create a long-term vision for renewables in Peru. Peru needs to set and implement long-term renewable energy targets and create mandatory goals for renewable energy integration. A long-term plan is also vital in encouraging investors supporting energy transition in Peru.

A National Renewable Energy Plan it could be used introduce greater market competition and drive renewable energy auctions in Peru, which are currently subject to fluctuations in the energy market and do not have a fixed timeline or a clear set of goals. The plan could also be applied to make technology-specific decisions within auctions. For example, a National Wind Energy Plan could be applied to integrate 5,000 MW of wind power in the next five years, with a plan to auction about 1,000 MW each year until the renewable energy goal is achieved.

(2) National Plan of Rural Electrification

One of the most important measures under the rural electrification regulatory framework was the government's obligation of approving a Rural Electrification Plan (PNER), which is a long-term policy document with a lifespan of 10 years that includes policy, objectives, strategies, methodology, list of projects and financing sources, aiming to organize in a long-term frame the development of rural electrification.

Rural Electrification National Plan (PNER) 2016-2025 issued by virtue of Ministerial Resolution N °579- 2015-MEM/DM dated as of 1 January 2016. The PNER aims to promote renewable energy for rural electrification, among its other objectives. This Plan seeks to supply electricity to towns in rural areas of Peru as means to contribute to their socio-economic development, mitigate poverty, improve their quality of life and discourage the migration from the economy to the cities. The document outlines the ways in which the goal can be achieved through the formulation of studies that allow the development of renewable energy (hydro, solar and wind) and updating of the designs of the rural electric systems, as well as giving priority to projects based on the use of renewable energy resources, and the formulation of the Renewable Energy Master Plan.

In the National Rural Electrification Plan 2016-2025, MINEM[183] states that it plans to reach its goal of 99% electrification and provide electricity to 3.3 million people in rural areas by 2025 (MINEM has since announced that it expects to reach this target by 2021).

For the period 2013-2022, the plan aims to invest USD 1280 million in rural electric systems, USD 53 million in small hydropower plants, USD 294 million in solar PV modules, and USD 42.5 in wind power plants. The plan establishes the use of renewable energy as criteria in project selection with a weight of 10% in the evaluation process of rural energy projects.

5.3.3 Approach for Rural Electrification

There are the following characteristics in rural Peru[184]:

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[182] The plan does not provide any further guidelines on the integration of renewables in Peru's energy mix.
[183] Ministry of Energy and Mines (MINEM) https://www.gob.pe/minem
[184] Mayra Viviana Aguirre Ramírez. 2016. How-to-enhance-rural-electrification-requirements-in-Peru. Centre for Energy, Petroleum and Mineral Law and Policy, University of Dundee.

- A wide geographical diversity;
- Rural populations are usually dispersed and have low energy consumption, which results in high capital costs and investments with a low investment return;
- High poverty rate among the population and relatively low payment capacity of rural populations for energy use prevents the expansion of the domestic grid to rural areas because it would be impossible to pay for the investment;
- Rural consumers usually receive a low-quality electricity service given the lack of maintenance of the existent power lines in rural areas.

From a more practical perspective and outside the regulatory framework for rural electrification, the Peruvian government has considered the following options for meeting the demand for energy in remote or isolated locations:

- The first alternative is to enlarge and expand the existing power grid;
- The second alternative is to use solar PV for domestic use in those areas that have solar potentials, such as in the highlands and the Amazon region;
- The third alternative is to use hydropower with a small installed capacity in areas with hydro power resources;
- The fourth alternative is to use wind power in those areas near the coast of Peru.

Overall, these programs, together with grid extension facilities, have led to narrowing the gap on rural electrification. Although there is a preference for enhancing rural electrification goals by connecting rural communities to power distribution network, this alternative does not cover or include isolated areas. In addition, when comparing grid extension to other options, it can be expensive. Therefore, renewable energy resources, such as solar, become better alternatives for enhancing rural electrification demand.

(1) Renewable Solution

Peru has a good potential for solar and wind resources. Peru has a great potential for developing Solar PV since the economy benefits from a high annual irradiation level that ranges from 4.5 kWh/day in the amazon region up to 6.5 kWh/day in the south region.[185] The National Rural Electrification Plan aims to supply electricity to the most isolated populations by installing plants that run on renewable energy resources (in particular, a system consisting of solar PV panels with energy storage. Rural electrification also offers an opportunity for small-scale solar PV. Peru's goal of reaching 99% electrification by 2021 involves the installation of small-scale solar PV systems for remote households without grid power access, with planned investments of $385 million by 2021.

Peru has good wind resources, and it has been proposed that, technically and economically, it is possible that electrifying entire rural communities in Peru can be made with only wind energy resources.[186] MINEM has also been looking for solutions with hydro power resources based on specific local resources potentials.

(2) Grid Connection

As mentioned, different technologies are used based on a selection of energy resources, which consider grid extension of the National Interconnected Power System and Isolated Systems as the first option, from which the Rural Electric Systems are expected to develop. Given this situation, in recent years, the General Director of Rural Electrification of the Ministry of Energy and Mines (DGER) has been implementing some projects with the use of solar photovoltaic systems and also wind power.

[185] Ministry of Energy of Mines and National Service for Meteorology. Peru's Solar Energy Atlas. Lima. 2003. p.17.
[186] WindAid Institute. https://www.windaid.org/light-up-a-life/peru-electrification-programs/

Electricity demand is not evenly distributed in Peru. Distribution within National (SEIN) is divided by region into the Central, Northern and Southern Zones. There is a strong concentration of power plants in the Central Zone as the result of greater access to hydropower and natural gas resources in the region and a high demand for energy. There are also better facilities for transmission lines in the region. The Central Zone therefore has an energy surplus, and supplies energy to Northern and Southern Zones, which experience energy deficits.

With high wind and hydro resources in the north and solar resources in the south, there is a large opportunity to develop renewables in these two regions, both on and off-grid. Developing renewable energy resources in the north and south would have significant benefits for these two regions by reducing energy dependence on the central region, avoiding congestion in transmission lines and improving regional energy security.

However, it should be noted that many of these local communities are located in remote areas, making it incredibly difficult and costly to connect them to the electricity grid.

(3) Off-grid Energy

Off-grid energy is one of the largest untapped markets in Peru, and the mining and industry sectors represent a large opportunity to implement renewable energy technologies, especially solar, wind and hydro. Many mines and industries have constructed their own hydroelectric facilities or have short-term PPAs (<5 years) with hydro and gas generators for less than $40/MWh. Some mines and manufacturing facilities also rely on power from diesel generators, which is costly, inefficient and polluting.[187]

A long-term solar, wind or hydro PPA (10-20 years) could be an attractive option for mining or industrial facilities, which have large areas of land that can be used for electricity generation. These companies are interested in reliable, cheap sources of energy, giving the electricity cost in the mining sector typically account for about 30% of total operation costs. In addition, it is reported most mining companies have been collecting detailed load, energy consumption and meteorological data for their environmental impacts and compliance requirements, and these data can be used in feasibility studies for renewable projects.

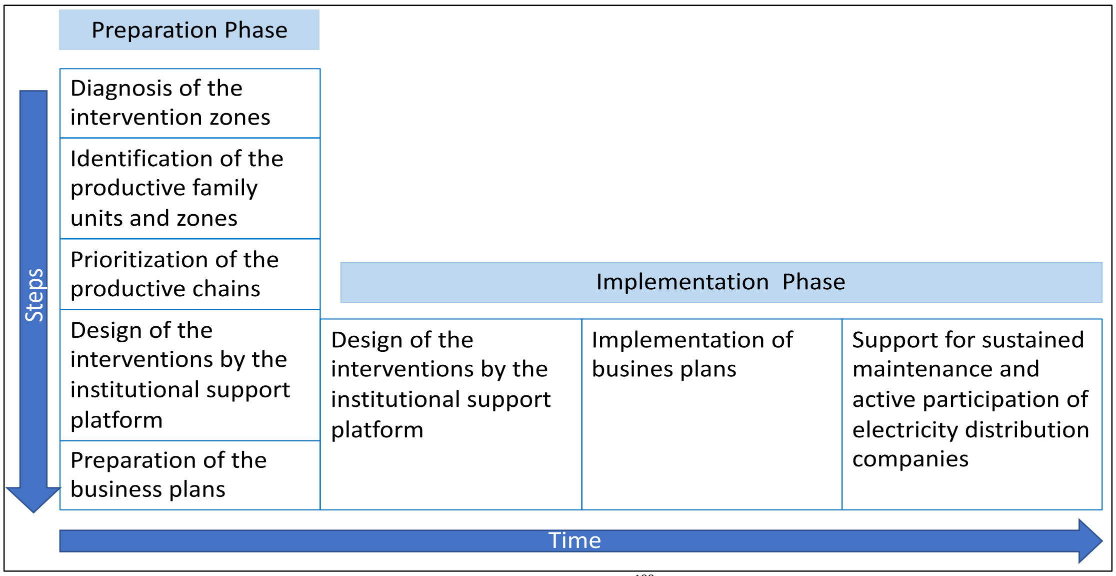
5.3.4 Promotion of Productive Use of Energy

Generating and increasing productive use of energy is one of the key drives for rural electrification. The General Directorate of Rural Electrification uses the value-chain approach to continue building up the capacity for productive uses of electricity, financed by its Rural Electrification Fund. These approaches include using solar home systems (SHS) to serve remote population and working with electricity distribution companies (EDCs) and NGOs to promote productive uses of electricity that increases electricity demand. The efforts aim to improve the viability of rural electricity systems and strengthen the development impact of rural electrification while contributing to the economic growth and increased welfare of the rural residents.

The World Bank Rural Electrification Project (REP)'s pilot program to promote productive uses of electricity covered an extensive geographic area, including semiarid coastal communities, Amazon rain forests, and Andean highlands, directly benefitting at least 100,000 people and having an estimated economic value of about $1 million at project closing. The program helped families, cooperatives, and small- and micro-enterprises to adopt electricity using equipment to process coffee, cocoa, rice, cereals, milk, baked goods, meat products, handicrafts, and other wood and metal products. Consequently, agricultural activities and produce processing expanded from increases in effective irrigation system, including water pumping.

[187] The Netherland Government. Commercial-opportunities-in-the-peruvian-energy-sector. 2018.

The Institutional Support Platform (ISP) was designed under REP to bolster and sustain the promotion of productive uses of electricity functioned mostly at the project's initial stages and mainly to spread the conceptual model. The actual promotion of productive uses of electricity was carried out as a series of area-specific activities. Figure 5.56 illustrates the overall scheme of promotional activities. The NGOs worked together with the ISP, which provided overall facilitation and coordination with other government and NGO programs in agriculture and rural development, as well as technical institutes and universities. This program design was modelled after the World Bank assisted rural electrification framework and projects in Indonesia.



Source: Adapted from Consorcio Macroconsult S. A. and Instituto Cuánto[188]

Figure 5.56 Pilot Program on Productive Uses of Electricity Intervention Scheme

The Institutional Support Platform effectively diagnosed rural energy scarcity and issues, catalysed necessary responses among financing agencies, municipalities, and EDCs. It was also effective in convoking key stakeholders, such as the concerned domestic and regional authorities, as well as universities, institutes, and NGOs that could provide training and capacity building support, including promotional events, to roll out the model of productive electricity uses.

5.3.5 Recommendation

Through efforts from the Peruvian government international organizations and other stakeholders, energy access in Peru has continued to improve over the past three decades. Not only is electricity more easily accessible for Peruvians, but it is also cheap enough to distribute adequately. By properly educating the rural population on the safe use of electricity, Peru has also better ensured a low level of electrical accidents. In this way, Peru is doing the right things to facilitate its rural communities' quicker, safe, and ethical development of its rural communities.

The experience in Peru shows that the greatest difficulty in carrying out these grid extension projects is "population dispersion". A large geographic scope and the diverse and varied geography prevent grid electrical services from reaching all rural populations. In the case of rural electrification, this results in projects having a high unit cost per household and low economic profitability, which also means that they are not attractive to private investment and require the

[188] Consorcio Macroconsult S. A. and Instituto Cuánto. 2016. "Servicio de consultoría para la evaluación socio-económica de resultados de sub-proyectores de electrificación rural." Lima, Peru: Ministerio de Energía y Minas.

active participation of the domestic and local governments. The recommendations and lessons drawn from Peru toward its rural electrification include:

- Many users expect grid connections to eventually reach their remote areas, but this will not be economically and logistically feasible for large number of population. Achieving the financial sustainability of rural off-grid electrification projects is a challenge that the governments and EDCs need to address. For example, given the remote and often isolated conditions where PV systems are installed, the EDCs need to identify low-cost maintenance measures and effective billing systems that can minimize delinquent payments. The users also need to be provided adequate training in the use and maintenance of the batteries and solar PV units;'
- To reach "the last mile" of rural electrification while ensuring sustainability, the government and the EDCs need to take specific actions. The government has incorporated the rural electrification model of mobilizing financing and the active involvement of EDCs, mainstreamed productive uses of electricity, and installed PV systems in isolated rural areas. The government may need to exercise greater flexibility on energy market structure, regular updates on the regulatory regime, more frequent revisions of the tariff sachems, and take other actions that would accommodate the rapid expansion of rural customers and their higher distribution costs. The EDCs need to ensure their continued financial contributions, provide better training of users on the maintenance of the rural electrification projects;
- Capacity building and training of qualified local technicians is needed to ensure the sustainability of the electrification program. Lack of qualified local technicians resulted in families or people from the community installing technologies without following the right procedures. They also repaired products experimentally and did not perform the corresponding maintenance. As a result, technologies did not work correctly and had a shorter lifespan would discourage their application and sustainable uses. Capacity building with the support from international development agencies could build up relevant capacity around electrification projects that were carried out. Training and communication methodologies and strategies for rural electricity users could be developed in the areas such as indoor electrical connections, residential photovoltaic systems, and productive uses of electricity;
- Continued and effective political and technical support are needed. The promotion of productive uses of electricity needs consistent and adequate levels of technical assistance and investment support, without which their sustainability would be put at risk. If the positive outcomes from promoting the productive use of electricity are to be sustained, it is important for the government to maintain political and technical support for promoting productive uses. NGOs, together with the ISP, need to continue to work directly with individual producers, and the government institutions need to revive their leadership and proactive follow-up as originally designed.

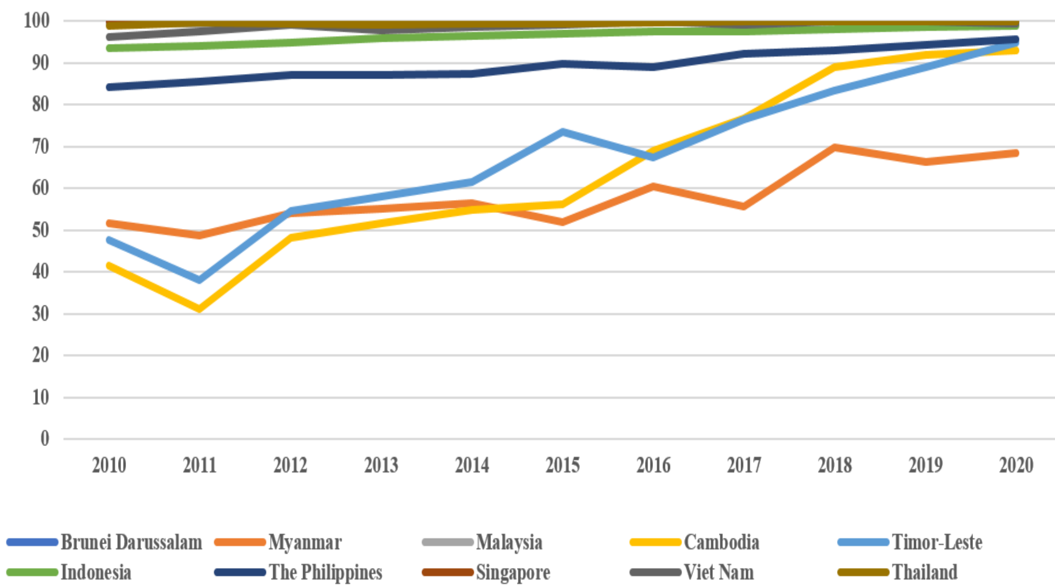
5.4 Southeast Asia

5.4.1 Issue and Challenge

The geography of Southeast Asia is unique, with islands, peninsulas, and densely populated areas divided by highlands and mountainous areas. The energy access of some economies in the region is still hampered by the major geographic conditions. Numerous populations with energy poverty tend to be concentrated in mountainous terrain, and isolated areas such as islands and/or remote areas, where grid extension is extremely difficult and investment costs are too high.

Energy access in Southeast Asia economies is still hampered by some problems. In Indonesia, the population without electricity access lives on the isolated islands of Maluku, and East Nusa Tenggara and other parts of the population in remote rural areas of Papua which also characterized by extreme geographical features. While in the Philippines, residents without electricity access belong to isolated islands in the southern part of Mindanao, and part of the population lives in remote areas with extreme geographical conditions in Mindanao. In Malaysia, a handful of the population who lives in the mountains of Sabah and Sarawak on the island of Kalimantan are also without access to electricity. As for Viet Nam, the remaining 1% of households without electricity access are located in the remote mountainous areas where the power grid extension can be extremely difficult.

Figure 5.57 depicts the electricity access in 10 ASEAN economies between 2010-2020. In 2010, only half of the population in Cambodia, Timor-Leste and Myanmar could benefit from electricity access with 41.6%, 47.7%, 51.7%, respectively, while the other half of the population in these three economies still suffer energy poverty. Despite millions of users have gained access to electricity in the region since 2000, about 45 million people remain without electricity today, which include APEC economies, Indonesia, and the Philippines.[189]



Unit: % of population
Source: World Bank data

Figure 5.57 Access to Electricity in Southeast Asia (2010-2020)

5.4.2 Policy Support for Electrification

Policies addressing energy access, renewable energy, energy efficiency and climate change are all a part of a robust policy framework for enhancing energy access. Fundamental policy support is required to develop power infrastructure taking energy access as a priority. Energy access issues in ASEAN member economies have been addressed by improving the policy system for power access in areas without access to electricity, increasing public and private sector financing investment in off-grid electrification solutions, and strengthening government capacity building in policy

[189] IEA, 2020. Southeast Asia Energy Outlook 2019.IEA/OECD.

formulation, financing and executing innovation strategies and methods. Table 5.51 lists selected policies and targets of energy development, including electrification, in Southeast Asia.

Table 5.51 Selected Policies and Targets of Energy Development and Electrification in Southeast Asia

Economies	Sector	Policies and targets
Brunei Darussalam	Efficiency	Reduce total energy consumption by 63% from BAU levels by 2035.
	Renewables	Achieve 10% of electricity generation from renewables by 2035.
	Climate change	Reduce CO2 emissions from morning peak-hour vehicle use by 40% from BAU level by 2035.
Cambodia	Electrification	Electrification for all villages by 2020 and 70% electrification forhouseholds by 2030.
	Renewables	Increase hydropower capacity to 2 241 megawatts by 2020.
	Climate change	Reduce GHG emissions 27% from baseline emissions by 2030 with international support.
Indonesia	Electrification	Achieve electrification ratio of 99.7% by 2025.
	Efficiency	Reduce energy intensity by 1% per year to 2025.
	Renewables and New energy	Increase share of “new and renewable energy” in primary energy supply to reach 23% by 2025 and 31% by 2050.
	Climate change	Reduce GHG emissions 26% by 2020 and 29% by 2030 from BAU levels, and 41% by 2030 with international support.
Malaysia	Efficiency	Promote energy efficiency in the industry, buildings and residential sectors with methods of standard setting, labelling, energy audits and building design.
	Renewables	Increase capacity of renewables to 2 080 MW by 2020 and 4 000 MW by 2030.
	Transport	Introduce 100 000 electric vehicles by 2020 with 125 000 charging stations.
	Climate change	Reduce GHG intensity of GDP by 35% by 2030 from 2005 level, increase to 45% reduction with enhanced international support.
Myanmar	Electrification	Achieve electrification rate of 80% by 2030.
	Efficiency	Reduce primary energy demand by 8% by 2030 from 2005 level.
The Philippines	Electrification	Achieve 100% electrification by 2022.
	Efficiency	Reduce energy intensity 40% by 2030 from 2010 level. Decrease energy consumption by 1.6% per year by 2030 from baseline forecasts.
	Renewables	Increase the share of non-hydro renewables-based generation capacity to 12.5% by 2025 and 21% by 2030.
	Climate change	Reduce GHG emissions by 8% by 2030 and by 25% from BAU levels with international support.

Source: IEA. Southeast Asia Energy Outlook 2019

Despite the fact that Southeast Asia's energy consumption has slowed marginally in recent years due to greater energy efficiency and economic adjustments, the International Energy Agency predicts that demand will rise by 60% by 2040. To meet these demands, significant investments in new power generating and transmission infrastructure will be required. Although the Association of Southeast Asian Nations (ASEAN) has said that traditional power sources would meet the majority of future demand, climate change concerns are increasingly concentrating policy and investor attention on the need for clean energy options. ASEAN economies have set a target of using renewable energy to meet 23% of the region's primary energy supply.

Extending the grid to the population with no access to electricity involves a high cost of investments. Most utilities, including those state-owned, wouldn’t take investment risks unless they are subsidized. Furthermore, the electricity subsidy scheme is not ideal or appealing in the region, and economies may face financial burdens due to high investment costs. However, off-grid power systems may be the preferred alternative due to the high investment cost. Off-grid initiatives, on the other hand, necessitate government intervention in terms of financing to build and improve off-grid infrastructure to deliver cost-effective, reliable, and sustainable electricity.

More incentive policies for energy access should be introduced along with increasing the attractiveness of renewable energy development, and other incentive policies related to grid extension are needed to raise the electricity access rate in the rural areas with energy poverty issues. The consistency and effectiveness of incentive policies are needed for off-grid options. The related governments should research and construct long-term renewable energy development plans, as well as set practical and achievable development targets and adopt scientific, rational, and effective support policies toward the full electricity access of all the population in the region. Recommendations in this regard include:

- Addressing the accessibility to energy issue and the “last mile” challenge: in recent years, ASEAN economies are actively participating in and devoted themselves to the cause of energy access in various ways, and significant results have been achieved. However, due to the above-mentioned geographical conditions of some isolated islands and remote rural areas, the problem of energy access still exists. To overcome the "last mile" challenge of energy access, economies ought to formulate strong policies and actions based on their specific domestic geographic conditions, use renewable energy resources, implement new and suitable technologies, develop workable project finance models, attract social and private capitals, use foreign capital to achieve the electrification and energy access targets in the economies;
- Strong support policy is the key driver to energy accessibility: Government’s role in boosting investments is very essential. It is the driving force behind approximately 70% of global energy investment. Securing energy sources, lowering carbon emissions, improving air quality, and increasing basic energy supplies in remote places such as rural areas, isolated islands, and mountains all require the implementation of the appropriate policies and incentives. Cleaner, smarter, and more efficient energy technology and broader financial involvement and fewer obstacles to energy investment are required for universal and low-cost energy access. Energy investment and technological development should also be aided by the relevant policies;
- Due to geographical conditions and constraints in many rural and remote areas, the accessibility of electricity has been unaffordable to population, and the investments for the related projects need mainly from the public financial sources. Some ASEAN economies, such as Indonesia and the Philippines, have developed government applicable fiscal policies and taxation schemes for electrification projects in rural and remote areas, which include local regulations, tax reductions, and tax exemptions for solar home systems and microgrid equipment. The support from the government through the subsidy systems has been proved in practice effective on reducing investment costs, encouraging broad participation, and expanding the boundary of energy access.
- Energy accessibility in isolated islands and remote rural areas: At the policy level, the government can undertake comprehensive planning, based on the island’s natural and resources characteristics, such as these in Indonesia and the Philippines, which might be rich in tourism resources. The government can focus on the characteristics of tourism development to layout related industries at the same time in key areas supporting energy development planning, rational allocation of tourism resources, developing energy supply facilities, promote local renewable energy development. At the technical level, for islands with potential development, projects using the off-grid connectivity scheme can adopt the right project development models such as PPP, which is jointly invested by the private and public, with the private responsible for the operation and maintenance of the energy system;
- Access to modern energy forms, electricity, clean cooking stoves, high-quality lighting, and sustainable fuels, is critical for the region development because the energy services made possible by modern energy forms can provide a solid foundation for escaping the poverty trap, particularly in remote rural communities. Relevant legislation, policies,

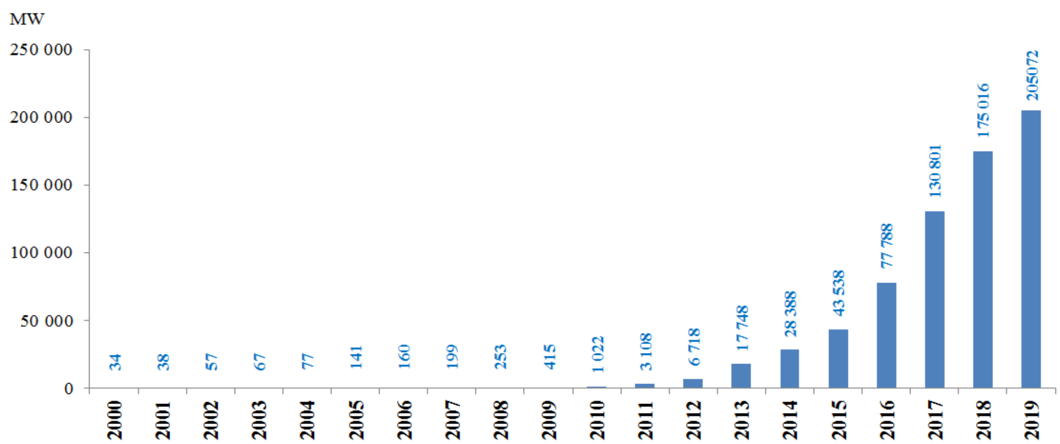
supporting programs and incentives should be developed and implemented to facilitate access to the modern energy;

- Affordable access to electricity in rural and remote areas: The isolated islands or remote rural areas are often having a small number of populations and also are characterized by low-income level, which indicates that electricity cost would be unaffordable for many residents due to its higher cost. Therefore, policy support is needed in order to find ways of improving the level of productivity of economic activities in those areas to achieve a high income for the people as well as enhance the population's quality of life. However, experience shows that a holistic approach is needed to raise the productivity of the local population. Therefore, it is critically important to ensure the participation of all stakeholders in the processes.

Chapter 6: Case Study of the Development and Deployment of Renewable Energy Technology

6.1 Solar Photovoltaic Development in China

China has made significant progress in the development of renewable energy in recent years, ranking the first in world in terms of solar PV, wind power, and hydropower installed capacity. Photovoltaic electricity is among the fastest-growing renewable energy industry. The installed capacity of solar PV power generation has expanded dramatically. Over about a decade, the capacity growth has jumped from 1.02 GW in 2010 to 205 GW in 2019, as Figure 6.58 illustrates. China's cumulative installed solar PV capacity reached 43.5 GW by the end of 2015, exceeding Germany’s to become the world's highest installed solar PV generation capacity.



Source: IRENA

Figure 6.58 Installed Photovoltaic Power Generation Capacity in China (2000-2019)

In 2020, the newly installed capacity of solar power generation is 48.69 GW, including 48.5 GW of photovoltaic power generation and 100 MW of solar thermal power generation. Compared with 2019, the newly installed photovoltaic power generation capacity increased by 61.4% year on year. Among them, the newly installed capacity of centralized photovoltaic power stations increased by 32.6 GW, up by 82.5% year on year. The new installed capacity of distributed solar PV was 15.9 GW, up 30.4% year on year. Accordingly, by 2020, China's cumulative installed capacity of solar power generation reached 253.4 GW, including 252.8 GW of photovoltaic power generation and 540 MW of solar thermal power generation. The cumulative installed capacity of solar power generation increased by 23.8% year on year. Among them, the accumulative installed capacity of centralized photovoltaic power stations was 174.7 GW, up 23.3% year on year. The total installed capacity of distributed solar PV was 78.1 GW, up 24.8% year on year.

The cumulative installed capacity of solar power generation accounted for 11.5% of the China's total installed power generation capacity. Both the new and accumulated installed capacity of photovoltaic power generation continued to be ranked the first globally. The following section briefly reviews and summarizes the practice and experience of the expansion of the solar PV sector in China.

6.1.1 Phase of Solar PV Development

The development of the solar PV sector in China can be classified into the following phases, which include quantity increasement, scaling-up, and quantity improvement.

- Small-Scale Demonstration (before 2001): Using foreign technology, China established a series of solar cell production lines in the late 1980s, the economy's solar cell production began to take its shape gradually. Tianwei Yingli launched the first polysilicon battery and application system demonstration project in China in 1998, with an annual production capacity of 3 MW;
- Raising Manufacturing Capacity (2002-2009): In September 2002, Wuxi Suntech officially launched its first 10 MW solar cell production line. The first domestic polysilicon project, with a capacity of 300 tons per year, began operations in 2005. China became the world's top producer of solar cells in 2007, with an annual production of 1.09 GW;
- Large-scale development of the whole industrial value chain (2009-2015): Since 2009, China has been working on the "Golden Sun" demonstration project, with the installed capacity of around 300 MW in its initial stage. In 2009 and 2010, the government companies launched two rounds of bidding processes for projects for photovoltaic concessions to build grid-connected photovoltaic power stations in the western region with favourable solar resources, which effectively facilitated promoting the progress of solar PV technological progress, raised the scale of manufacturing, and resulted in large-scale development of the domestic photovoltaic power generation capacity;
- Quality improvement and efficiency improvement (2016 to the present): The photovoltaic development has progressively shifted from focusing on scale development to achieving smart and high-quality industry development by promoting technological progress, improving operating quality, reducing electricity generation costs, optimizing development and reducing subsidy dependency. Through the promotion of distributed photovoltaic generation and the diverse forms, named as "PV+", the photovoltaic application field has been expanded strongly and widely over the period to solve the problems of solar power plants. Through the initiative and establishment of the bases of "Solar PV Front-Runner", advances in photovoltaic technology have been further stimulated, the application market for advanced technologies has been broadened, and the solar sector upgraded.

  Over the period, effective market regulation on solar PV power generation have been established. Optimisation of the solar PV sector has been achieved through assessing and evaluating the costs of land uses, monitoring and improving the effectiveness of the local government supports, and effective planning of the solar PV projects. These have ensured the reduction of non-technical costs of the solar PV projects, and a continued quality and sustainable development of the solar PV sector.

6.1.2 Incentive and Supporting Measure

China is now recognized as the world leader in the solar photovoltaic industry. The formation and growth of the photovoltaic sector have been strongly intertwined with the supports of domestic energy policies, development strategies and plans, and other related and incentives.

(1) Policy and Guideline

Based on the Renewable Energy Law, China has introduced various regulations and technical requirements for renewables, including solar PV, wind power, biomass, and others, from energy project development, construction, to plant grid connection, and other key segments, such as plant operation, maintenance and management. A feed-in tariff mechanism was established along with the industry information monitoring and evaluation systems. A basic framework for a standard, fair, and orderly industrial policy environment has been established. Since the promulgation of the Renewable Energy Law in 2006, as listed in Table 6.52, China has issued the various supporting policies related to the solar photovoltaic sector.

Table 6.52 Selected Policies Supporting the Solar Photovoltaic Sector in China

Category	Policy and Guideline
Development planning, law and regulations	• Renewable Energy Law of the People's Republic of China (amendment) • Long-term Development Plan for Renewable Energy (NRDC Energy [2007] No. 2174) • Measures for the Guaranteed Full Purchase of Renewable Electricity (NDRC Energy [2016] No. 625) • Notice on the management of full guarantee purchase of wind power and photovoltaic power generation（NRDC Energy [2016] No. 1150） • The 13th Five-Year Plan for renewable energy development（NRDC Energy [2016] No. 2619）
Industrial support and construction management	• Promoting the healthy development of photovoltaic industry (National Development Plan ([2013]24） • Notice of the Interim Measures for the management of photovoltaic power plant project（NEA NE [2013] No. 329） • Notice on the Interim Measures for the Management of Distributed Photovoltaic Power Generation Projects（NEA NE [2013] No. 433） • promoting the application of photovoltaic technology products and industrial upgrading（NEA NE [2015] No. 94） • Notice on implementing information management of Renewable energy Power Generation Projects（NEA NE [2015] No. 358） • Guidelines on establishing a target guidance system for the development and utilization of renewable energy（NEA NE [2016] No. 54） • Guidance on improving scale management of photovoltaic power generation and implementing competitive allocation projects (NRDC Energy [2016] No. 1163） • Notice on trial implementation of green Electricity Certificate Issuance and Voluntary Subscription trading system for Renewable Energy sources（NRDC Energy [2017] No. 132）
Fiscal, tax incentives and financial support	• Supporting financial services for distributed photovoltaic power generation（NEA NE [2013] 312） • Deepening the implementation of the reform of the energy industry investment and financing system（NEA Legislation Reform [2017] 88） • Notice on leveraging the role of price to promote the healthy development of photovoltaic industry（NDRC Price Reform [2013] 1638） • Notice on the implementation of distributed photovoltaic power generation in accordance with the electricity subsidy policy and other related issues（Finance [2013]390） • Notice on issues related to exemption of government funds for spontaneous and self-consumption of distributed photovoltaic power generation（Finance [2013] 103） • Notice on Actively Promoting the Work Related to Un-subsidy and Parity of Wind Power and Photovoltaic Power Generation ([2019] 19)
Land use	• Notice on the Issuance of Land Use Control Indicators for Photovoltaic Power Station Engineering Projects（National Land Resources Regulations ([2015] 11） • Notice on Issues Concerning the Use of Forest Land in the Construction of Photovoltaic Power Plants（Forest [2015] 153）
Photovoltaic for poverty alleviation	• Notice on the issuance of the work plan for the implementation of photovoltaic poverty alleviation projects（NEA NE [2014] 447） • The implementation of poverty alleviation by photovoltaic power generation（NDRC Energy [2016] 621）

(2) Support and Subsidy Scheme

To promote renewable energy development, based on legally adopted "Renewable Energy Law" in 2006, support and subsidy schemes were established and implemented, including setting up renewable energy targets, rules for compulsory grid connection of renewable generation projects, stipulating comprehensive renewable energy subsidy systems, cost-sharing systems, and special fund systems for renewable energy project development. Various pricing schemes, at diffenet time, were issued and adjusted, reflecting the specific conditions of different stage of renewable energy development.

(3) Technical Standard and Certification System

Over the period, the solar PV sector has established relevant standardization institutions, and developed the relatively completed technical standard systems, which now encompasses the entire industrial value chain, and cover the entire project life cycle. Standard testing and certification capacity has been strengthened, and the quality of renewable energy equipment has been steadily improved and ensured.

(4) Creating Employment Opportunity and Contributing to Poverty Alleviation

Solar photovoltaic sector have directly contributed to job creation and social and economic development in China. According to the Annual Review "Renewable Energy and Jobs" (IRENA, 2019)[190], China's photovoltaic industry created some 2.2 million jobs in 2018, accounting for 61% of the global total, while China's wind energy industry created 510 000 jobs, accounting for 44% of the global total.

As an innovative application model for targeted poverty alleviation, "Solar PV for Poverty Alleviation", strives to assist the underprivileged and foster stable income growth of the rural and poor population. The National Energy Administration and the State Council's Poverty Alleviation Office approved two batches of the Photovoltaic Poverty Alleviation projects in 2016 and 2017 respectively, totalling roughly 9.35 GW and assisting 1.3 million impoverished families across China. In 2019, the State Council's Poverty Alleviation Office and the National Energy Administration collaborated to review and issue the second batch of photovoltaic poverty alleviation plan of the 13th Five-Year Plan, which included photovoltaic poverty alleviation project plans for 15 provinces and regions, 165 counties, totalling 3,961 village-level photovoltaic poverty alleviation projects, with a total installed capacity of 1.7 GW.

6.1.3 Practice and Experience

Some main drives for the solar PV sector's development and establishment in China can be summarised as below.

(1) Implementing the domestic strategy is an important prerequisite for the rapid development of new and renewable energy

Since the second oil crisis in the 1970s, the concept of energy security has emerged in the energy field, with the security of supply as the key starting point, and governments have begun to invest significant amounts in a research area related to renewable energy utilization. During this period, as part of the research programs, China also developed one of the world's first grid-connected wind farm.

The implementation of the "863 Plan" to create high technology sector has been a major aspect of the domestic development strategy since the 1980s, and new and renewable energy has been among the key areas to be explored in terms of technological development and application. The white paper on China's Population, Environment, and Development in the 21st Century, issued by the State Council in 1994, was China's first domestic sustainable development strategy. It was emphasised in the paper that the only way to change from the traditional development model of

[190] https://www.irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019

"pollution first, treatment later" is to invest in research, development, and promotion of new and renewable energy and materials.

After 2003, China's development plan has remained focused on promoting sustainable growth. As one of the largest energy consuming economies in the world, the government determined to increase the development and exploitation of new and renewable energy resources, which has become a strategic decision to promote sustainable development and build a resource conserving society, especially fostering wide and large-scale development of the new and renewable energy industry, particularly solar PV, and wind power. The new and renewable energy has been recognized as China's strategic emerging sector since 2010, and the active development of new and renewable energy sector has become an urgent need and among the top agenda to gain international competitive advantages, materialise the sustainable development initiative, and seize the economic growth opportunities.

Since the 18th National Congress of the Communist Party, China has prioritized the development of ecological civilization as a top priority among its strategies. President Xi Jinping established a target in 2014, aiming at "increasing the share of non-fossil energy in primary energy consumption to approximately 20% by 2030." The 19th National Congress of the Communist Party of China proposed to promote the revolution of energy production and consumption, create a clean, low-carbon, safe and efficient energy system, and expanding the clean energy sector have become an important strategic deployment. In line with China's gradual attention to environmental issues and energy transition, utilisation new and renewable energy resources, and development and deployment of new and renewable energy technologies have become a key component of the domestic development strategy.

(2) Planning industry development

China's plans have guided the development of new and renewable energy sector systematically at various stages and levels, resulting in a situation in which installed wind and photovoltaic capacity ranks among the top in the world. Innovations applied, technologies updated and equipment manufacturing capacity increased, engineering skills accumulated, all of these have contributed to lay a solid foundation for vigorously promoting green energy transition and upgrading of the existing energy systems.

The Proposal on the Formulation of the Ten-Year Plan for National Economic and Social Development and the 8th Five-Year Economic and Social Development Plan, prepared by the CPC Central Committee, were released in 1990. Both plans called for that efforts should be made to achieve new scientific and technological advancement in high-tech fields such as new materials and new and renewable energy, which set forth the requirements for exploring the feasibility of industrial development and technological research as well as building up the new and renewable energy industry in China.

In 1995, the CPC Central Committee advocated "actively developing new and renewable energy resources and improving the energy structure of energy supply" in the Proposal of the CPC Central Committee on the Formulation of the 9th Five-Year Plan for National Economic and Social Development and the Long-Term Goals for 2010. The "11th Five-Year Plan for Renewable Energy Development" was proposed to "give full play to the advantages of wind energy resources in the "three North" (Northeast, North, and Northwest) regions, and develop large and extra-large-sized wind farms. The 13th Five-Year Plan for Renewable Energy Development aims to innovate the renewable energy development modes, optimize the development layouts of renewable energy projects, accelerate technological progress and cost reduction of renewable electricity generation, further expand the scale of deployment of renewable energy technologies. The plan also aims at effectively guiding the healthy development of the renewable sector, standardizing relevant technical design, manufacturing, installation, operation and management of new and renewable energy technologies.

(3) Supporting the progress of the renewable sector

Constant policy improvement is among the critical factors in promoting the large-scale development of the renewable energy. Prior to the 11th Five-Year Plan, China's renewable energy mostly fostered industry development through demonstration projects as well as scientific and technological research. For example, the wind power market and industrial system have been gradually developed and formed since the adoption of the Renewable Energy Law and a series of policy supporting documents, with the industrial strength greatly enhanced and the market scale continually extended. Nearly 100 policy documents supporting and regulating the development of the solar photovoltaic industry were issued by 2013 after the State Council issued the "Several Opinions on Promoting the Healthy Development of the Photovoltaic Industry", which effectively promoted the rapid expansion of the scale of solar photovoltaic in China, contributing the rapid technology progress and improvement in capacity and efficiency of equipment manufacturing, and in the end, reduction of power generation costs from renewables.

With the continuous expansion of the scale of renewable energy, the state has proposed a number of measures, including investment early warning system, solar photovoltaic market environment monitoring and evaluation mechanism, and green certificate system etc, all of which have made useful attempts to solve the problems related with maximal renewable energy absorption and relieving the financial pressure resulted from the renewable energy subsidies.

In 2018, the National Energy Administration issued the Notice on the Relevant Requirements for Wind Power Construction Management and the Notice on Solar Photovoltaic Power Generation, both of which stated quite clearly that newly approved centralized onshore wind power projects, offshore wind power projects, and ordinary photovoltaic power stations should all be allocated through competitive processes. The feed-in tariffs are seen to be a crucial competitive optimal condition for the biding. In 2019, the National Energy Administration published the Notice Regarding Solar Photovoltaic-related Matters, stipulating to follow the development plan, use competitive processes, implement subsidy-free tariff, terminate the unapproved projects, and ensure generation and absorption of renewable electricity. These are to establish a good investment environment and business condition for renewable energy project development and ensure electricity from renewables being sent to the grid and delivered to the consumers.

To further actively promoting subsidy-free wind power and solar photovoltaic power generation, the National Development and Reform Commission and the National Energy Administration jointly issued the Notice on Actively Promoting Subsidy-free Grid connection of Wind Power and Solar Photovoltaic Power Generation (NDRC 2019 No. 19) in January 2019, which primarily cover the following areas:

- Organise the pilot renewable projects with subsidy-free and low-cost grid connection;
- Optimize the investment environment for subsidy-free and low-cost grid connection projects;
- Guaranteed priority for power generation and fully guaranteed purchases of generated electricity;
- Encourage subsidy-free and low-cost renewable projects to obtain revenues through participation in green certificate trades;
- Conscientiously fulfilling the responsibility of power grid companies in relation to grid connection;
- Promote the development of wind and solar photovoltaic power generation participation in electricity market;

- Reduce transmission and distribution charges for local transactions;
- Solidly encourage the local subsidy-free and low-cost projects to supply electricity to the local consumers;
- Promote the development of wind and solar photovoltaic power projects in conjunction with cross-provincial and cross-regional power transmission;
- Develop innovative project finance model;
- Enhance the support for the total energy consumption assessment mechanism.

(4) Boosting the development of renewables through the diversification of market participation

With the technology advancement, improved development model, including both centralized generation and decentralized generation projects, over the period the costs of renewable energy projects have steadily reduced, lowering the investment threshold and enabling the conditions for the coexistence of multiple entities in the renewable energy market. It has been estimated that currently private sector account for 50% of total investment in solar PV power projects, and the vast majority of solar photovoltaic manufacturing enterprises are privately owned. Diversifying market participants have helped push the technological progress, and speed up renewable energy project development, increase the economic efficiency of the solar sector. After the third round of the competition among the enterprises in the Solar Front-runner Bases, the feed-in tariff after the bidding reached as low as 0.31 CNY/kWh, which is actually very close to the grid parity.

(5) Market competition has boosted manufacturing capacity and efficiency

Through the early stages of renewable energy development, the government introduced, digested, and absorbed sophisticated technologies to support the localization of wind power technology and develop the local manufacturing capacity. The bidding for large-scale wind power farm concession in China started in 2003. The "Golden Sun" demonstration projects and the bidding for solar photovoltaic concession have been ongoing since 2009. Through the enlarged domestic market, China has been increasing its manufacturing capacity while lowering the costs of equipment supply for the projects.

With the rapid expansion of renewable energy manufacturing capacity, China is able to provide market support for advanced technological products through the Solar Photovoltaic Leader program and other specially designed initiatives, supporting the solar photovoltaic industry into the "high efficiency era", which have encouraged a variety of technological innovation in the manufacturing industry and improved component efficiency.

(6) Industrial development through international collaboration

China has paid close attention to the use of both local and international resources from the commencement of economic reform and opening up and has committed to strengthening international cooperation. Among the most important include:

- Set up cooperation mechanisms with Europe, America, Japan, and other economies, as well as a strategic framework for the industry summits, policy support from functional departments for international collaboration, and particular execution by the local governments, scientific research bodies, and busines entities;
- The "Science and Technology Cooperation Plan for New and Renewable Energy International" was officially released and launched in February 2008 by the Ministry of Science and Technology and the National Development and Reform Commission. Domestic scientific researchers and institutions have been encouraged to participate actively in international energy R&D program, drawing the expertise from international R&D resources. On the other hand, global firms have been encouraged to establish energy

R&D bases in China, undertaking cooperative research project in the new and renewable energy technology field;

- CDM had been used as a platform for international cooperation in the areas of new and renewable energy, helping China introduce needed capital and enhancing the capability of renewable energy enterprises.

(7) From pilot and demonstration to scaling-up the deployment of renewables

To innovate the development mode and promote the sustainable development of the solar photovoltaic industry, the demonstrations, at the early stages, primarily includes concession bidding demonstrations, advanced technology demonstrations, industrial integration demonstrations, multi-energy complimentary energy system demonstrations, and renewable energy based micro-grid demonstrations.

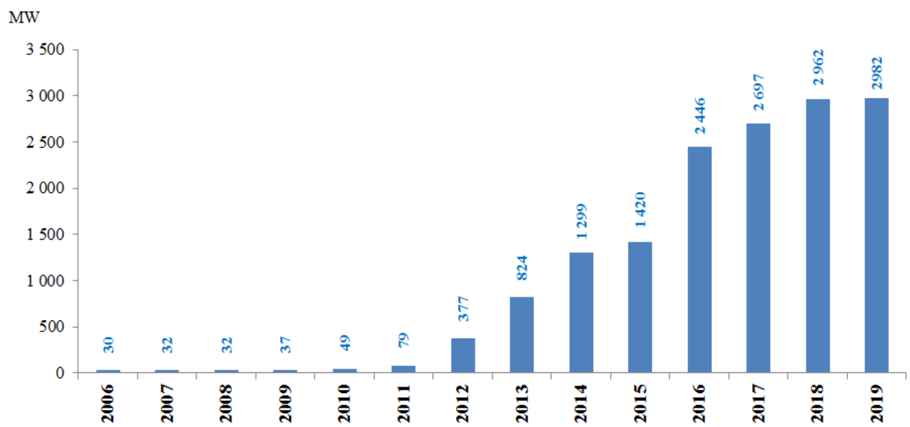
Advanced technology demonstrations include the Front-runner Solar Photovoltaic Bases, and solar thermal power generation. Industrial integration demonstrations include PV+, Solar for Poverty Alleviation, PV+agriculture, PV+building, and other PV+ models. Multi-energy complementarity has been demonstrated by making full use of the complementary benefits of different energy resources, such as hydro, wind, and solar, to address the grid connection issues of renewables, support ability of power gird to absorb increased proportion of electricity generation from renewable energy resources. The renewable energy based microgrid pilots aim to demonstrate the flexible and efficient use of distributed power supply, and to solve the problems of grid connection of a large number of distributed power supply systems in diverse forms.

6.2 Solar Photovoltaic Development in Thailand

Thailand has a diverse natural resource bases and plentiful sunlight, with maximum irradiation in April and lowest in December. The average annual temperature is around 24 ℃, with an estimated average of 1800 hours of sunshine each year. In central and north-eastern Thailand, the annual sunlight duration surpasses 1850 hours. As a result, Thailand has the most experience with solar energy development among Southeast Asian economies. According to the IRENA statistics, the installed renewable capacity in Thailand expanded from 4,051 MW to 11,860 MW between 2006 and 2019, ranking second after Viet Nam among the Southeast Asian economies. Figure 6.59 shows the change of installed Solar PV capacity in Thailand over the period of 2006-2019.

At earlier stage, Thailand's renewable resources were primarily hydro power, while over the period, the renewable energy landscape has been evolving. At present, biomass accounts for 36.9% of installed renewable energy capacity in Thailand, followed by hydropower (32.2%) and solar (26.1%). The current PV policy goal is to reach 10GW installed capacity by 2036. In 2013-2018, centralized solar power stations accounted for 95.3% of the total installed solar power generation capacity. It has been noted the recent development of floating solar in Thailand, which is estimated to account for 27% of distributed solar power installations in 2018-2020.

Thailand has established an update energy strategy, with more focusing on the development of solar energy. Since the implementation of the Renewable Energy Development Policy in 2008, Thailand has become a hub of 11 solar power plants with installed capacity among the top 25 in Southeast Asia, accounting for 52.7% of the region's total installed solar capacity. At present, the Thailand has become one of key competitive markets for the global PV suppliers.



Source: IRENA

Figure 6.59 Installed Solar PV Capacity in Thailand (2006-2019)

6.2.1 Overview of the Development

In terms of resources, Thailand is situated at north of the equator, benefiting from long period of sunshine and high radiation intensity, endowed with rich solar energy resources. Thailand has more than 1750kWh/m^2 of total annual solar energy radiation, according to the SolarGIS atlas, making it the region with the most plentiful solar energy resources.

Thailand has concentrated on the solar energy development since implementing the Renewable Energy Development Policy in 2000. Thailand's government has since supported the installation of 100,000 residential solar panels and 1,000 commercial rooftop solar panels, with an estimated total installed capacity of 800MW. Thailand's installed renewable electricity generation capacity reached 5.71 GW in 2014. The grid-connected installed capacity of renewable power increased by 11.8 % year on year, reached to 8.92 GW in 2018. Thailand's total installed power capacity is composed of 23.0% renewable energy, for which solar energy accounted for 26.3 % of electricity produced.

In general, the majority of solar power plants in Thailand are relatively small with less than 5MW. For example, 459 power plants have a total capacity of 2353.9 MW, clustered mainly in Shapay Prefecture, Huafuli Prefecture, Fopi Prefecture, and Fotong Prefecture. There are about 15 photovoltaic manufacturing enterprises in Thailand, with an annual production capacity of about 5 GW, thanks to the Thai government's significant support for renewable energy development, particularly solar industry. According to the Energy Source Regulatory Commission of Thailand's Report, most of off-grid independent power generation projects in Thailand are rooftop solar panel installations as of September 2019.

6.2.2 Incentives for the Solar Development

Thailand has explicitly defined the goal of producing electricity from solar energy, wind energy, geothermal energy, and other renewable resources since the fifth National Economic and Social Development Plan. Due to a lack of comprehensive macro planning, the development pace was relatively slow at the beginning. Thailand however began to create a comprehensive new and renewable energy policy, and formulated long-term plan for the renewables after the 1990s, and a series of reforms in energy sector have been implemented.

(1) Initial policy

In 1992, Thailand adopted the Energy Conservation Promotion Act. After that, the government has not only issued a series of royal decrees and administrative laws to monitor and control factories and buildings’ energy consumption, but also established the Energy Conservation Promotion Fund based on this Act. Various organizations helped eligible renewable energy projects, particularly in Thailand's rural areas, with funding provided for the running costs and provided incentives for the investment.

(2) FIT subsidy

Among the first, Thailand announced FiT subsidy terms for rooftop solar PV systems of 200 MW and community grounded PV power plants of 800 MW in 2013. As shown in Table 6.53, These solar PV systems were provided with the FiT for 25 years, and the project was completed at the end of December 2013.

The 2018 Residential Rooftop Solar Scheme incentivizes households to build domestic solar photovoltaic installations in their houses and allows consumers to transmit surplus electricity to the domestic grid, with the government subsidizing the electricity price.

Table 6.53 Feed in Tariffs of Selected Solar PV Projects

Type of the Project	Feed in Tariff	Period
0-10kW small photovoltaic system	6.69 THB/kW（USD 0.22/kW)	25 years
10k-450kW vedium-sized photovoltaic system	6.55 THB/kW（USD 0.21/kW)	25 years
450kW-1MW Photovoltaic power station	6.16 THB/kW（USD 0.20/kW)	25 years
Large power station with capacity more than 1MW	5.66 THB/kW（USD 0.168/kW)	NA
Community power station	The FIT subsidy rate for the first three years was 9.75 THB/kW; From the fourth year to the tenth year, it is 6.5 THB/kW.	FIT decrease year by year over the perid.

(3) Power Purchase Contract System

The Thai government released a new energy policy in 2017, modifying the power purchase agreement with wind and solar power plants owners and operators, with a to increase the rate of renewable energy power utilisation. Then new power purchase agreement contracts have a 20-year term. The new company power purchase agreement differs from the previous "non-company contract power purchase agreement" as it defines the specific amount of electricity that the power plant needs to provide to the State Power Administration. This means that during the peak load periods, renewable power plants have to continuously deliver electricity to the power grid. Because solar power is subject to the weather conditions to generate electricity throughout the day, Thailand's private sector has been investing more in solar photovoltaic power plants' operation and management, as well as energy storage, as a result of the regulation amendments.

Following its determined targets, Thailand adopted the Thai Power Development Plan 2018-2037 (PDP2018) in April 2019, which updated the economy's solar development goals for the next 20 years, including a total of 10 GW rooftop solar PV installations and a total of 2.73GW floating solar PV projects developed by EGAT on the nine reservoirs.

The total installed solar capacity in Thailand currently is approximately 3 GW. Toward the multiple purposes of solar resource exploitation, the Thai energy authority has set approximately USD 5 billion for electricity development, and more solar photovoltaic power plants have been under development and construction. Furthermore, Thailand has a diverse agricultural plantation bases, covering sugarcane, rice, fruit, coffee, and other types of crops. To cope with the situation of currently weak power supply infrastructure and need for agricultural irrigation, the solar photovoltaic water pump systems can be installed across the agricultural lands. With related energy storage facility, the systems help satisfy the 24-hour continuous irrigation needs, and will be more beneficial for local farmers and end-users.

6.2.3 Experience Summary

(1) Strong policy support

In Thailand, the power purchase contract, which serves as a base for bank financing, comprises two parts: a base price and a subsidy price. A large number of investors have been attracted to apply for power purchase contracts due to the allowed high return on investment. Through the power purchase agreement with the grid company, the solar PV projects in Thailand had successfully secured the bank financing independently. Thailand is also the first economy in the world to securitize photovoltaic power projects, attracting market capitals to invest in the photovoltaic projects.

On the other hand, as mentioned, Thailand announced in 2013 a subsidy FiT rate for 200 MW rooftop solar PV systems and 800 MW community grounded solar PV power projects. The conversion of the contractual arrangements regarding the power purchase actively promoted the efficiency of the use of renewable energy resources, urging domestic private sector players to increase their investments in the solar photovoltaic power plants' operation and maintenance, and add storage facilities and capacity at the solar PV plants so to improve the performance and quality of power supply of the plants.

(2) Development of specific measure to suit for local condition and need

Due to the availability of land and the topography limitations, solar photovoltaic projects in Thailand have been primarily in the forms distributed rooftop installation and floating solar photovoltaic. Thailand's 20-year solar development goals were amended in April 2019. A total of 10 GW rooftop solar installations and a 2.7 GW floating solar installations have been included in the plan.

Besides providing electricity needs to all households, the rooftop PV systems can also generate additional revenue by selling surplus electricity to the electricity market by connecting them to the power grid. Thailand has long sunshine hours throughout the year, so the prospect of a solar photovoltaic power generation system for the home is very promising, the development in the related fields offers a bright future. Furthermore, solar photovoltaic systems are ideal for the isolated and remote rural areas, where there's still a lack of sufficient electricity access. However, it has been noted that only 3-4MW of domestic solar power installations were connected to the grid by 2019, far short of the 10GW target. The Thai Ministry of Energy has decided to further adjust the related support policy and raise the solar photovoltaic power generation purchase price from 1.68 Baht/ kWh to 2-2.20 Baht/kWh in order to encourage more households to install solar photovoltaic power generation systems.

Thailand's National Electricity Authority (EGAT) also announced the plans to develop 16 solar photovoltaic floating power stations in nine dams/reservoirs by 2037, totalling more than 2.7 GW of installed capacity. Floating solar photovoltaic power stations, compared to land solar power stations, have the advantage of saving land resources and maximizing the self-cleaning capability of floating photovoltaic panels. Furthermore, water quality can be improved by covering the water surface so to minimize evaporation and inhibit the growth of microorganisms in the water. At the same time, the solar panels can be fully exposed to light because there is no shadowing over the water areas, while the water may help cool the photovoltaic modules and cables, increasing the efficiency of power generation of the plants.

Chapter 7: Conclusion Remark

The study analyses and evaluates the current status of the renewable energy development and the gaps of the development between different economies in the APEC region by using the metrics covering power sector development, sustainability, energy consumption and energy access. Renewable energy resource endowments, renewable technology development and cost composition, energy regulatory regime and development policy and plan, environment and corresponding infrastructure for renewable energy development, condition of investment and financing for renewable energy project, distributed energy utilization, and the renewable energy-based approach promoting energy access in the APEC region are examined and assessed.

The main factors that drive scaling-up renewable energy development in the APEC region, as well as possible innovative development methodologies, are examined in this report. The following points are made as the summary and conclusion remarks of the study in order to further support scaling-up renewable energy in the APEC region.

(1) Strengthening Policy Support

Effective government policies, which can play a critical role in overcoming economic, technological, and institutional barriers, have aided the development of renewable energy technology and projects. APEC economies' power sectors have widely introduced market competition, separating the government function from enterprise business operation, developed regulatory framework for the energy sector, implemented a feed-in tariff scheme, renewable energy quota and subsidy system and other policy mechanisms to create, promote and foster the healthy and orderly development of renewable energy sector. Economies have also been enhancing the market structure and improving regulation to result in the optimal result of combing the direction of macro policy, and market and business operation. Tax cuts and exemptions can assist the businesses to ease financial stress and preserving their capital chains. Simultaneously, renewable energy subsidy schemes need to be strengthened and adjusted with the development of renewable energy in order to maintain their effectiveness. Varied stages of industrial development, the objective of subsidy, and all stakeholders should all be considered in the policy formation processes, as should different subsidy and support mechanisms. Subsidies for renewable energy technologies that are competitive in the market can be gradually removed.

(2) Promoting Technological Progress and Cost Reduction

One of keys to achieving scaled development of renewable energy is technological advancement and cost reduction. Rapidly expanding in science and technology, growing in research and development, scaled technology application and deployment, and adequate industry and supply chain competitiveness have all contributed to the substantial decrease in the costs of renewable energy technology, particularly over the last decade. It is recommended that APEC economies continue to increase government funding for R&D, promote scientific and technological research, and demonstration, and invite more private sector participation in development and innovation, and support industrial development of renewable energy resources utilization. These will contribute to break key technological and industrial bottlenecks, such as large-scaled energy storage technology, safe, secure and cost-effective grid connection of a high proportion of renewable energy development, and stable, flexible and efficient power grid. Businesses could be allowed to play a larger role in research and development and innovation, so achieving technological advancement and cost reduction through industry competition, and therefore finally realizing affordable renewable energy electricity.

(3) Reenforcing Financial Support

Renewable energy has a comparatively high initial investment and low operating cost when compared to most conventional power sources, although it still requires some capital investment in the follow-up operation phase. In the APEC region, some businesses are still found hesitant to build more renewable energy projects due to the substantial financial requirements. It is recommended that economies reduce government overheads related to project management, project licence application, and project power grid integration to reduce the costs of renewable energy generation projects. Through the establishment of renewable energy development funds and other measures, financial support for private enterprises and renewable energy power generation enterprises can be provided, and private funds can be guided toward the invest in renewable energy project, which is among the key promoting the large-scale development of renewable energy.

(4) Innovating Financing and Business Model

Renewable energy projects are capital-intensive, and finance costs heavily influence project costs. To promote renewable energy projects, reliable and effective investment and financing channels are required, as well as preferential investment and financing regulations to drive down the costs. It is suggested that APEC economies develop effective financial tools to enable low-cost financing for renewable energy projects, and encourage innovation in diverse business and financing models for the renewable energy project. Interest subsidy policies could be carefully and fully utilized in order to lower financing expenses. Green finance, in addition to banks commercial loans, as the primary source of funding, can help businesses lower their financing costs and extend business models such as private offering, exchangeable stock bonds, crowdfunding, financial leasing, and trust. Simultaneously, it will be needed to increase the capacity of local banks and practitioners to finance sustainable energy projects.

(5) Improving the Business Environment

Large-scale renewable energy production necessitates both clear development goals and a stable and healthy economic environment. It is recommend for necessary policy adjustment in APEC economies in response to market trends and demands, simplifying and standardizing the approval processes for renewable energy projects, and shortening the duration for the relevant approvals; relevant competent entities and authorities are required to continuing to catalogue and release land space and related information for renewable energy project development, encourage wind power, solar photovoltaic, and other renewable energy projects to use the land in a composite manner, and lower the land costs for renewable energy projects. Innovating the renewable energy project development mechanism is also important, asl well as choosing project investors and developer through bidding and encouraging market vitality and transparency. On the other hand, other issues need to be addressed, which include enhancing the confidence of renewable energy investors and encourage renewable energy investment through strengthening policy implementation and monitoring, reducing policy uncertainty, eliminating potential investment risks induced by policy uncertainty, and promoting renewable energy investment.

(6) Improve the Flexibility of the Power System

Meeting renewable energy generation on a large scale necessitates the power system's flexibility. In terms of power supply, it is suggested that economies with a high share of coal power units could increase their systems' flexibility by adjusting the technical configuration and operational capability of the existing power generating units. Flexibility retrofitting of the existing units should be organized regularly for the existing units, and new units the system must be capable for the flexibility requirements. It is suggested that economies with right conditions accelerate the development of pumped storage power plants and other form of energy storage capacity. Grid-related issues, including a planned network reinforcement to increase power supply security, reliability, and stability in order to ensure renewable energy integration and power supply for economic development. With a recommendation to look at China's rural power grid renovation measures: firstly, energy development strategy is in place; the size of renewable energy generation should be in accordance with the domestic renewable energy development fund and should correspond to the capacity of the regional power grid. Second, the development and use of auxiliary service capacity, such as peak and frequency regulation for renewable energy project, supporting smoothly connection to the power grid and contributing to a more flexible power system, is among basic guarantees for scaling-up renewable energy deployment.

(7) Accelerating the Deployment of Distributed Energy System

Distributed energy systems are located close to end users, which can improve over energy efficiency, and create condition for the usage of renewable energy resources in the immediate vicinity. The utilization of micro- or mini-grid technology, in particular, has made the distributed energy resource a viable power supply option for places that are not served by the existing power grid or have a poor power and other infrastructure, such as isolated mountainous areas and remote islands. It is critical to create right energy policies that encourage the use of distributed energy resources. The relevant APEC economies should boost policy support for distributed energy, improving policy types, amending and improving key regulatory structures such as energy pricing, harmonizing related technical standards and guidelines, providing technical support, and developing needed capacity building programs. In addition, to assess the development potential of distributed energy, investigate economically viable technical routes and development modes for distributed energy systems are necessary to accelerate the pace of the development of distributed energy.

(8) Promoting Energy Access through Renewable Energy Resource

Although energy access is no longer a main issue in most APEC economies, yet significant numbers of people remain without electricity in some areas, particularly in remote, sparsely populated, and geographically disadvantaged rural areas. Distributed energy supply based on renewable energy resources, including the use of microgrid technology, provides the conditions for enhanced energy supply reliability and stability for energy access in these areas, thanks to the significant drop in the costs of renewable energy technology and equipment. Relevant economies should research and formulate relevant supporting policies, adjust relevant regulatory systems for relevant regions, provide relevant technical support and capacity building for stakeholders, and investigate appropriate business models to make renewable energy based distributed energy projects profitable and financially sustainable. Different technical options can be applied, based on the specific local situation, for energy access, from distribution power grid extension, to distributed energy resources solution and to the home solar systems, etc. The experience suggests that supporting productive use of electricity is among the key measures for economic development, alleviating poverty, raising the income level and the purchase power of the rural population, and hence fundamentally solving the issues of rural energy access.

(9) Learning from Advanced Experience

In the APEC region, there are a variety of economies with varying levels of social, economic and renewable energy development. It is suggested that the APEC economies, particularly developing economies, could benefit from advanced ideas and successful experience from other economies. As shown in the relevant sections of the report, experiences have gained in different economies in tackling different pressing issues of renewable energy development. For example, the experience from China and Thailand could be used as references for the solar PV technology development, sector planning, and solar project deployment. These could also be the references to formulate and implement a domestic strategy for new and renewable energy development, coordinating the strategies guiding each stage of the development of all related segments of the solar sector. The study shows the importance of intensifying relevant policy supports to promote industrial progress and build subject diversity, and raise competitiveness of the market. A step-by-step approach, taking demonstration projects as pilots to collect data and information, getting feedback and experience, adjusting and refining the policy framework, later promoting the technology across the economy, and constructing and operating the renewable energy projects that are appropriate for local situations, has been approved workable.

(10) Fostering Stronger Regional Cooperation

The development of renewable energy resources has become a consensus among all the APEC economies in terms of ensuring energy security, reliability and affordability. Economies with different background and requirements in the field of renewable energy utilisation can better realize a complementary advantage and achieve the target of green growth by strengthening international and regional cooperation, making full use of renewable energy development know-hows from the economies with established manufacturing capacity, advanced technology, successful planning, construction and operation practices, as well as these where renewable energy is still at relatively early stages of the market penetration. One of the major ways toward the large-scale growth of renewable energy across the APEC region is to encourage the demonstration project, enhance technical and engineering capacity, and optimize resource allocation through information and experience sharing, capacity building, technology transfer, and international and regional trade of goods and services. The study calls for greater endeavour to establish and implement green economic recovery strategies, powered by greater renewable energy, and through stronger regional and international collaboration, in the context of the global economic slow-down and uncertainty induced by the COVID-19 pandemic since the early 2020.

References

[1] APEC Secretariat (2019), APEC at a Glance 2019, Available via https://www.apec.org/Publications/2019/02/APEC-at-a-Glance-2019
[2] https://www.apec.org/About-Us/About-APEC/Member-Economies
[3] http://www.xinhuanet.com/world/2018-11/18/c_1123730304.htm
[4] APEC Secretariat (2021), APEC at a Glance, Available via https://www.apec.org/Publications
[5] APEC Energy Database (2020) APEC Energy Working Group EGEDA. https://www.egeda.ewg.apec.org
[6] Key World Energy Statistics (2020) IEA. https://www.iea.org/statistics/kwes/supply
[7] 2014 APEC Leader's Declaration, https://www.apec.org/Meeting-Papers/Leaders-Declarations/2014/2014_aelm.aspx .
[8] 2015 APEC Leader's Declaration, https://www.apec.org/Meeting-Papers/Leaders-Declarations/2015/2015_aelm.aspx .
[9] 2016 APEC Leader's Declaration, https://www.apec.org/Meeting-Papers/Leaders-Declarations/2016/201_aelm.aspx.
[10] 58th Energy Working Group Meeting, Antofagasta, Chile, 14-18 October 2019. https://www.ewg.apec.org/ewg58.html
[11] BP. Statistical Review of World Energy 2020. 2020.
[12] CREEI, ACE. The Present Layout and the Prospect of ASEAN Power Interconnection Projects. 2019.
[13] CREEI, ACE. ASEAN Feed-in tariff (FIT) Mechanism Report. 2017.
[14] IEA. World Energy Outlook 2019. 2019.
[15] IEA, 2019. https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity
[16] https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health
[17] https://www.fs-unep-centre.org/global-trends-in-renewable-energy-investment-2019/#downloads
[18] IRENA, Renewable Capacity Statistics 2020, 2020
[19] REN21, Renewables 2020 Global Status Report, 2020.
[20] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf.
[21] World Bank Group. Doing Business 2020. 2020.
[22] UNEP， Global Trends in Renewable Energy Investment
[23] 水电水利规划设计总院，东盟国家可再生能源发展规划及重点案例国研究，2019.
[24] 水电水利规划设计总院，中国可再生能源国际合作报告 2019，2020.
[25] 水电水利规划设计总院，东盟上网电价（FIT）机制报告，2018
[26] 水电水利规划设计总院，东盟国家能源可及实践经验及展望，2020
[27] 水电水利规划设计总院，东盟电力互联互通项目进展和展望，2019
[28] 东盟能源中心、水电水利规划设计总院，东盟电力合作报告
[29] 香港特别行政区政府统计处，香港能源统计 2019 年年刊，2020.
[30] Climate Policy Database. http://climatepolicydatabase.org/index.php/Climate_Policy_Database
[31] Australia's Renewable Energy Target (2015). https://www.cleanenergycouncil.org.au/advocacy-initiatives/renewable-energy-target
[32] Australia National Energy Guarantee (2018): http://coagenergycouncil.gov.au/publications/energy-security-board-%E2%80%93-final-detailed-design-national-energy-guarantee
[33] Canada's Energy Future 2019. www.cer-rec.gc.ca/energyfutures
[34] The 5th Strategic Energy Plan (2015): https://www.enecho.meti.go.jp/en/category/others/basic_plan/
[35] 9th Electricity Demand and Supply Basic Plan 2019-2034 (2020):
[36] Renewable energy outlook for ASEAN, IRENA and ACE. 2016, http://www.mofcom.gov.cn/article/i/jyjl/j/202005/20200502962939.shtml
[37] 水电水利规划设计总院，东盟电力互联互通项目进展和展望，2019
[38] 国网能源研究院有限公司，国内外电力市场化改革分析报告，2019.
[39] 全球能源互联网发展合作组织，《全球能源互联网标准体系研究》，2018；
[40] IEC, https://www.iec.ch/
[41] IEEE, https://standards.ieee.org/.
[42] EIA, annual energy outlook 2011 with projections to 2035
[43] 何国庆,王伟胜,刘纯,张悦,梁志峰,孙文文,李光辉.分布式电源并网技术标准研究[J].中国电力,2020,53(04):1-12+176.
[44] Navigant research, http://www.navigantresearch.com/
[45] http://www.chinanews.com/cj/shipin/cns/2018/10-18/news789480.shtml
[46] 中国电力出版社：《2019 世界电力行业跨国投资分析报告》
[47] IRENA [International Renewable Energy Agency]. 2016a. Investment Opportunities in Latin America: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects. Abu Dhabi: International Renewable Energy Agency.
[48] IRENA. 2016b. Investment Opportunities in the GCC: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects. Abu Dhabi: International Renewable Energy Agency.
[49] IRENA. 2014. Global Atlas for Renewable Energy: Overview of Solar and Wind Maps. Abu Dhabi: International Renewable Energy Agency. http://www.irena.org/DocumentDownloads/Publications/GA_Booklet_Web.pdf .
[50] ESMAP. RE resources mapping. https://www.esmap.org
[51] https://wwindea.org
[52] Cristina Lozej Archer, Mark Z. Jacobson. Evaluation of global wind power. Published 2005, Journal of Geophysical Research
[53] IRENA. 2020. Renewable Power Generations Costs in 2019
[54] Wright, T. P. 1936, Factors Affecting the Cost of Airplanes. Journal of the Aeronautical Sciences, 3, 122-128.
[55] McDonald, A., & Schrattenholzer, L. 2001, Learning rates for energy technologies. Energy Policy, 29, 255-261.
[56] Wilson, C. (2012). Up-scaling, formative phases, and learning in the historical diffusion of energy technologies. Energy Policy, 50(0), 81-94.

[57] European Patent Office (EPO). https://www.epo.org/index.html
[58] The International Standards and Patents in Renewable Energy (INSPIRE). http://inspire.irena.org/Pages/patents/Patents-Search.aspx
[59] Ball, J. et al. (2017), The new solar system: China's evolving solar industry and its implications for competitive solar power in the United States and the world, Steyer-Taylor Center for Energy Policy and Finance, Stanford University, March
[60] Zhang Zhankui,Li Yan,Chi Yongning,Tian Xinshou . Research on Domestic and Foreign Status and Progress of Renewable Energy Grid-connected Technical Standards. Power supply and consumption ,2017,34(09):9-13.
[61] IEC, https://www.iec.ch/renewables/standardization.htm
[62] https://www.fs-unep-centre.org/wp-content/uploads/2020/06/GTR_2020.pdf
[63] 国家电网有限公司，服务新能源发展报告，2020.
[64] IRENA, Scaling up Variable Renewable Power: The Role of Grid Codes, 2016.
[65] IRENA, International Standardisation in the Field of Renewable Energy, 2013.
[66] 张占奎,李琰,迟永宁,田新首.国内外可再生能源并网技术标准现状及进展研究[J].供用电,2017,34(09):9-13.
[67] http://www.chinanews.com/cj/shipin/cns/2018/10-18/news789480.shtml
[68] IEC，https://www.iec.ch/renewables/standardization.htm
[69] NREL，Comparison of Standards and Technical Requirements of Grid-Connected Wind Power Plants in China and the United States，2016
[70] IRENA, Scaling up Variable Renewable Power: The Role of Grid Codes, 2016.
[71] IRENA, RENEWABLE ENERGY MARKET ANALYSIS SOUTHEAST ASIA
[72] 吴晓楠,吴凡,张燕平.秘鲁电力行业市场化改革进程及启示[J].电力需求侧管理,2019,21(02):77-80.
[73] 国家能源局，关于 2017、2018 年度全国电力价格情况监管通报
[74] BNEF 2020, Global Trends in Renewable Energy Investment 2020, Frankfurt School-UNEP Centre/BNEF. 2020 http://www.fs-unep-centre.org (Frankfurt am Main)
[75] BNEF, Bloomberg New Energy Finance, various issues
[76] Gupta A.R., 2020, Financing India's Renewable Energy Vision, ORF Issue Brief No. 336, January 2020, Observer Research Foundation.
[77] IEA 2020, World Energy Investment Outlook 2020, International Energy Agency, Paris
[78] IEA 2020, World Energy Outlook 2020, International Energy Agency, Paris
[79] IESR, 2018, Igniting a rapid deployment of renewable energy in Indonesia: Lessons Learned from Three Countries, Institute for Essential Services Reform, November 2018, Jakarta, Indonesia.
[80] IRENA (2020), Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi.
[81] Shrimali G., 2018, Renewable energy in India-Solutions to the financing challenges, Asie Visions, No.98, Ifri, February 2018.
[82] Sitorus S., Rakhmadi R., Haesra A., Muhammad E. W., (2018)., Energizing Renewables in Indonesia: Optimizing Public Finance Levers to Drive Private Investment, Climate Policy Initiative, November 2018. https://www.climatepolicyinitiative.org/wp-content/uploads/2018/11/Energizing-Renewables-in-Indonesia-Optimizing-Public-Finance-Levers.pdf
[83] REN21. 2020. Renewables 2020 Global Status Report, (Paris: REN21 Secretariat).
[84] World Bank, 2016, PROJECT APPRAISAL DOCUMENT ON A PROPOSED CLEAN TECHNOLOGY FUND (CTF) GUARANTEE IN THE AMOUNT OF US$44 MILLION TO THE LGU GUARANTEE CORPORATION FOR A PHILIPPINES RENEWABLE ENERGY DEVELOPMENT PROJECT, Report No: 72689-PH, Energy and Extractives Global Practice, East Asia and Pacific Region, April 18, 2016.
[85] BoS costs for solar PV include cable and wiring, grid connection, racking and mounting, safety and security, electrical and mechanical installation, customer acquisition, financing costs, permitting, system design and profit margin.
[86] https://www.allenovery.com/en-gb/global/news-and-insights/publications/new-developments-for-Viet Nam-renewable-energy
[87] https://www.newindianexpress.com/business/2019/mar/13/govt-modifies-rules-to-help-solar-parks-get-land-1950447.html
[88] https://www.powerengineeringint.com/renewables/iea-to-help-indonesia-to-accelerate-the-energy-transition/
[89] https://www.international-climate-initiative.com/fileadmin/Dokumente/landingpages/EW05_Renewable_Energy_Capacity_Building.pdf
[90] https://www.livemint.com/Politics/QW4cJ9yjhmvUtOZCPyOt3J/Govt-eases-environment-clearance-rules-for-solar-projects.html
[91] https://ec.europa.eu/international-partnerships/where-we-work/Viet Nam_en
[92] https://www.eliagrid-int.com/elia-grid-international-active-in-Viet Nam-with-three-projects-to-support-renewable-integration/
[93] https://www.wfw.com/wp-content/uploads/2018/08/WFWBriefing-Renewable-energy-Philippines.pdf
[94] https://ieefa.org/op-ed-mexico-is-poised-for-a-renewable-energy-revolution/
[95] https://www.pwc.com/sg/en/publications/assets/renewable-energy-in-asia-pacific-2018.pdf
[96] https://www.marketlinks.org/resources/analysis-renewable-energy-auctions-six-countries
[97] https://www.thedialogue.org/wp-content/uploads/2018/05/mexico_renewable_energy_future_0.pdf
[98] https://www.nature.com/articles/d42473-018-00330-7#:~:text=Determined%20to%20make%20up%20lost,is%20serious%20about%20energy%20transition.
[99] https://amplussolar.com/resco-solar
[100] https://aseanenergy.org/energy-cooperatives-option-for-pushing-indonesias-energy-transition/
[101] https://climatepolicyinitiative.org/wp-content/uploads/2018/11/Energizing-Renewables-in-Indonesia-Optimizing-Public-Finance-Levers.pdf
[102] https://www.climatepolicyinitiative.org/publication/energizing-renewables-in-indonesia-optimizing-public-finance-levers-to-drive-private-investment/
[103] https://www.thejakartapost.com/news/2019/02/07/indonesian-institutions-struggle-to-get-funding-for-green-energy-projects.html.
[104] https://www.adb.org/sites/default/files/publication/541531/renewable-energy-financing-indonesia.pdf
[105] https://www.ibef.org/industry/renewable-energy.aspx
[106] https://library.fes.de/pdf-files/bueros/philippinen/13975.pdf

[107] https://www.dbp.ph/developmental-banking/infrastructure-and-logistics/financing-utilities-for-sustainable-energy-development-fused/
[108] https://www.fs-finance.com/the-rise-of-the-banh-mi-how-Viet Nam-became-the-renewable-energy-powerhouse-of-southeast-asia/
[109] https://www.allenovery.com/en-gb/global/news-and-insights/publications/banking-solar-in-Viet Nam--a-look-at-the-next-wave-of-renewable-power-projects-in-Viet Nam
[110] https://www.vir.com.vn/unlock-long-term-financing-for-solar-power-in-Viet Nam-73242.html
[111] https://solarbusinesshub.com/2020/10/10/adb-provides-186-million-green-loan-for-257-mw-solar-pv-project-in-Viet Nam-one-of-the-largest-in-southeast-asia /
[112] https://www.wfw.com/wp-content/uploads/2018/08/WFWBriefing-Renewable-energy-Philippines.pdf
[113] A Donastorg et al 2017 IOP Conf. Ser.: Earth Environ. Sci. 83 012012, Financing Renewable Energy Projects in Developing Countries: A Critical Review
[114] https://solarbusinesshub.com/2020/10/10/adb-provides-186-million-green-loan-for-257-mw-solar-pv-project-in-Viet Nam-one-of-the-largest-in-southeast-asia/
[115] https://www.climateinvestmentfunds.org/economy/mexico
[116] https://renewablesnow.com/news/canadian-solar-secures-funds-for-126-mwp-project-in-mexico-716291/
[117] Renewables finance and investment: how to improve industry with private capital in China Pingkuo LIU1 , Penghao CHU1, J. Mod. Power Syst. Clean Energy (2019) 7(6):1385–1398 https://doi.org/10.1007/s40565-018-0465-6
[118] https://www.cnbc.com/2019/11/04/china-does-not-need-foreign-help-in-renewable-energy-wood-mackenzie.html
[119] https://www.nortonrosefulbright.com/en-me/knowledge/publications/71562ac3/renewable-energy-snapshot-Viet Nam
[120] Z. Ming et al. / Renewable and Sustainable Energy Reviews 31 (2014) 23–3728
[121] https://www.iisd.org/system/files/publications/public_finance_renewable_energy_china.pdf
[122] Omri, A, 2014. An international literature survey on energy-economic growth nexus: Evidence from country-specific studies. Renewable and Sustainable Energy Reviews, 38, pp.951–959.
[123] https://www.imf.org/en/Publications/WEO/Issues/2020/06/24/WEOUpdateJune2020
[124] https://www.iea.org/articles/the-impact-of-the-covid-19-crisis-on-clean-energy-progress
[125] https://www.iea.org/reports/world-energy-investment-2020/key-findings?utm_content=buffer47e92&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer
[126] https://www.fvee.de/fileadmin/publikationen/Themenhefte/sf2004/sf2004_05_01.pdf
[127] https://www.iea.org/reports/sustainable-recovery/covid-19-and-energy-setting-the-scene
[128] https://www.eliagrid-int.com/elia-grid-international-active-in-Viet Nam-with-three-projects-to-support-renewable-integration/
[129] Zhao, Z.-Y., Chen, Y.-L., & Chang, R.-D. (2016). How to stimulate renewable energy power generation effectively? - China's incentive approaches and lessons. Renewable Energy, 147-156.
[130] https://www.iea.org/statistics/rdd/
[131] 全球能源互联网发展合作组织:《全球能源互联网标准体系研究》, 2018
[132] http://www.depd.gov.bn/SitePages/eData%20library.aspx
[133] http://www.memi.gov.bn/SitePages/Home.aspx
[134] https://www.iea.org/countries/chile
[135] http://climatepolicydatabase.org/index.php/National_Energy_Policy_2050
[136] https://www.censtatd.gov.hk/hkstat/sub/sp90_tc.jsp?productCode=B1100002
[137] http://www.xinhuanet.com/gangao/2017-01/20/c_1120355303.htm
[138] http://www.powermag.com/indonesias-pt-pln-cancels-22-gw-of-planned-capacity-citing-lax-demand/
[139] https://www.enecho.meti.go.jp/en/reports/
[140] http://climatepolicydatabase.org/index.php/Sustainable_Energy_Development_Authority_Act_2011_Malaysia_2011
[141] http://www.jccief.org.cn/v-1-9314.aspx
[142] https://www.labour.org.nz/release-renewable-electricity-generation-2030
[143] https://png-data.sprep.org/dataset/png-development-strategic-plan-2010-2030
[144] https://www.iea.org/policies/6307-national-energy-plan-for-2010-2040-politica-energetica-nacional-del-peru-2010-2040
[145] https://www.doe.gov.ph/
[146] https://minen ergo.gov.ru/node /1920
[147] https://www.ema.gov.sg/index.aspx
[148] https://www.moeaboe.gov.tw
[149] http://www.eppo.go.th/index.php/en/policy-and-plan/en-tieb/tieb-pdp
[150] https://www.eia.gov/
[151] https://www.readkong.com/page/alternating-currents-indonesian-power-industry-survey-2018-7031263
[152] IEA, "Policies", https://www.iea.org/topics/renewables/policies, viewed 21 October 2019
[153] .https://en.evn.com.vn/d6/news/Revision-of-National-Power-Development-Master-Plan--66-163-414.aspx
[154] Infrastructure Goal and Strategies, Medium Term Development Plan III 2018-2022
[155] PWC Global Power & Utilities. 2016. Electricity beyond the grid: Accelerating access to sustainable power for all. https://www.pwc.com/gx/en/energy-utilities-mining/pdf/electricity-beyond-grid.pdf
[156] Nygaard I. and T. Dafrallah. 2016. "Utility led rural electrifica- tion in Morocco: combining grid extension, mini-grids, and solar home systems." Wiley Interdisciplinary Reviews (WIREs) Energy and Environment 5(2): 155–168.
[157] Consorcio Macroconsult S. A.–Instituto Cuánto. 2016. "Servicio de consultoría para la evaluación socio-económica de resultados de sub-proyectors de electrificación rural." Lima, Peru: Ministerio de Energía y Minas
[158] ADB, 2015, Business models to realize the potential of renewable energy and energy efficiency in the Greater Mekong Subregion. Mandaluyong City, Philippines: Asian Development Bank, 2015.
[159] ADB 2019, Renewable Energy Financing Schemes for Indonesia, Asian Development Bank, November 2019, Manila, Philippines.
[160] Barroco J., and M. Herrera, Clearing barriers to project finance for renewable energy in developing countries: A Philippines case study, Energy Policy 135 (2019).

[161] Barroso L A., Bouile D., P. del Río, O. Ferreño, C. Marschel, M. Muñoz and R. Ramírez, 2017., Renewable Energy Auctions in Latin America and the Caribbean, Global Environment Facility (GEF)
[162] Bertheaua. P, Dionisioc J., Jüttea C., and Aquinoc C. ,(2019), Challenges for implementing renewable energy in a cooperative-driven off-grid system in the Philippines, Environmental Innovation and Societal Transitions, • March 2019.
[163] Cozzi, P., 2012, Assessing Reverse Auctions as a Policy Tool for Renewable Energy Deployment, Number 007, ENERGY, CLIMATE, AND INNOVATION Program, THE FLETCHER SCHOOL TUFTS UNIVERSITY, May 2012.
[164] Fortaleza, W., Diokno M. T., Ong T. A., Bordamonte, J., 2016. Geing TheRE Geing through the humps and red lights that hinder the advance of green energy, the Friedrich-Ebert-Stiftung – Philippine Office, 2016.
[165] IEA 2017. Energy policies beyond IEA countries. Retrieved on April 4, from https://www.iea.org/publications/freepublications/publication/EnergyPoliciesBeyondIEACountriesMexi co2017.pdf
[166] IESR, 2018, Igniting a rapid deployment of renewable energy in Indonesia: Lessons Learned from Three Countries, Institute for Essential Services Reform, November 2018, Jakarta, Indonesia.
[167] IRENA (2020), Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi.
[168] Javier Molina; Nadia Scharen-Guivel; and Eric Hyman. 2018. Analysis of Renewable Energy Auctions in Six Countries. Washington, DC: Crown Agents USA, and Abt Associates, Prepared for the U.S. Agency for International Development.
[169] Liu P., and Chu P., 2019, Renewables finance and investment: how to improve industry with private capital in China, Journal Mod. Power Syst. Clean Energy (2019) 7(6):1385–1398
[170] Ming Z., Ximei L., Yulong L., and Lilin P., 2014., Review of renewable energy investment and financing in China: Status, mode, issues and countermeasures, Renewable and Sustainable Energy Reviews 31 (2014) 23–37
[171] Nguyen, T. C., A. T. Chuc, and L. N. Dang. 2018. Green Finance in Viet Nam: Barriers and Solutions. ADBI Working Paper 886. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/green-finance-viet-nam-barriers-and-solutions
[172] PwC, 2018, The next frontier for infrastructure investments: Renewable Energy in Asia-Pacific, PricewaterHouse Cooper, Singapore.
[173] https://www.eia.gov/energyexplained/renewable-sources/incentives.php
[174] Building a Sustainable Energy Future: The Greater Mekong Subregion, Asian Development Bank.
[175] Update of the GMS Regional Master Plan, Asian Development Bank, October 15, 2010
[176] https://www.irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019
[177] McCollum, D., L. Gomez Echeverri, K. Riahi, and S. Parkinson. "Sdg7: Ensure access to affordable, reliable, sustainable and modern energy for all." (2017): 127-173. Retrieved from: http://pure.iiasa.ac.at/id/eprint/14621/1/SDGs-interactions-7-clean-energy.pdf. Accessed 15 August 2021
[178] Nerini, Francesco Fuso, Julia Tomei, Long Seng To, Iwona Bisaga, Priti Parikh, Mairi Black, Aiduan Borrion et al. "Mapping synergies and trade-offs between energy and the Sustainable Development Goals." Nature Energy 3, no. 1 (2018): 10-15. Retrieved from: https://discovery.ucl.ac.uk/id/eprint/10037715/3/Tomei_Manuscript%20-%20Energy%20and%20the%20SDGs_final.pdf. Accessed 15 August 2021
[179] Aglanu, Leslie Mawuli. "Powering up Sub-Sahara Africa's renewable energy revolution through diffusion." (2018)
[180] https://openknowledge.worldbank.org/bitstream/handle/10986/33191/Sustainability-Review-2019.pdf?sequence=1&isAllowed=y
[181] IEA, 2019. https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity
[182] WBD, 2018. https://data.worldbank.org/indicator/AG.SRF.TOTL.K2?locations=PG
[183] WBD, 2020. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=PG
[184] www.adb.org/publications/basic-statistics-2018
[185] Ibid ADB basic statistics. https://www.adb.org/countries/papua-new-guinea/poverty
[186] WBD, 2020. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=PG
[187] ADB Member Fact Sheet, 2020. https://www.adb.org/sites/default/files/publication/27788/png-2020.pdf
[188] ADB Country Strategy and Programme, Papua New Guinea (CSP PNG), June 2006, p.4
[189] ADB Country Economic Review, Papua New Guinea, June 2000, p.5
[190] World Bank Country Brief, Papua New Guinea, May 2010: http://web.worldbank.orq/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/PAPUANEWGUINEAEXTN/O,,contentMDK:20174825~menuPK:333775~pagePK:1497618~piPK:217854~theSitePK:333767,00.html
[191] https://unstats.un.org/unsd/energystats/dataPortal/
[192] Rawali, Manu, Anna Bruce, Atul Raturi, Brian Spak, and Iain MacGill. "Electricity Access Challenges and Opportunities in Papua New Guinea.
[193] Renagi, O. and Babarinde, J. A. (2017), Sustainable Energy Policy for Papua New Gduinea Incorporating Mandatory Environmental Impact Assessment (EIA), Melanesian Journal of Geomatics and Property Studies, Vol. 3, pp. 1-10
[194] https://postcourier.com.pg/national-electrification-plan-near-completion/
[195] http://news.pngfacts.com/2016/04/adb-supports-png-to-increase-access-to.html
[196] Pacific Power Association (PPA). 1998. Pacific Power Benchmarking Summary Report: 2017 Fiscal Year. PPA. Suva, Fiji
[197] Pacific Power Association (PPA). 1999. Pacific Power Benchmarking Summary Report: 2018 Fiscal Year. PPA. Suva, Fiji
[198] Renewable energy opportunities and challenges in the Pacific Islands region: Papua New Guinea, IRENA, 2013, p. 3, https://www.irena.org/DocumentDownloads/Publications/Papua%20New%20Guinea.pdf
[199] The Lowy Institute. 2017. Infrastructure Challenge for Papua New Guinea. Sydney. http://interactives.lowyinstitute.org/publications/PNGin2017/png-in-2017-infrastructure-challenges-for-papua-new-guineas-future.html#thirteen.
[200] EU TAF. 2017. Stocktaking Mission to Analyze Private Sector Activities and the Funding Opportunities in Renewable Investments in the Pacific Region Program Identification and Formulation.
[201] MTDP 2011-2015, p.57
[202] MFAT 2018 'Evaluation of New Zealand's Country Programme in PNG, Part IV, prepared by Adam Smith International.
[203] PPA, Pacific Energy Investors Forum. 2018. https://www.ppa.org.fj/event/pacific-energy-investors-forum/
[204] PPL.2020. Electricity Tariff. http://www.pngpower.com.pg/electricity-tariffs, access on 7 October 2020
[205] https://emtv.com.pg/png-power-signs-agreement-with-ifc/

[206] https://www.pg.undp.org/content/papua_new_guinea/en/home/presscenter/pressreleases/2020/promoting-renewable-energy-in-papua-new-guinea-.html
[207] Chinese Embassy in PNG 2018. http://pg.china-embassy.org/chn/xwdt/t1566991.htm
[208] https://www.pm.gov.au/media/papua-new-guinea-electrification-partnership
[209] IRENA. 2013. Pacific Lighthouses – Renewable Energy Opportunities and Challenges in the Pacific Islands Region: PNG
[210] https://globalwindatlas.info
[211] Basil, S. H. (2018), March PNG Energy Policy, Port Moresby, Papua New Guinea.
[212] https://www.thenational.com.pg/bill-to-establish-energy-authority-in-progress-kua/
[213] Duncan, Samantha. 2011. Papua New Guinea Energy Strategic Review.
[214] IRENA. 2016. Renewable Energy Benefits: Decentralized Solutions in the Agro-food Chain.
[215] During the field mission it was mentioned that some activities in the region provide solar off-grid lighting to households. https://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/cm-stories/papua-new-guinea-300-days-of-sunshine
[216] Nygaard I. and T. Dafrallah. 2016. “Utility led rural electrification in Morocco: combining grid extension, mini-grids, and solar home systems.” Wiley Interdisciplinary Reviews (WIREs) Energy and Environment 5(2): 155–168.
[217] EnDev Peru. Nrgising Development Project. 2018
[218] Política Energética Nacional del Perú 2010-2040.
[219] Ministry of Energy and Mines (MINEM) https://www.gob.pe/minem.
[220] Mayra Viviana Aguirre Ramírez. 2016. How-to-enhance-rural-electrification-requirements-in-Peru. Centre for Energy, Petroleum and Mineral Law and Policy, University of Dundee.
[221] Ministry of Energy of Mines and National Service for Meteorology. Peru’s Solar Energy Atlas. Lima. 2003. p.17.
[222] WindAid Institute. https://www.windaid.org/light-up-a-life/peru-electrification-programs/
[223] The Netherland Government. Commercial-opportunities-in-the-peruvian-energy-sector. 2018
[224] Consorcio Macroconsult S. A. and Instituto Cuánto. 2016. “Servicio de consultoría para la evaluación socio-económica de resultados de sub-proyectors de electrificación rural.” Lima, Peru: Ministerio de Energía y Minas.
[225] IEA, 2020. Southeast Asia Energy Outlook 2019.IEA/OECD