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# Integrating Electrical Vehicles and Solar Rooftop PV in Electricity Distribution Systems with Continued Performance of Distribution Transformers

**APEC Energy Working Group**

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Asia-Pacific
Economic Cooperation

# Integrating Electrical Vehicles and Solar Rooftop PV in Electricity Distribution Systems with Continued Performance of Distribution Transformers

**Technical and Policy Recommendation Report**

**APEC Energy Working Group**

**December 2022**

APEC Project:  EWG 03 2020A

Produced by
Watcharin Boonyarit (Project Overseer)
Department of Alternative Development Energy Development and Efficiency
Ministry of Energy
17 Rama I Road, Kasatsuk Bridge,
Pathumwan, Bangkok 10330 Thailand
Telephone: +66-2129-3344
Fax: +662 226 1416
Email: munlika_s@dede.go.th

In partnership with
Pierre Cazelles
Director - Global Partnerships
International Copper Association
Email: pierre.cazelles@copperalliance.org

Developed by
Sommai Phon-Amnuaisuk
Director, Asia-Pacific
International Institute for Energy Conservation
Email: sphonamnuaisuk@iiec.org

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org



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## Table of Contents


1 INTRODUCTION .......... 8
1.1 Background .......... 8
1.2 Presence of Solar PV Systems and EVs in Distribution Networks .......... 8
1.3 About This Report .......... 9
2 SITUATION ANALYSIS .......... 10
2.1 Summary of Key Energy Statistics on Solar PV Use and Transportation .......... 11
2.2 Solar PV and EV Situation in APEC Economies .......... 15
2.3 GHG Emissions Reduction from Rooftop Solar PV and EV .......... 34
3 IMPACTS OF ROOFTOP SOLAR PV & EV ON DISTRIBUTION NETWORK .......... 37
3.1 Impacts of PV on Distribution Network .......... 37
3.2 Impacts of EV on Distribution Network .......... 42
3.3 Potential Benefits of Coordinated PV and EV Integration .......... 43
4 GRID CONNECTION REQUIREMENTS FOR ROOFTOP SOLAR PV .......... 45
4.1 Current Practices and Standards .......... 46
4.2 Grid Connection Requirements in APEC Economies .......... 48
5 CONCLUSIONS AND RECOMMENDATIONS .......... 60
5.1 Conclusions .......... 60
5.2 Recommendations .......... 61
6 REFERENCES .......... 63
7 ANNEXES .......... 77
7.1 Annex A: Assumptions used in GHG Accounting .......... 77
7.2 Annex B: Workshop Report .......... 79

# Figures

Figure 2-1: Annual Installed Capacity (MW) Addition of Distributed Solar PV by Customer Segment 19
Figure 2-2: Project EV by 2040 (Philippines DOE, 2021) ........ 29
Figure 2-3: Annual Installation of Residential Solar PV Capacity in Singapore ........ 30
Figure 2-4: Average Annual Solar Capacity Installation in the Residential Sector - U.S. ........ 33
Figure 3-1: Original Duck Curve predicted by CAISO in 2013 ........ 39
Figure 3-2: Predicted Net Load vs Actual Net Load 2012 - 2020 ........ 40
Figure 3-3: Sunny Day Load Profile – Hypermart Building with Rooftop Solar PV ........ 41
Figure 3-4: Cloudy Day Load Profile – Hypermart Building with Rooftop Solar PV ........ 41
Figure 3-5: Low Voltage Feeder Load Profiles with/without EV Load ........ 43
Figure 4-1: Grid Code Structure and Type of Codes ........ 45
Figure 4-2: Relationship Between Different Tools and Application Activities ........ 47
Figure 4-3: Key Application Procedure in Applying for Feed-in Tariff (FiT) in Hong Kong, China ........ 52
Figure 4-4: FERC SGIP Technical Screen Summary ........ 57
Figure 4-5: Typical Utility Interconnection Process ........ 58
Figure 7-1: Assumptions and factors used for GHG accounting ........ 77

# Tables

Table 2-1: Key Energy Statistics in APEC Economies ........ 11
Table 2-2: GHG Emissions that can be avoided with current utilisation of Rooftop Solar PV ........ 35
Table 3-1: Possible Impacts on Distribution Network and Transformer ........ 37
Table 4-1: Summary of Grid Connect Requirements in APEC Economies ........ 48
Table 4-2: Type of License for Solar PV System in Singapore ........ 55
Table 4-3: Maximum Installed Capacity of Residential Rooftop Solar PV in Thailand ........ 56

# Glossary of Terms

**Battery electric vehicle** – vehicle powered solely by an electric battery and is charged through a charging port.

**Distributed energy resource** - small, modular, energy generation and storage technologies that provide electric capacity or energy where it is needed; capacity is dependent on particular needs and usually installed on site or near site of use.

**Demand response** - reducing or shifting electricity usage during peak periods in response to time-based rates or other forms of financial incentives.

**Loss of Life** – relates to the ageing and lifetime use of a distribution transformer.

**Feed-in-tariff** - an energy policy focused on supporting the development and dissemination of renewable power generation. This scheme allows providers of energy from renewable sources, such as solar, wind or water, receive a price for what they produce based on the generation costs.

**Hybrid electric vehicle** – vehicle with both battery and electric motor, but electric motor is used to assist the gas-powered engines; power comes only from gasoline.

**Net metering** - is a billing mechanism that credits solar energy system owners for the electricity they add to the grid.

**Plug-in hybrid vehicle** – vehicle with both battery and electric motor and can be powered by both charging in a charging port and fueling the gas tank.

**State of charge** – amount of energy available in a battery at a specific point in time relative to its full capacity.

# Abbreviations

| | |
|---|---|
| APEC | Asia-Pacific Economic Cooperation |
| BEV | Battery Electric Vehicle |
| CAGR | Compounded annual growth rate |
| CHP | Combined heat and power |
| CT | Current transformer |
| DER | Distributed energy resources |
| DR | Demand response |
| DSM | Demand side management |
| EE&C | Energy efficiency and conservation |
| EIA | U.S. Energy Information Administration |
| EPS | Electric power systems |
| EV | Electric vehicle |
| EWG | Energy Working Group of the APEC |
| FiT | Feed-in-tariff |
| GDP | Gross Domestic Product |
| ICE | Internal combustion engine |
| IEA | International Energy Agency |
| IEEE | Institute of Electrical and Electronics Engineers |
| LGU | Local government unit |
| LOL | Loss of Life |
| LV | Low voltage |
| MV | Medium voltage |
| NEMAS | Net Energy Metering Assessment Study |
| PHEV | Plug-in Hybrid Electric Vehicle |
| PV | Solar Photovoltaic |
| R&D | Research and development |
| RE | Renewable energy |
| REC | Renewable Energy Certificate |
| RPS | Renewable Portfolio Standards |
| SoC | State of charge |
| TFEC | Total final energy consumption |
| TPES | Total primary energy supply |
| WTE | Waste-to-energy |

# Units

| | |
|---|---|
| GJ | Giga joule |
| GW | Gigawatts |
| GWh | Gigawatt-hour |
| hr | Hours |
| kTOE | Kilo tonnes of oil equivalent |
| kW | kilowatts |
| kWh | Kilowatt-hour |
| $m^2$ | Square meters |
| MW | Megawatts |
| MWac | Megawatts alternating current |
| MWdc | Megawatts direct current |
| MWh | Megawatt-hour |
| $tCO2_{eq}$ | Tonnes of carbon dioxide equivalent |
| TOE | Tonnes of oil equivalent |
| PJ | Peta joules |
| W | Watts |

# 1 INTRODUCTION

## 1.1 BACKGROUND

The project Integrating Electrical Vehicles and Solar Rooftop PV in Electricity Distribution Systems with Continued Performance of Distribution Transformers (EWG 03 2020A) has the overall objective to help formulate recommendations to sustain the electricity distribution system performance and reliability when integrating rooftop solar PV (photovoltaic) and electric vehicle (EV) charging systems, and thus contributing to the sustainable modernization of electricity distribution systems with preserved performance and reliability. The project is jointly implemented by the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy of Thailand and the International Copper Association (ICA).

The project includes extensive literature reviews of impacts of rooftop solar PV and EV connections to distribution networks, and preparation of technical and policy recommendations for utilities, manufacturers, and policy makers. In line with the overall objective, the specific objective of the project is to build the capacity of APEC economies' utilities and policymakers to understand and address the technical, environmental, and economic impacts on distribution transformers of connecting rooftop solar PV installations and electrical vehicles charging stations to electricity distribution systems.

## 1.2 PRESENCE OF SOLAR PV SYSTEMS AND EVS IN DISTRIBUTION NETWORKS

The integration of solar PV systems into distribution networks may present unwanted effects on system stability and power quality to distribution system equipment, such as distribution transformers (DTs) and conductors. These effects are mainly caused by the intermittent nature of solar PV generation, capacity of the solar PV system, and its point of connection within the network. Given high power consumption of EV chargers, EV charging demands have become a new type of load for electric utilities; however, uncertainties in EV connection points as well as time and period of charging have caused challenges for utilities to predict the behavior of this new load.

Greater penetration of solar PV in electricity grid can impose significant challenges on the grid in terms of voltage and frequency stability. A thorough study on the impacts of solar PV penetration on the distribution network voltage profile shows that the intermittency of a PV system can result in voltage rise and fluctuations, and these negative impacts become worse as the integration of PV system increases. Large-scale grid integration of PV systems can potentially impact the grid frequency stability. Power quality is also one of the major concerns for integrating PV systems into the grid. The main power quality parameters regarding PV integration involve voltage, power fluctuations, and harmonic distortions.

EV charging can potentially cause voltage drop, voltage deviation, voltage instability, overloading of distribution lines, system instability, harmonics and system losses, and higher occurrence of short-circuit currents to the distribution network. These potentially damaging effects would result for a need to provide additional investments for the upgrading of the distribution infrastructure and expanding generation capacity. EVs, however, can be income generating as the energy stored in the vehicle can be part of the electricity market and serve as ancillary service and faster ramp up source.

In addition to the grid stability and power quality, combined PV and EV integration also impact network equipment. For DTs, daytime loading may be decreased due to increased capacity from solar PV generation. However, when solar PV capacity is increased above its optimal cumulative capacity, reverse power flow can occur, resulting to overloading of DTs and conductors. Integrating EV charging systems into a low voltage distribution network can also cause overheating of the network equipment, especially when EV charging is uncontrolled. The severity of the impact to DT depends not only on the amount of load, but also on the EV connection point; if the EV is connected to a weak bus and receiving charge, then the impact is more likely to be prominent.

Electric utilities are generally aware of the impacts of PV and EV integration, and to ensure stability of distribution power system and quality of power supply, local utilities require all rooftop solar PV installations/projects to be approved before connecting into the electricity grid. The grid connection requirements for rooftop solar PV or "grid codes," help regulate quality of the local distribution networks and prevent adverse impacts on network equipment.

While the integration of solar PV systems and EVs separately to the distribution network presents challenges to the system, the coordinated operation of solar PV and EV charging can be complementary to each other. It can overcome the grid stability and power quality issues that may arise due to individual integration of these devices. Several research works have investigated and reported the individual impact of PV system and EV charging on the grid operation. However, a very few studies have been reported in the literature that investigates the combined impacts of PVs and EVs on grid stability, power quality, and energy economics.

## 1.3 ABOUT THIS REPORT

This Technical and Policy Recommendation Report summarizes review and assessment of adoption of rooftop solar PV systems and EVs, and impacts of PV and EV to the distribution network. The review and assessment are based primarily on research works and survey questionnaires distributed to all APEC economies. The report contents are structured around the following main sections:

1) Introduction;
2) Solar PV and EV Situation in APEC Economies – summarizing key statistics on rooftop solar PV and EV adoption in each APEC economy;
3) Impacts of Rooftop Solar PV & EV on Distribution Network – based on literature reviews, discussing the impacts of solar PV and EV adoption on stability and power quality of distribution network, and impacts on distribution transformers' loading and lifetime;
4) Grid Connection Requirements for Rooftop Solar PV – reviewing grid connection codes in APEC economies to quality operation of distribution networks; and
5) Conclusions and Recommendations.

# 2 SITUATION ANALYSIS

Solar PV and EV are among the available technologies expected to help address the global climate crisis while economies continue to advance their economic and development goals. In power generation, solar PV is one of the mature technologies in modern renewable energy and, thus, its adoption has increased significantly in recent years. The IEA reported that solar PV remains to be at the forefront of renewable electricity generation. At a global scale, renewable energy will account for 95% of the additional capacity until 2026, with more than half coming from solar PV. (IEA, 2021). Meanwhile, the APEC EWG expects solar power to be the fastest source of energy to grow under a business-as-usual scenario in the economic region, with a 6.8% CAGR (APERC, 2019).

China is a significant player in the solar industry, having the largest solar power installed capacity of 253 GW as of 2020. However, majority of the economy's solar energy is on the utility scale, but it is expected that distributed solar energy and will flourish following the Chinese Government's policy to boost renewable consumption (Reuters, 2021). In terms of rooftop solar installation, Australia is considered a leader in solar PV adoption in the APEC region and globally with an installation rate of 275 W per capita per annum. Approximately 30% of households have rooftop solar PV, where there are around 3 million installations as of November 2021 (Department of Industry, Science, Energy, and Resources, 2021).

Viet Nam has surpassed expectations when the economy had a solar PV project boom, which started in 2019, making it the top solar PV energy producer in the ASEAN. In only one year, between 2018 and 2019, solar PV capacity in the economy increased from 134 MW to 5.5 GW (The Asean Post, n.d.) and in just one month in December 2020, Viet Nam recorded an additional 6.71 GW in rooftop installation. In contrary, Russia and Papua New Guinea (PNG) needs to scale up their efforts to fully utilise solar energy within their area. As of 2019, Russia is drafting a net metering scheme for rooftop solar PV while PNG has recently allowed power generation from solar rooftop PV as previously, it was illegal to generate own electricity from solar PV at the household level.

Meanwhile, EV adoption is slowly making its way into the global vehicle fleet, with hopes of eventually phasing out carbon-intensive internal combustion engine (ICE) vehicles in land transport. Singapore and Chinese Taipei have ambitiously signified that it will phase out ICE vehicles by 2040 while Thailand aims to exclusively manufacture EVs by 2035. In the APEC, it is forecasted that battery EV (BEV) and plug-in hybrid EV (PHEV) will have a combined share of 18% in the total vehicle fleet in 2050 while hybrid EV is 6.4% of the vehicle fleet in the same year. It is also expected that in the ASEAN alone, EV sales will increase by almost 25% by 2022. Some ASEAN economies aim to be an EV manufacturing hub such as Indonesia and Thailand, alongside China who is also investing in the research and development of EV technology and EV manufacturing. Meanwhile, Korea is one of the economies who have earlier planned for EV adoption and EV research and development since the early 2000's. One of the common strategies being adopted by the economies to introduce EVs is to have such technology within their government and public transport fleet first or provide tax incentives for EV users. The USA and China are currently the largest EV users globally. However, economies such as the Philippines, Brunei Darussalam, and Papua New Guinea are yet to develop their EV policy while Malaysia lacks a clear EV programme despite tax exemptions for EV. PNG's unique transport system is dependent on water transport and the Pacific Island economy has a very low road density, so a different approach on EV adoption may be needed.

## 2.1 Summary of Key Energy Statistics on Solar PV Use and Transportation

Table 2-1 summarizes the key energy statistics of each APEC economy relevant to this study. It includes data on power generation and energy consumption in the transport sector.

***Table 2-1: Key Energy Statistics in APEC Economies***

| APEC Economy | Average Daily Solar PV Output (kW-hr/$kW_p$) | Installed Capacity | | Solar PV Generation (Reference year) | Electricity consumption (Reference year) | Transport sector energy consumption / demand (Reference year) |
|---|---|---|---|---|---|---|
| | | Rooftop Solar PV (Reference year) | Total Solar PV (Reference year) | | | |
| **Australia** | 4.95 | 13,000 MW (2020) | 26 GW (2021) / 1 kW of solar panel per person (2021) | 21,033 GWh (2020) | 9.9 MWh per capita (2019) | 1,748.4 PJ (2018-2019) |
| **Brunei Darussalam** | 3.81 | 100 kWp (2021) | - | 2.0 GWh (2018) | 8.9 MWh per capita (2018) | 18.85 PJ (2018) |
| **Canada** | 3.15 | 1,499.08 MW in Grid-connected distributed (2021) | 4,595.79 MW (2021) | 4,479 GWh (2020) | 11.78 MWh per capita (2020) | 2,855 PJ (2018) |
| **Chile** | 5.09 | 167 MW (Mar 2021) | 4.6 GW (Mar 2021) | 6,304 GWh (2019) | 4.1 MWh per capita (2019) | 396.65 PJ (2018) |
| **China** | 4.02 | 107.5 GW (2021) from distributed solar | 306 GW (2021) | 325,915 GWh (2021) | 4.9 MWh per capita (2018) | Approximately 12,800 PJ (2018) |
| **Hong Kong, China** | 3.25 | 2.1 MW (2018) | 6.29 MW (March 2017) | 1.0 GWh (2018) | 6.3 MWh per capita (2018) | Approximately 83.33 PJ (2018) |

| APEC Economy | Average Daily Solar PV Output (kW-hr/kW$_p$) | Installed Capacity | | Solar PV Generation (Reference year) | Electricity consumption (Reference year) | Transport sector energy consumption / demand (Reference year) |
|---|---|---|---|---|---|---|
| | | Rooftop Solar PV (Reference year) | Total Solar PV (Reference year) | | | |
| **Indonesia** | 3.67 | 18.2 MW (2020) | 198 MW (2019) | 98.0 GWh (2019) | 1.0 MWh per capita (2018) | 2,538 PJ (2018) |
| **Japan** | 3.39 | 770.117 MW (2020) | 78.2 GW (2021) | 74,114 GWh (2019) | 7.6 MWh per capita (2019) | 2,962 PJ (2018) |
| **Korea** | 3.80 | 1,094.6 MW (2019) grid-connected and distributed | 20.1 GW (2021) | 13,022 GWh (2019) | 10.9 MWh per capita (2019) | 1,450 PJ (2018) |
| **Malaysia** | 3.71 | 10.67 MW (2018) capacity connected to the low voltage distribution grid | 69.27 MWac (2018) | 573 GWh (2018) | 5.0 MWh per capita (2018) | 881 PJ (2018) |
| **Mexico** | 4.89 | 2,015 MW (2021) of distributed generation mostly from solar PV | 4,440 MW (2019) | 6,591 GWh (2019) | 2.3 MWh per capita (2019) | 1,513 PJ (2018) |
| **New Zealand** | 3.47 | 122.765 MW (July 2021) of <10kW capacity panels in the residential sector | 186.7 MW (2021) | 126 GWh (2019) | 8.5 MWh per capita (2019) | 222.74 PJ (2018)<br>On-road petrol end use = 12.88 PJ (2018)<br>On-road diesel end use = 19.07 PJ (2018) |

| APEC Economy | Average Daily Solar PV Output (kW-hr/$kW_p$) | Installed Capacity | | Solar PV Generation<br><br>(Reference year) | Electricity consumption<br><br>(Reference year) | Transport sector energy consumption / demand<br><br>(Reference year) |
|---|---|---|---|---|---|---|
| | | Rooftop Solar PV (Reference year) | Total Solar PV<br><br>(Reference year) | | | |
| | | 3.961 MW (July 2021) of >10kW capacity panels in the residential sector | | | | |
| **Papua New Guinea** | 3.59 | Aims to utilize 2% of Port Moresby's peak demand to come from rooftop solar PV (2019), which is estimated to be 700 MW by 2021 | - | - | *Energy consumption* 11.74 million BTU per person (2018) | 25.2 PJ (2018) |
| **Peru** | 4.22 | - | 139,655.48 MW (2022) | 58 GWh (2020) | 1.5 MWh per capita (2018) | Approximately 344 PJ (2018) |
| **The Philippines** | 3.80 | 100 MW (2019) | 1,019.3 MW (2020) | 1,372.6 GWh (2020) | 2,949 kTOE in households (2020)<br><br>34,292 GWh in households (2020) | 9,843 kTOE (2020) |
| **Russia** | 3.37 | 15 MW (2018) in the residential sector | 2.0 GW (2021) | 985 GWh (2019) | 6.9 MWh per capita (2018) | 4,229 PJ (2018) |

| APEC Economy | Average Daily Solar PV Output (kW-hr/$kW_p$) | Installed Capacity | | Solar PV Generation (Reference year) | Electricity consumption (Reference year) | Transport sector energy consumption / demand (Reference year) |
|---|---|---|---|---|---|---|
| | | Rooftop Solar PV (Reference year) | Total Solar PV (Reference year) | | | |
| **Singapore** | 3.55 | 13.1 $MW_p$ (Q1, 2020) in residential installations | 203 MW (2018) | 341 GWh (2019) | 9.3 MWh per capita (2018)<br><br>3,969.9 GWh in households (2021) | 1,378.8 GWh (2021)<br><br>2,582.5 kTOE (2019) where,<br>2,320.1 kTOE petroleum products<br>2.7 kTOE natural gas<br>259.8 kTOE electricity |
| **Chinese Taipei** | 3.44 | 4,537.42 MW (2020) | 5.2 GW (2020) | 4,144 GWh (2019) | 11.2 MWh per capita (2018) | 13,221.7 MTOE in road transport (2020) |
| **Thailand** | 4.02 | 9.018 MW (June 2021) in the residential sector | 3.0 GW (2020) | 5,182 GWh (2019) | 2.8 MWh per capita (2018) | 1,253 PJ (2018) |
| **USA** | 4.30 | 19,961.8 $MW_{dc}$ (Q1 2021) in the residential sector | 123 GW (2021) | 93,129 GWh (2019) | Primary energy consumption = 282 million BTU/person (2021)<br><br>3.8 trillion KW-hr (2020) | 26,697.2 PJ (2018) |
| **Viet Nam** | 3.44 | 2.876 GW (2020) | 18.4 GW (2021) | 9.678 GW of Solar rooftop PV (2020) | 2.4 MWh per capita (2018) | 573.62 PJ (2018) |

## 2.2 Solar PV and EV Situation in APEC Economies

### 2.2.1 Australia

#### 2.2.1.1 Institutional and Policy Framework

The Clean Energy Regulator is Australia's Government body responsible for the accelerated carbon abatement of the economy. It was formed through the Clean Energy Regulator Act of 2011. Among its responsibilities is oversight of the administration of large-scale and small-scale renewable energy structures to encourage the addition of renewables in electricity generation. The Department of Industry, Science, Energy, and Resources is the overarching government body responsible for Australia's reliable, secure, and affordable energy systems, including policy making. The Department publishes annually the Australian Energy Update to serve as Australia's official source of energy statistics.

The Renewable Energy (Electricity) Act was first enacted in 2000 mainly to encourage electricity generation from renewables and as part of it, reduce greenhouse gas emissions and ensure that use of renewable resources is ecologically sustainable (Clean Energy Regulator, 2021). It was administered by the Department of Industry, Science, Energy, and Resources. Other legislations that support the renewable energy targets of Australia are outlined in the Clean Energy Regulator's website[1].

In November 2021, Australia released the Future Fuels and Vehicles Strategy, which sets out the economy's technology-led approach in reducing emissions from the transport sector. It prioritizes the following initiatives: 1) EV charging and hydrogen refuelling infrastructure, 2) early focus on commercial fleets, 3) improve information for motorists and fleets, 4) BEV integration into the grid, and 5) support to Australian innovation and manufacturing.

#### 2.2.1.2 Solar PV

It is estimated that solar rooftop installation rate in Australia is 275 W/capita/annum. The IEA reported residential annual solar PV capacity addition of 1.3 GW and 1.8 GW in 2018 and 2019, respectively. However, estimates in the same analysis by IEA forecasts a decreasing average annual addition of 1.0 GW in 2022 and 0.9 GW between 2023 and 2025 (IEA, 2020).

#### 2.2.1.3 EVs

In the first half of 2021, combined sales of BEV and PHEV is 8,688 units, which represents 1.57% of the light vehicle market. For hybrid EV, sales in 2020 reached 60,417, which is almost double from the 2019 sales of 31,191 vehicles. Meanwhile, EV's registered between 2020 and 2021 is recorded at 23,000. As of September 2021, the EV market in Australia has 60 models available where 17 are BEV, 21 are PHEV, and 22 are hybrid vehicles (Australian Government Department of Industry, Science, Energy, and Resources, 2021).

[1] http://www.cleanenergyregulator.gov.au/About/Legislation-and-regulations

## 2.2.2 Brunei Darussalam

### 2.2.2.1 Institutional and Policy Framework

The Ministry of Energy serves as the overall government body in the regulation of Brunei Darussalam's energy sector, where its Sustainable Energy Division is responsible in policy making and program implementation of renewable energy and EE&C projects. They also serve as the focal agency for the implementation of Brunei Darussalam's net metering scheme and regulator of solar PV contractors. The Ministry of Transport and Infocommunications meanwhile, is responsible for the economy's transport sector and is the implementing agency of the Pilot EV Project, where the Brunei Climate Change Secretariat is a partner in its implementation. In addressing climate change, Brunei has set up multi-stakeholder groups at varying levels to adopt a whole of government approach. These are the Brunei Darussalam National Council on Climate Change and Executive Committee on Climate Change for high-level decision making and Mitigation, Adaptation and Resilience, and Support Framework Working Groups for climate change action implementation (Brunei Darussalam Nationally Determined Contribution 2020, 2020).

Brunei Darussalam launched its National Climate Change Policy in July 2020, which sets out the economy's low carbon and climate resilient pathway for sustainable development. This resulted to the updating of Brunei Darussalam's NDC, which was submitted in December 2020. Among the key strategies identified in the National Climate Change Policy are RE and EV. In support of its RE strategy, programs such as Net Metering and Solar PV Contractor registration are in place. Moreover, the Autoriti Elektrik Negara Brunei Darussalam released the Code of Practice for Small Scale Solar PV System Connection to Low Voltage Network for small scale developers (solar power generation capacity range < 0.9 $MW_{ac}$) who wish to connect to the low voltage network. Meanwhile, in support of its EV strategy, Brunei Darussalam has recently launched its EV Pilot Project.

### 2.2.2.2 Solar PV

The current installed capacity of RE in Brunei Darussalam only comes from a solar PV plant. The target of increasing RE share in the economy's energy mix includes solar and waste-to-energy (WTE), with the latter expected to also address solid waste problems. In 2021, a net metering scheme has been introduced in Brunei Darussalam to attract small-scale solar PV generation. The only known official solar rooftop PV installation is in a commercial building of Bumiputra Building Complex, with installed capacity of 8.0 KW.

### 2.2.2.3 EVs

Brunei Darussalam has a low rate of EV adoption. As of 2017, the share of EVs in the total economy fleet is only less than 0.1%. There are 282 HEV and 18 BEV registered as of 2017. Nevertheless, Brunei Darussalam has set a target on EVs to grow its share to 60% of the total vehicle sales, but with no specific target year. In March 2021, the EV Pilot Project was launched, and it aims to increase awareness about EVs and charging stations. Also part of the Project is to conduct a study to identify the public's perception and response towards shifting to EV, including its marketability and potential in Brunei Darussalam (The Star Malaysia, 2021).

### 2.2.3 Canada

#### 2.2.3.1 Institutional and Policy Framework

The Environment and Climate Change Canada is the lead federal department responsible for addressing the economy's environmental issues and is guided by the Strengthened Climate Plan (A Healthy Environment and a Healthy Economy) and the 2030 Emissions Reduction Plan (ERP). In addition, a Clean Electricity Standard is being developed as part of the Government of Canada's commitment to achieve net zero electricity grid by 2035 and as a subsequent activity under the 2030 ERP. Along with Natural Resources Canada, their responsibilities extend over matters relating to RE, among others (Environment and Climate Change Canada, 2020). The Energy Fact Book provides key information on the Canadian energy market and statistics. The 2021-2022 version pointed out Canada's evolving energy mix, where wind and solar PV are the fastest-growing sources in electricity generation. The government sees that ongoing development in the areas of grid-scale electricity storage, carbon capture and storage, hydrogen, and electric and alternative fuel vehicles have the potential to further transform Canada's energy system (Natural Resources Canada , 2021).

Some of the notable policies recently announced relating to EV adoption includes the EV and alternative refueling infrastructure incentives worth $182 million and the light duty vehicles zero emission vehicle sales target of 20% by 2026, 60% by 2030, and 100% by 2035. (Transport Canada, 2022)

#### 2.2.3.2 Solar PV

Solar PV is the least utilized energy source in Canada, together with tidal. In 2020, solar power generation is only 0.7% of the total electricity generation by source where the largest contributor is the province of Ontario.

As of 2021, solar PV's total capacity installed is 4,595.79 MW. Of the Solar PV's total capacity, 1,499.08 MW is connected to the distribution grid.

#### 2.2.3.3 EVs

Electric vehicles comprise 3% of the 9.1 million units sold in 2021. The EV stock (cars) is estimated at 209,171 in 2020. An increasing number of EV registration has been observed in the past five years. In the first quarter of every year, the number of EV[2] registration annually are as follows: 31,563 in 2021; 19,603 in 2020; 14,871 in 2019; 11,221 in 2018; and 7,673 in 2017.

### 2.2.4 Chile

#### 2.2.4.1 Institutional and Policy Framework

A key policy framework in the Chilean energy system is its electricity market reform that started in the 1970's, as well as its power market energy transition and National Electromobility Strategy in the recent. Chile's Electricity Act promulgated in 1982 laid the foundation for the economy's electricity supply, where generation, transmission, and distribution were regulated separately. In 2008, the government passed the Non-conventional Renewable Energy Law, which was primarily focused on the development of the Renewable Portfolio Standards that serves as the main mechanism to encourage

[2] BEV, PHEV, and HEV

investments in RE. In 2015, the Government institutionalized increasing the share of renewables and modifying the auction system of the electricity market. This resulted in grid congestion problems as more variable renewable energy sources became part of the generation mix. As such, in 2016 the government passed a Transmission Law, which made the power generation planning process more inclusive of other sources in favor of the grid system. In 2018, an energy roadmap was released where it adopts low-emission energy sources as one of the seven strategic areas to foster development. (Wang, et al., 2020) In terms of EV adoption, Chile has developed the National Electromobility Strategy, which outlines the economy's short- and medium-term actions to eventually shift to EVs by 2050, where 40% within the private sector and 100% in the public sector.

Chile's power market implements a unique block bidding system. Instead of the generators bidding for 24 hours a day, the block bidding system sets it in specific time intervals, referred to as blocks. There are two types of block bidding system implemented and these are 1) Supply Block 1 where bidding period is set within a specific number of hours to make up the 24-hour period and 2) Supply Block 2 where it covers three months (quarterly) for the bidding. These systems provide an opportunity for variable energy resources, such as solar and wind, to be utilized well and be competitive in the market. Supply Block 1 aims to find the lowest possible price per 24-hour period, and it favors the solar generators in a manner that they are expected to bid during the block where there is solar energy available. Meanwhile, Supply Block 2 aims to reduce the annual electricity price as it favors the seasonality of renewables such as hydro and wind in a year.

#### 2.2.4.2 Solar PV

Chile has an abundant source of solar energy. The Atacama Desert in the north boasts 9 KW-hr/m$^2$/day of solar irradiance, which is the highest in the world (Asia Pacific Energy Research Centre, 2021). Its central region is also a good location to harness solar power. Despite these, solar power generation is still low in the economy as majority of power generation comes from hydro and coal. The IEA reported annual solar PV capacity addition in the residential sector of 0.002GW in 2019, 0.006GW in 2018, and 0.005GW in 2017.

#### 2.2.4.3 EV

There are 191 EVs (car) sold in 2020, which constitutes only 0.1% of Chile's car sales. As such, it is estimated that EV stock (cars) is 833 as of 2020. The National Electromobility Plan is aiming for a 40% share of EV in private vehicles and 100% share of EV in public transport vehicles by 2050.

### 2.2.5 People's Republic of China

#### 2.2.5.1 Institutional and Policy Framework

China's Renewable Energy Law was introduced in 2006. It basically recognizes the importance of utilizing RE sources and its benefits to the economy's energy mix and lays out the foundation for RE deployment and research and development. It is implemented by the State Council, who also determines the RE targets and programs necessary for the enactment of the RE Law. They are supported by the regional and local people's governments in its implementation. China's FIT mechanism has been ordered by the National Development and Reform Commission to improve by changing the benchmark feed-in tariff for centralized PV power stations to a guided tariff and reducing the intensity of subsidies for distributed PV projects. Moreover, the National Energy Administration of China has institutionalized for the provincial's administrative region to set a proportion of RE in their electricity consumption.

The Chinese Government has issued policies that support not just EV adoption, but also of its R&D and manufacturing. The State Council issued Development Plan for Energy-saving and New Energy Automotive Industry 2012-2020 for the development of the EV industry in China. It sets out a goal of reaching a manufacturing capacity of two million BEV and PHEV per year by 2020. To achieve this, the State Council then issued the Guiding Opinions on Accelerating the Popularisation and Application of New Energy Vehicles in 2014, where it covers among others basic infrastructure, technology and innovation, financial subsidies, and tax incentives. Moreover, the Ministry of Industry and Information Technology also issued an Administrative Provision in 2017 on the safety and quality of EVs by requiring the units to meet the technical requirements and pass the safety inspections and other testing requirements. (CMS Legal, 2018)

China's Five-Year Plan, which is currently in its 14$^{th}$ version covering the years 2021 to 2025, is focused on sustainability of growth and quality of life (ADB, 2021). Its target on environment and climate change includes reducing energy intensity by 13.5% per unit of GDP as a binding target and increasing the share of non-fossil fuels in the primary energy consumption to 20% as a non-binding target. Also, the Plan's dual circulation paradigm targets to increase the share of emerging industries that includes EVs, to 17%.

### 2.2.5.2 Solar PV

China has put a record number of solar panels on rooftops in 2021 as growth in residential areas outpaced installations on solar farms. A total of 55 GW of solar capacity was built in 2021, close to the all-time high set in 2017, with 21.6 GW coming from rooftop residential installations, according to the National Energy Administration (PV Magazine, 2022). Figure 2-1 shows the capacity installation additions by customer segment between 2016 and 2021, which highlights the increase in residential solar PV rooftop installation. Meanwhile, the IEA forecasts that between 2020 and 2022, there is a decline in capacity additions due to uncertainties over the new policy scheme and targets in the 14$^{th}$ Five-Year Plan. In addition, between 2022 and 2025, growth in annual PV additions is projected to resume, averaging from 40 to 50 GW capacity.

***Figure 2-1: Annual Installed Capacity (MW) Addition of Distributed Solar PV by Customer Segment***


Source: Ms. Lyu Fang's presentation Workshop on PV and EV Integration to the Low Voltage Distribution Network (22 April 2022)

### 2.2.5.3 EVs

The electric car stock is estimated at 4.5 million units as of 2020, and it accounts for 44% of the global EV stock. The EV adoption in China has an estimated compounded annual growth rate of 36% between

2016 and 2020. In 2020, the share of EV sales in the economy is at 5.7% but this is a 9% decrease compared to the previous year.

### 2.2.6 Hong Kong, China

#### 2.2.6.1 Institutional and Policy Framework

Hong Kong, China's Environment Bureau (ENB) has been at the forefront of the government's plans and programs relating to the environment and climate change across all sectors. In the Chief Executive's 2020 Policy Address on Environment and Conservation, Hong Kong, China's "green recovery" will include subsidizing existing private residential estates for the installation of EV charging-enabling infrastructure in car parks to be led by ENB. Moreover, its plan to achieve carbon neutrality will explore the areas of zero-carbon energy and decarbonization technology, energy efficiency of new and existing buildings, zero-carbon vehicles and green transportation, and large-scale WTE facilities. (Office of the Chief Executive, 2020)

Although WTE is the preference to reduce carbon emissions in the energy sector, mainly because of its co-benefit of addressing solid waste management issues in the region, the Government has nevertheless recognized the viability of solar power. Hong Kong, China's Electrical and Mechanical Services Department published a guidance document for the residential sector who wish to install their own solar PV systems. It details the installation and regulatory requirements, mainly for the safety requirements. The Government has also introduced a FIT scheme for small-scale distributed RE generating systems (GovHK, 2021), as well as the issuance of RE Certificates.

Hong Kong, China's power generation sector is owned and operated by the private sector. The Government's responsibility is limited to setting rules and regulations and creating policies that ensure energy needs are met, environmental impacts of the energy sector are minimized, and efficient use and conservation of energy is practiced. The Government monitors the performance of the private sector companies to ensure that the policies of the Region are complied with.

#### 2.2.6.2 Solar PV

The total installed capacity of PV systems is at 6.29 MW as of March 2017. Annual generated energy by PV systems is equivalent to 6.29 GWh, which is about 0.014% of the annual electricity consumption of Hong Kong, China in 2016. In a 2019 study commissioned by the Electrical and Mechanical Services Department in Hong Kong, China's potential for PV application in buildings reported the following: 1) the available roof area suitable for solar PV is 25.7 $km^2$, 2) recommended area of a PV panel in Hong Kong, China is between 3.246 and 5.010 $km^2$, and 3) the estimated annual electricity generation from solar PV installed in buildings would be 505,326 to 880,733 MWh.

#### 2.2.6.3 EVs

The EV stock in the region as of 2020 is approximately 18,500 units. The EV adoption rate by year has significantly increase in the last ten years; in 2010, EV adoption rate was at 0.1%, in 2015 at 5.2%, and in 2020 at 12.4%.

## 2.2.7 Indonesia

### 2.2.7.1 Institutional and Policy Framework

The Ministry of Energy and Mineral Resources is the Indonesian Government's regulatory body tasked in carrying out government affairs in the fields of energy and mineral resources. The government's General Plan for National Energy, through Presidential Declaration 22/2017, institutionalizes the implementation of energy policy across sectors to achieve the targets in the National Energy Policy. It serves as the reference for domestic and local planning processes related to the energy sector. Specific to solar energy utilization, in 2020 the Ministry of Energy and Mineral Resources released a guidebook for the utilization of rooftop solar power development and net metering scheme.

Presidential Regulation 55/2019 was promulgated as the Acceleration of the Battery-Based Electric Motor Vehicle Program for Road Transportation. In 2020, the Public Launching of Battery-Based Electric Motorized Vehicles (KBLBB) was held as the information dissemination program for Presidential Regulation 55/2019. The main objective of KBLBB is to reduce Indonesia' dependence on fuel imports, which is mainly used in the transport sector. Moreover, Presidential Decree 55/2019 also paved way to the Ministry of Energy and Mineral Resources' Regulation No. 13/2020 Provision of Electric Charging Infrastructure for Battery-Based Electric Motor Vehicles. There are plans to build 2,400 EV charging points and 10,000 battery exchange station until 2025. The Indonesian Government is also planning on strengthening its automotive industry through the manufacturing of EVs (MEMR, 2020).

One of the notable developments for EV in Indonesia is their goal of becoming an EV hub in Southeast Asia, wherein one of the motivations being is that Indonesia has an established mining industry and rich mineral resources such as nickel. In 2021, government-owned company has partnered with Korean manufacturers to produce EVs and EV batteries. It is expected that construction of the manufacturing facility will be completed by 2023 and mass production of battery cells will begin in 2024 (Reuters, 2021).

### 2.2.7.2 Solar PV

The annual solar PV capacity additions in Indonesia is around 0.1 GW in the recent years. Historical data presented by the IEA shows the following capacity additions every year: 0.1GW in 2019, 0.1GW in 2020, 0.2GW in 2021, and estimates 0.2GW capacity addition in 2022. The average capacity addition between 2023 and 2025 is estimated to increase to 0.5GW per year. As such, total installed capacity as of 2020 is estimated at 0.3 GW and 0.4GW in 2021.

### 2.2.7.3 EVs

In 2019, the number of EVs sold by vehicle type are as follows: 15,500 units of electric two-wheeler motorcycle and 24 passenger vehicles. Meanwhile, it was reported that only one passenger EV was sold in 2018.

## 2.2.8 Japan

### 2.2.8.1 Institutional and Policy Framework

The Strategic Energy Plan is Japan's strategic policy framework on energy. It is currently in its sixth Outline, which was released in 2021. In the sixth Outline, the utilization of solar PV is dependent of technological development as the Government has targeted the implementation of advanced solar PV mountable on walls and roofs by 2030. In addition, the Government outlined the plan on enhancing the safety measures related to solar PV by developing a technical standard and enhancing the accident reporting process in small power sources by 2030. Likewise, the introduction of EVs and its corresponding infrastructure and supply chain will be enhanced as per the sixth Outline by 2030. However, no specific target was made for EV adoption. (METI, 2021)

#### 2.2.8.2 Solar PV

The net annual solar capacity addition in the residential sector are as follows: 0.6GW in 2018, 0.9GW in 2019, 0.5GW in 2020. It is estimated that in the succeeding years, the annual capacity additions would increase to 0.6 GW in 2021, 0.7GW in 2022, and average of 0.6GW between 2023 and 2025.

#### 2.2.8.3 EVs

Japan has an estimated EV penetration rate of 1% (Takezawa, 2021). In 2020, the estimated EV stock (cars) is 297,181 where EV car sales were 30,100 units equivalent to 0.6% of the total vehicle sales in that year.

### 2.2.9 Republic of Korea

#### 2.2.9.1 Institutional and Policy Framework

Korea passed the Energy Use Rationalization Act in 1980, which institutionalizes an energy policy geared towards stable energy supply and meeting the demand needed for the economy's economic development, minimisation of the environmental effects caused by energy consumption, and rationalisation on the use of energy. To support this, the Ministry of Trade, Industry, and Energy developed the Basic National Energy Plan and Basic Plan for the Rational Use of Energy and updates the Plans every five years.

Korea targets 20% RE in its energy mix or equivalent to an additional 49 GW capacity as stated in its 2030 RE Initiative Implementation Plan released in December 2017 by the Mistry of Trade, Industry and Energy. In April 2019, the RE Competitive Incentive Program was launched to leapfrog the transformation of the power industry that utilizes domestic RE. In June 2019, the Government announced the 3$^{rd}$ Energy Master Plan, which provides the medium- and long-term (2019 to 2040) framework to coordinate for the economy's energy policies based on the issues affecting Korea's energy system.

In 2020, the Government announced plans to subsidize 99,950 EVs where 65,000 are passenger cars, 13,000 are freight cars, 650 are buses, 21,000 are motorcycles, and 300 are PHEVs (Plug-in Hybrid Electric Vehicles) to increase EV adoption. This translates to an equivalent of KRW 520 billion for passenger cars, KRW 70 billion for freight cars, KRW 70 billion for buses, KRW 24 billion for motorcycles, and KRW 1.5 billion for PHEVs. (HEV TCP, 2020)

#### 2.2.9.2 Solar PV

The total solar PV capacity installed in 2019 was equivalent to 254 $MW_{dc}$ and this makes the cumulative installed capacity of solar PV at 1,094.6 MW or 9.3% of the total installed capacity as of 2019. The cumulative solar PV installation in the past years are as follows: 440.9 MW in 2015, 551.1 MW in 2016, 665 MW in 2017, and 840.4 MW in 2018.

#### 2.2.9.3 EVs

In 2020, the sales of EV (cars) reached 45,621, equivalent to 2.9% of the year's total car sales. As such, the estimated EV stock (cars) in 2020 is 146,591. It is believed that the adoption of EV in Korea is considered as key enabler for the development of the solar PV industry in the economy.

### 2.2.10 Malaysia

#### 2.2.10.1 Institutional and Policy Framework

Malaysia's National Renewable Energy Policy and Action Plan was first released in 2009, which resulted to an accelerated adoption of RE in the economy and results show that it went beyond the APEC-wide goal of doubling RE. Malaysia's has set a target of 31% RE by 2025, and it includes the provision of storage system to address intermittency of RE and ensure increase in penetration of RE sources. The Ministry of Energy, Science, Technology, Environment, and Climate Change is the Government body who develops policies related to electricity, RE, and energy efficiency. In support of solar PV adoption, the Malaysian government launched its fourth round of the Large-Scale Solar PV (LSSPV) tender for 1 gigawatt (GW) in May 2020 to attract more development in solar energy, particularly from local market players.

Malaysia's National Automotive Policy 2020 includes EV adoption but there is no clear target and direction on how to achieve this. Nonetheless, the Government's announcement of the 2022 National Budget has included tax incentives for EVs with hopes of increasing its adoption. It includes 100% tax exemption for EVs such as import and excise duties, as well as road tax and tax relief of up to RM 2,500 for those paying to charge their EVS. (Techwire Asia, 2021) Moreover, the NEM 3.0 Program allots 500MW of solar rooftop PV for the net metering scheme.

#### 2.2.10.2 Solar PV

In 2018, the solar PV installation totaled to 69.27MWac, where 2.77 $MW_{ac}$ is from the residential sector. The annual cumulative PV power installation that is grid-connected/ distributed are 90.75MW in 2014, 139.36MW in 2015, 197.98MW in 2016, 230.19MW in 2017, and 302.68 MW in 2018. It is reported that PV capacity connected to the low voltage distribution grid is equivalent to 10.67MW while PV capacity connected to the high voltage transmission grid is 229MW. The 2021 APEC Energy Overview shared that recent studies concluded that the current energy system of Malaysia can accept solar PV readily.

#### 2.2.10.3 EVs

There were 2 EVs sold in 2018, and 32 EVs sold in 2019.

### 2.2.11 Mexico

#### 2.2.11.1 Institutional and Policy Framework

The General Climate Change Law and Energy Transition Law sets out Mexico's target to have 35% RE share in the generation mix by 2024 (ICLG.com, 2021). Meanwhile, the Mexican Ministry of Energy is the lead Government body in policy making and regulator for power generation, transmission, and distribution in Mexico.

The Comisión Federal de Electricidad (CFE), the largest electricity supply company in México, which is government-owned, made a controversial decision to remove net metering for distributed power generation. At the time of the reporting, no explanation was provided by CFE, but they were previously quoted that the net metering scheme is affecting their revenue. (PV Magazine, 2018). Moreover in 2021, the Mexican government released a decree for the amendment of the economy's Power Industry Law; however, the proposed changes do not support the utilization of renewable energy. Among the changes proposed include the dispatch priority for CFE, with them giving the last priority to wind and solar power generators and releasing them from the obligation to acquire energy through auctions. (Global Compliance News, 2021)

Mexico's approach to increasing EV adoption is made prominent through tax and fiscal incentives. The Federal Law on New Automobiles Taxation exempts EV, including hybrid vehicles, from fees concerning their sale or import. In addition, the Income Tax Law grants benefits in the form of higher amounts for permissible deductions, to persons who invest in EV or acquire their temporary use. A further fiscal incentive takes the form of a tax credit of 30% of the investment made in public power supply facilities for EVs.

The CFE promotes the use of EVs through the installation of an independent light meter which would prevent the applicable electricity tariff range from increasing, thus keeping the EV user's fee within the domestic standard spectrum instead of the high consumption rate. They are also working with the EV industry to improve the current 900 EV charging infrastructure and install addition 201 charging centers, which will be financed through the Energy Transition and Sustainable Energy Use.

Local legislation specific in Mexico City provides EVs with attractive benefits to promote their purchase and use. Electric and hybrid vehicles are excluded from the vehicle verification proceedings and can circulate daily without limitation, unlike other urban vehicles subjected to "no-circulation" programmes. Public and private parking lots must include exclusive parking spots for electric and hybrid vehicles. Mexico City's EcoTAG, a special type of the prepaid card used to transit through the city's urban highways, grants electric and hybrid vehicle owners a 20% discount on the regular fee.

#### 2.2.11.2 Solar PV

The Mexican government aims to produce more than one-third of its electricity from clean energy over the coming years and cut carbon emissions by 22% by 2030. In its Paris Agreement commitment, 35% of power generation must come from renewables and should increase to 43% by 2040 (Mexico Business News, 2022). Hence, the dependency on solar PV rooftop system in the residential segment is expected to grow further.

The residential segment with high power consumption is one of the main drivers in the Mexican rooftop solar market. In addition, a combination of a massive solar resource with a related reduction in PV system costs has contributed to fast growth in this segment in Mexico. This growth is expected to continue unabated, driven by net-metering and net-billing schemes that are particularly attractive in unsubsidized tariff consumers from the residential segment. Under this scheme, the residential user meets their own consumption and excess solar energy is credited against future consumption, or net billing, where excesses are sold to the grid. IDB invest, a member of the IDB Group, supports the growth of the distributed solar generation in Mexico by providing financing scheme for the deployment of solar PV systems at homes. It will accelerate the deployment of more than 2,500 residential solar rooftop power systems, with a generation capacity of over 8MW and producing zero emissions (IDB Invest, 2020). However, CFE's decision to postpone the net metering scheme for distributed energy generation provides hindrance to the accelerated uptake of rooftop solar installations.

Distributed solar power generation registered significant growth rate during the period 2018-2019; it grew to an installed capacity of 693 MW from 94,893 rooftop solar systems in June 2019, up from 570 MW installed in December 2018 from 85,000 installations. It is estimated that average annual addition for the residential sector in the succeeding years between 2020 to 2025 is 0.1 GW.

#### 2.2.11.3 EVs

The transport sector is currently the highest energy-consuming sector in Mexico because of the preference to use private vehicles and limited public transport. Moreover, the heavy truck for freight transportation is a dominant service in the economy. Much of the road transportation uses fossil fuel-based energy sources such as gasoline, diesel, and LPG. As such, reducing emissions from the transport sector by shifting to EVs would benefit the economy in its climate policies. In 2020, EV (cars) sales were only 0.3% of the total vehicles sales, which is equivalent to 2,516 units. The EV (cars) stock is estimated at 7,248 in 2020.

### 2.2.12 New Zealand

#### 2.2.12.1 Institutional and Policy Framework

The Government of New Zealand has committed 100% RE generated electricity by 2030. To achieve this, several policies were put in place such as the Climate Change Response (Zero Carbon) Amendment Act of 2019. It sets the net zero emissions of New Zealand, except for biogenic methane where its goal is to reduce its emissions within 24% to 47% below 2017 levels by 2050. Interim target is to reduce its emission to 10% below 2017 level by 2030. In June 2020, the Resource Management Amendment Act of 2020 was issued to include, among others requiring local governments to include climate change in their planning process and decision-making. It has established an emissions trading scheme (ETS) and is believed to be the main driver for the current RE investments in the economy. As of this writing, there are no sector-specific support or fiscal mechanisms such as FiT or renewable portfolio standards. (Lloyd, 2021)

New Zealand has no specific EV policy but has made the following pronouncements that could support its accelerated adoption: 1) the economy is set to have its EV Policy by mid-2022 as suggested by its Climate Change Commission where it will include, among others emissions-standard for light vehicles that will be imported (Argus Media, 2021), and 2) the Government implemented in December 2020 its “EV first policy” as part of its target to shift to 100% EV by 2025/2026 for the government vehicles and in support of achieving the net zero target by 2050 (Ministry of Business, Innovation and Employment, 2021).

#### 2.2.12.2 Solar PV

The total installed capacity of <10kW solar PV panels in the residential sector is estimated at 122.765 MW as of July 2021. With this, the average capacity installed between 2013 and 2021 is 3.369 kW to 3.926 kW. For a >10kW solar panel, the total installed capacity is 3.961 MW as of July 2021. The average capacity installed between 2013 and 2021 is 15.024 kW to 27.116 kW. It is estimated that in 2018, around 800 households are installing solar panels every month.

#### 2.2.12.3 EVs

The estimated EV stock (light EV) is 24,481 units where 75% is BEV and 25% is PHEV as of 2021. This translates to a share of 0.6% in the total light vehicles stock in New Zealand. In the previous year, 2020, number of EV registration is 5,454, which is equivalent to 2.3% of the total light vehicle registration.

The Government is committed to have all of its fleet to be emissions free by 2025/ 2026. As the fourth quarter of 2020-2021, the New Zealand Government has 2.37% EV in its total fleet. Of this, 260 are BEV and 91 are PHEV (Ministry of Business, Innovation and Employment, 2021).

### 2.2.13 Papua New Guinea

#### 2.2.13.1 Institutional and Policy Framework

The National Energy Policy serves as the main document that reports the energy situation in Papua New Guinea (PNG), including the plans and programs and priorities in the energy sector. Among the strategies related to solar PV identified in the National Energy Policy are as follows: encourage installation of solar PV in all public facilities and off-grid areas; promote installation of at least 100,000 units of solar PV systems in households by 2020, and; develop a new legislation for solar energy as an RE resource. The Renewable Energy Policy is also set to be developed by the National Energy Authority, which will detail the harnessing of solar energy. (Department of Petroleum and Energy, 2017) PNG's Vision 2050 asserts that PNG will be fully powered by renewable energy by 2050.

In terms of EV adoption and regulation, PNG is yet to develop an EV Policy as of this writing.

#### 2.2.13.2 Solar PV

PNG's first trial on rooftop power generation was launched in its capital Port Moresby in December 2019. Up until this time, it was illegal to install and generate power from rooftop solar PV. In the first round of the trial, it allowed 2% of Port Moresby's peak demand to come from rooftop solar PV. The capital city alone has up to 2,500 hours of sunshine available per year.

Off-grid solar products, especially lighting appliances, have become popular in the island economy following the Lighting PNG project of the International Finance Corporation. In the project, it was concluded that factors affecting the popularity of off-grid solar lighting products include the low grid electrification rate and availability of the product through mid-mile distribution network (IFC, 2019). As of December 2019, 60% of households have solar lighting units.

#### 2.2.13.3 EVs

The island economy has a low road density. Majority or 60% of PNG's population depends on water transport, including the transfer of goods and services. There is still low vehicle ownership in Papua New Guinea; in 2013, it was estimated to be at 12 per 1,000 people and in 2020, 15 per 1,000 people. The forecast estimates that by 2030, 23 in 1,000 people will own a vehicle. Currently, PNG has no policy and incentives for EVs.

## 2.2.14 Peru

### 2.2.14.1 Institutional and Policy Framework

Renewable energy in Peru is regulated and promoted through Legislative Decree No 1002, which was promulgated in 2008. It includes RE auctions scheduled every two to three years where energy supply contracts are awarded to bidders who offer the best price for a 20-year period.

There is currently no legislation related to the regulation and uptake of EVs. However, the Bill Project (2182/2017-CR) was introduced in the National Congress to declare domestic interest and public necessity to promote the use of EVs and its required charging facilities. Moreover, in May 2018 the Government removed the excise tax for EVs and the Ministry of Energy and Mines, the Ministry of Transport and Communications, and the Ministry of Economy and Finance are working together on a subsidy to encourage the use of EVs through the issuance of bonds (CMS Legal, 2018).

### 2.2.14.2 Solar PV

A massive Photovoltaic Programme was launched in 2017 to support Peru's Rural Electrification Plan that will utilize solar power, specifically with the aim of using solar PV systems to electrify the most remote rural areas of the economy. As of March 2021, the Programme electrified 205,000 homes, more than 2,300 educational institutions, and 630 health establishments. In the next years, the Massive Photovoltaic Programme will electrify 48,000 homes in North Peru and 26,500 homes in the central region with solar PV.

### 2.2.14.3 EVs

HEV importation in Peru has been increasing annually. Every year since 2016, the number of HEV imported to the economy are as follows: 11 in 2016, 96 in 2017, 175 in 2018, and 177 as of June 2019. As such, the estimated HEV and PHEV in the economy in 2019 is 519 units.

## 2.2.15 The Philippines

### 2.2.15.1 Institutional and Policy Framework

The Department of Energy (DOE) is the Philippine's government agency with the overall responsibility of the economy's energy sector. Its Renewable Energy Management Bureau serves as its focal on plans and programs relating to the utilization and development of renewable energy. Meanwhile, the National Renewable Energy Board (NREB) serves as the advisory body of the DOE in recommending policies related to renewable sources and for the monitoring of the implementation of Renewable Energy Act of 2008. Local government units (LGU) are equally important for the accelerated utilization and development of renewable energy projects as they have, to some extent, authority and accountability to infrastructure projects within their geographical jurisdiction. They are governed by the Department of Interior and Local Government (DILG). A joint memorandum between DILG and DOE has been institutionalized to guide LGUs facilitate the implementation of energy projects within their locality. Likewise, the DOE is also the implementing agency for the development of the EV industry in the Philippines. It is supported by the Department of Trade and Industry by providing incentives and encouraging investments while the Department of Transportation will play a key role in vehicle registration and in the expansion of the EV industry in public transport. The Electric Vehicle Association of the Philippines (EVAP) is an industry association group that partners with the government to support EV adoption in the economy. It hosts an EV Summit annually.

The development of solar PV projects in the Philippines is institutionalized through the Renewable Energy Act of 2008. It was promulgated through Republic Act No. 9513 which serves as the main policy framework for the promotion and utilization of renewable energy sources in the economy, which would support energy self-sufficiency and greenhouse gas emissions reduction. Through this law, different policy mechanisms that would support the promotion of renewable energy were developed including the Feed-in Tariff system and Net metering scheme, among others. It also paved way for the development of the National Renewable Energy Program (NREP), which primarily sets out the framework to help achieve the goals of the Renewable Energy Act of 2008. On solar power, the NREP intends to mainstream an additional 284 MW solar power capacities and work towards achieving the aspirational target of 1,528 MW by 2030 and grid parity by 2020.

There is currently no regulatory framework on the use and promotion of EVs and EV industry in the Philippines, but the DOE is working on a draft. Nonetheless, a guideline for EV charging stations was released in August 2021 through DOE Department Circular no. DC2021-07-0023 in August 2021.

#### 2.2.15.2 Solar PV

Solar power generation is only starting to gain momentum in the Philippines despite its renewable energy law enacted in 2008. The Philippines has good potential and year-long supply of solar energy as for most parts of the economy has an average of 1,241 kWh/kWp to 1,387 kWh/kWp yearly total and high PV potential in the northern most part of Luzon and southern parts of Mindanao. Harnessing the sun’s potential could help meet the economy’s increasing electricity demand and decrease its dependence on imported fuels. However, the variability and intermittent nature of solar power is considered by the government as the main challenge to fully shift to 100% renewables.

The Philippines saw a boom in solar installations between 2015 and 2016. In March 2015, the DOE increased the annual capacity target for solar to 500 MW and has awarded 61 solar contracts that year (Shead, 2017). Aside from setting domestic targets, the DOE has also established net metering and feed-in tariff mechanisms to encourage investments in renewable energy sources. As of 2020, the DOE recorded a total of 1,089.62 MW installed capacity of solar where 1,083.19 MW is for commercial use and 6.43 MW for own use.

The IEA expects that the introduction of the Renewable Portfolio Standards (RPS) will increase the share of renewables in the total electricity consumption from 21% in 2019 to 35% in 2030. In addition, IEA estimates solar PV capacity addition of 0.3 GW in 2019 and 0.2 GW in 2020, while forecasts 0.2 GW in 2021, 0.5 GW in 2022, and annual average addition of 0.7 GW between 2023 and 2025 (IEA, 2020).

#### 2.2.15.3 EV

In 2018, there are 11,950 EVs registered where majority or 92.4% are two-wheelers, followed by trucks and jeepneys at 4.97%, private cars at 2.59%, and buses at 0.33%. In the following years, it was reported that there were 1,570 and 1,015 EV registrations in 2019 and 2020, respectively.

The EVAP forecasts growth of the EV market by 8% to 12% this decade, which translates to sales of 200,000 units by 2024 (Eco-business, 2021). In terms of adoption, the DOE uses 5% penetration rate for the business-as-usual scenario and 10% penetration rate for clean energy scenario. Figure 2-2 summarizes DOE’s projections on EV units using the two scenarios.

***Figure 2-2: Projected EVs by 2040***

| Vehicle Segment | Projected EV by 2040 (in Million) | |
|---|---|---|
| | Reference Scenario (REF) 5% Penetration rate | Clean Energy Scenario (CES) 10% Penetration rate |
| Motorcycle (MC) | 1.10 | 2.19 |
| Tricycle (TC) | 0.23 | 0.45 |
| Non-Conventional 2-wheel/3-wheel vehicles (NC) | 0.15 | 0.29 |
| Passenger Cars (PC) | 0.05 | 0.09 |
| Utility Vehicles (UV) for public use | 0.06 | 0.11 |
| Sports Utility Vehicles (SUV) | 0.09 | 0.19 |
| Buses | 0.00 | 0.00 |
| Trucks (includes all goods vehicles) | - | - |
| **Total** | **1.67** | **3.33** |

Source: Philippines DOE, 2021

## 2.2.16 Russia

### 2.2.16.1 Institutional and Policy Framework

Russia developed a strategy for the development of RE in 2009, which provided key direction for the development of RE projects in the economy until 2020. In June 2020, the Russian Energy Strategy was released where it intends to gradually increase the share of RE in Russia's energy mix until 2030 and 2035.

A legislation for micro-scale generation (< 15 kW) was adopted in 2019. Owners of micro-scale generating systems can sell their excess electricity to retailers but is considered as suppliers of last resort. The retailers will not be allowed to refuse the purchase of the excess electricity. Between January 2021 and January 2029, sales by the micro-generators from selling their excess electricity is exempted from personal income tax. (Heidemann & Bogdanov, 2021)

The Russian EV policy includes the government's plan to subsidize purchase of locally manufactured EV by covering 25% of the purchase price or a maximum of 625,000 Roubles starting 2022. The Government has also set a target of annual EV production of 220,000 units by 2030. Another incentive for EV is that it can pass through toll roads for free. (IEA, 2021)

### 2.2.16.2 Solar PVs

As of 2018, solar PV installation in the residential sector is estimated at 15 MW.

### 2.2.16.3 EVs

EV's account for more than 0.2% of the Russia's total passenger-car fleet in 2021. As of January 2021, number of EV's registered is 10,836. Meanwhile, EV's sold in 2020 is 687 units. This translates to a 95% increase of EV sales between 2019 and 2020. The forecast for Russia suggests that the EV market will continue to increase at a rate of 0.5 to 1.0 times annually.

## 2.2.17 Singapore

### 2.2.17.1 Institutional and Policy Framework

Singapore's Green Plan to address climate change includes the following key targets: stopping new registrations of diesel cars and taxis starting in 2025, installing 60,000 vehicle charging points nationwide with two-thirds in public car parks and one-third on private premises by 2030, and increasing solar deployment to 2 gigawatts of capacity by 2030 (EIA, 2021).

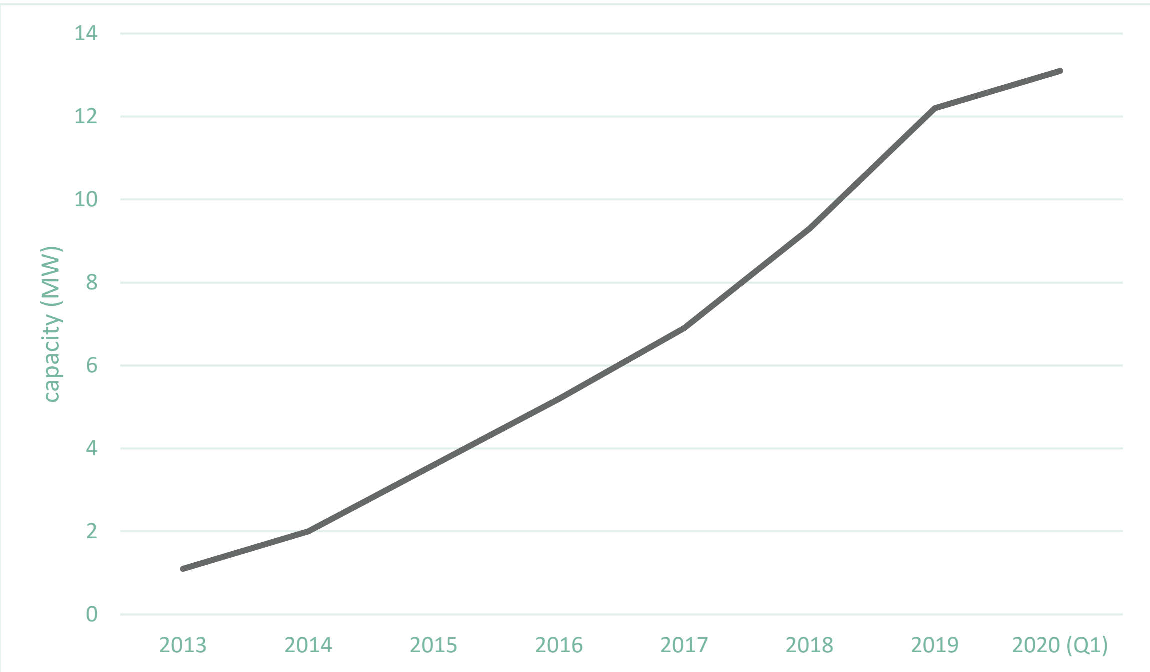
Solar PV is considered to be the only cost-effective and reliable RE option for power generation in Singapore. Additional rooftop solar PV systems will be installed in Housing and Development Board blocks and government sites through the Government's SolarNova program launched in 2015. Through a phased approach, Singapore added over 250 MW of solar PV capacity in five years and met its solar target of a 350 MWp during the first half of 2020. The government has set a new target of a 2 GWp target by 2030. (EIA, 2021)

Singapore's Road Traffic Act Chapter 276 provides subsidiary legislation that would support EV adoption such as vehicular emissions tax, licensing fees and rebates for EVs, and construction of EV charging infrastructures (CMS Legal, 2018). In May 2021, the Government has transferred EV regulation from the Electric Market Authority to the Land Transport Authority, who will review the technical standards and safety precautions relating to EV and set the charging standards (The Straits Times, 2021).

### 2.2.17.2 Solar PV

At the end of the first quarter of 2020, the number of residential PV installations totalled to 1,308 units, which is equivalent to 31.8% of total solar PV installations. In addition, this is equivalent to 13.1 MWp of residential solar PV capacity. In the past decade, solar PV installation has been steadily increasing as illustrated in Figure 2-3.

***Figure 2-3: Annual Installation of Residential Solar PV Capacity in Singapore***



#### 2.2.17.3 EV

The number of EVs registered in 2020 is 1,217 and increased to 1,549 in 2021. The latest data is equivalent to a 0.2% of EV share in the total vehicle fleet. The government has set a target to phase out ICE vehicles by 2040.

### 2.2.18 Chinese Taipei

#### 2.2.18.1 Institutional and Policy Framework

In 2017, the Electricity Business Act was revised to liberalize the electricity market in Chinese Taipei and promote RE power generation. In May 2019, a series of amendments to the Renewable Energy Development Act were likewise made to further its market liberalization strategy. The Government has set a target of 27 GW RE capacity by 2025. The application procedure for RE facilities with capacity less than 2MW was also simplified.

The Government has a Solar PV Promotion Plan, which aims for an additional 3.7 GW of solar capacity by 2021. In addition, a 3% subsidy is provided to consumers who will install solar PV systems on their rooftop and an additional 15% if they are located in the remote islands and the counties of Miaoli, Hualien, and Yilan. (CMS Legal, 2020)

Chinese Taipei's Cabinet approved in 2021 a draft amendment to the Vehicle License Tax to extend the license tax exemption for EVs until 2025. Likewise, an amendment to the Commodity Tax Act has been submitted, which will extend the commodity tax exemption for electric motorcycles and EV with value of less than NT$1.4 million to 2025.

#### 2.2.18.2 Solar PV

According to the latest statistics from the International Renewable Energy Agency, the island had around 5.8 GW of installed PV capacity at the end of 2020. As for the rooftop solar PV installation, the total capacity of rooftop solar PV reached 3.88GW in September 2020; industrial rooftops account for the largest share at 1.36GW, followed by agricultural and fishery facilities at 1.18GW, public buildings at 0.7GW and the private sector at 0.64GW. To further promote rooftop solar PV installation, all related government departments and agencies are currently conducting an inventory on rooftop spaces to identify more potential sites for an additional 88MW, and under the classroom air conditioners project, a total capacity of 272 MW of solar PV are being installed on the roofs of public schools, thus adding another 0.3 GW of rooftop-type solar PV.

At the same time, the government has established a coordination mechanism for all public agencies to conduct an island-wide inventory on potential sites of rooftop-type solar PV installation. For example, the Ministry of Economic Affairs (MOEA) aims to increase more than 1GW of solar PV targeting industrial zones in the northern, central, and southern parts of Chinese Taipei. Ministry of National Defense explores the spaces of military dormitories with low-level sensitivity; Council of Agriculture looks for indoor spaces of aquaculture, and agricultural facilities; Ministry of Transportation and Communication searches among port areas and municipal parking facilities. Taipower has also been instructed to timely establish feeder dispatch and grid-connection facilities for all potential sites mentioned above.[3]

[3] https://www.moea.gov.tw/Mns/english/news/News.aspx?kind=6&menu_id=176&news_id=92733

#### 2.2.18.3 EVs

In 2019, the EV sales totaled to 3,391 units, which is equivalent to 0.77% of the total vehicle sales. This increased in 2020 to reach EV sales of 6,360 units, equivalent to 1.39% of the total vehicle sales. The Government has set a goal of phasing out fossil fuel-based cars by 2040. To achieve this, Chinese Taipei needs additional growth of 0.4% in 2022 and 2.3% every year thereafter. However, current trend shows a steady growth that will enable only 57.2% EV penetration by the target year.

### 2.2.19 Thailand

#### 2.2.19.1 Institutional and Policy Framework

As early as 2013, the Thai Government launched a Solar Rooftop Program to support the deployment of solar PV rooftop systems. Its rules and regulations detailing the connection process and purchase agreements were developed by the Energy Regulatory Commission. (DEDE, n.d.) The economy's National Development Plan 2018-2037 emphasized the target to achieve 10,000 MW solar generation from the residential sector. To achieve this, the Government will grant licenses of 100 MW per year between 2019-2027 in households and increase it to 1,000 MW in the years thereafter. (Bangkok Post, 2019) In 2019, the Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA) launched a net metering scheme for residential PV installations with a generating capacity of up to 10 kW. The tariff is set for 10 years. (PV Magazine, 2019)

The Thai Government also announced its National EV Roadmap early in 2021 with the aim of transforming Thailand into an EV manufacturing economy with 30% EV in its total vehicle manufacturing by 2030. This is equivalent to 750,000 units in every 2.5 million cars manufactured. In addition, it is targeting to install 12,000 fast charging stations within the same timeline. The National EV Roadmap will also cover development plans for battery manufacturing and supplies, supporting infrastructure/s such as charging stations and power grid management, and the development of related laws and regulations to enable comprehensive and integrated implementation. (Baker Mckenzie, 2021) Other targets set by the Government include 1.2 million EV units on the road by 2030 and 2.5 million EV units by 2036. In terms of manufacturing, the target is to manufacture 1 million EV units by 2025, 6 million EV units by 2030, and 18.4 million EV units by 2035 with which by this year, only EVs will be manufactured in the economy.

#### 2.2.19.2 Solar PV

Between 2018 and 2021, the estimated annual solar PV capacity addition ranges from 0.1 GW to 0.3 GW. The following are the annual solar PV capacity additions: 0.3GW in 2018, 0.2GW in 2019, 0.1GW in 2020, 0.2GW in 2021, and estimated at 0.3 GW in 2022. The forecasted annual average addition is 0.4 GW between 2023 and 2025.

#### 2.2.19.3 EVs

There has been a sharp increase in the demand for EVs in recent years. Between 2018 and 2020, it is estimated that there has been 70% increase in EVs. As of 2020, the total number of EV in Thailand reached 192,000, consisting of motorcycles, three-wheelers, passenger cars, trucks, and buses. In the same year, the EV stock is estimated at 153,184 of both HEV and PHEV. However, in terms of registration, only 35,300 was recorded where 32,300 are PHEV and HEV and 3,000 are BEV. In April 2021, EV registration already reached 100,000.

## 2.2.20 United States

### 2.2.20.1 Institutional and Policy Framework

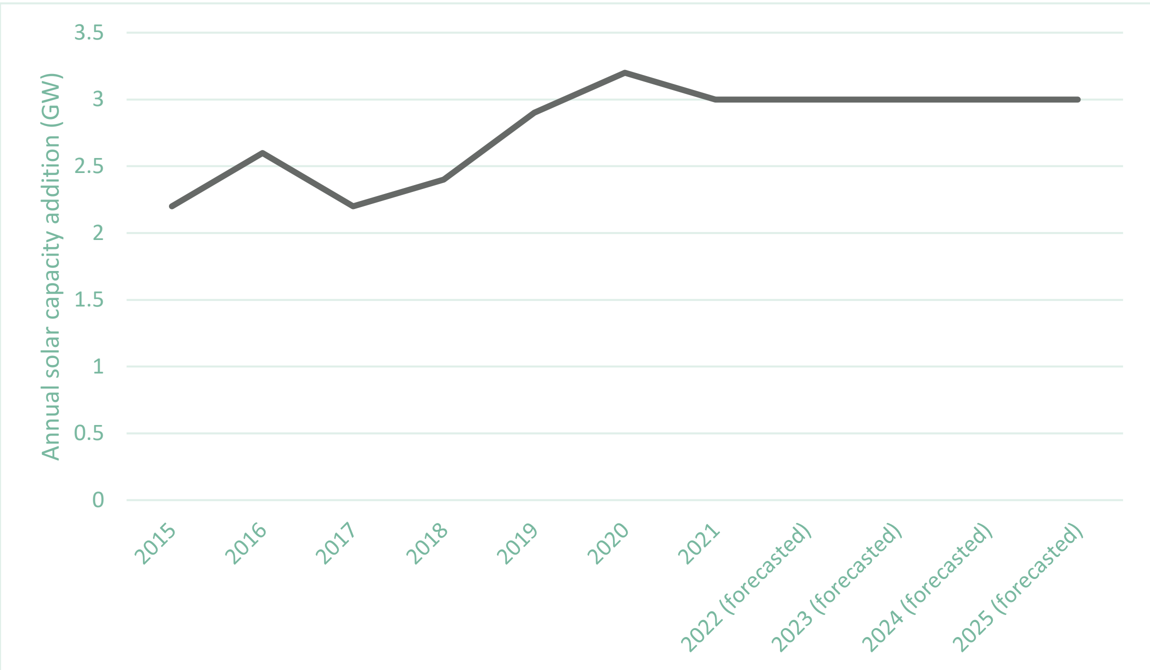
Several tax and fiscal incentives, as well as programs have been established to support the utilization of solar energy in the United States. The Investment Tax Credit is a federal tax incentive claimed against the tax liability of a residential, commercial, or utility-scale investor in solar energy projects. The tax credit is currently at 26% and will decrease to 22% in 2023. The Modified Accelerated Cost Recovery System accounts for the depreciation of the solar system by reducing the income (as a result of the PV system depreciation) that will be subjected to federal income tax. State programs and practices have also been institutionalized such as RPS, Solar Renewable Energy Certificates, Net Metering and Virtual Net Metering, third party financing, among others. (SOLSMART, 2021)

In August 2021, the Biden Administration has set an ambitious target of 50% EV sales share by 2030. This is institutionalized through an Executive Order, which includes provisions on the development of long-term fuel efficiency and emissions standards to save consumers money, cut pollution, boost public health, advance environmental justice, and tackle the climate crisis. Moreover, the Build Back Better Investment Agenda envisions for the United States. to be a leader in EV manufacturing, infrastructure, and innovation. (The White House, 2021)

### 2.2.20.2 Solar PV

The installed solar capacity in the residential sector is estimated at 19,961.8 $MW_{dc}$ as of the first quarter of 2021. Meanwhile, historical and forecasted data on the average annual solar PV installation in the United States is illustrated in Figure 2-4.

***Figure 2-4: Average Annual Solar Capacity Installation in the Residential Sector - U.S.***



#### 2.2.20.3 EVs

In 2020, 295,000 EV units were registered in the U.S. The EV penetration rate in the economy is estimated at 17% CAGR between 2016 to 2020. EV stock is at 10.2 million in 2020, which is equivalent to 17% of the global EV stock.

### 2.2.21 Viet Nam

#### 2.2.21.1 Institutional and Policy Framework

It is expected that the Government will issue a new price mechanism for rooftop solar that will replace the FIT mechanism. When FIT was first introduced in 2017, the tariff was very generous that it spurred the solar PV boom in Viet Nam (Do & Burke, 2021). The Ministry of Trade and Industry is currently working on the draft of the new price mechanism, which will further encourage the RE investments (Pinsent Masons, 2021). The Government has also placed tax exemptions for imported equipment used in solar PV systems. The National Renewable Energy Strategy 2015 sets the targets for developing renewables in the economy.

The Vietnamese Government is being encouraged to set policies that will support EV adoption in the economy (Nhat, 2021). One of the polices being reviewed by the Ministry of Trade and Industry and Ministry of Finance is the provision of tax incentives to encourage the development and use of electric vehicles in Viet Nam (Vietnam Plus, 2021).

#### 2.2.21.2 Solar PV

The capacity from solar rooftop PV is equivalent to 9.678 GW in 2020. Meanwhile, solar PV capacity additions in Viet Nam gained momentum in 2019 but slowed down during the COVID-19 pandemic. Nevertheless, Viet Nam is expected to continually increase their solar PV capacity. Historical data and projections on the annual solar PV capacity addition are as follows: 0.1 GW in 2018, 5.4 GW in 2019, 1.9 GW in 2020, 1.2 GW in 2021, 0.7 GW in 2022, and average of 1.3 GW between 2023 and 2025.

#### 2.2.21.3 EVs

The EV sales in 2020 was at around 1,000 units, both of BEV and hybrid, where hybrid units accounted for 99% of the sales. This is equivalent to only 0.003% of the total car sales in Viet Nam. Motorcycles are the preferred mode of private transport in Viet Nam. In 2020, VinFast reported 50,000 units of e-motorbikes sold.

## 2.3 GHG Emissions Reduction from Rooftop Solar PV and EV

Theoretically, the utilization of solar PV for power generation reduces greenhouse gas (GHG) emissions in the energy sector, in the same manner as the use of EVs for the transport sector. However, only tailpipe direct emissions from EV use reduces GHG emissions and the source of where the electricity use to power the EV may still come from fossil fuel-based generation, and as a result its overall GHG emissions is still relatively high. This is reflected in its Scope 2 GHG emissions accounting.

The GHG emissions of the combined use of solar PV and EV consider many factors. Nevertheless, one key feature in the estimation is that GHG emission is expected to increase when transformer loading increases. In this study, the project team tried to estimate for the corresponding GHG emissions that can be avoided by the APEC region with the simultaneous use of solar PV generation and EV charging. However, the lack of data on EV adoption makes it impossible to estimate for a practical GHG emissions. As such, only GHG emissions avoidance from the use of rooftop solar PV is calculated and is presented in Table 2-2. The assumptions and grid emission factors used are provided in Annex A.

***Table 2-2: GHG Emissions that can be avoided with current utilisation of Rooftop Solar PV***

| APEC Economy | Rooftop Solar PV Installed Capacity (MW) | Annual GHG emissions that can be avoided |
|---|---|---|
| **Australia** | 13,000 (2020) | 4,612,140.00 $tCO_2eq$ |
| **Brunei Darussalam** | 0.100 (2021) | 7.37 $tCO_2$ *if replacing NatGas*<br>9.74 $tCO_2$ *if replacing gasoline/ diesel* |
| **Canada** | 1,499.08 (2021) | N/A |
| **Chile** | 167 (Mar 2021) | 46,301.4r2 $tCO_2eq$ |
| **China** | 107,510 (2020) | 19,382,376.00 $tCO_2eq$ |
| **Hong Kong, China** | 2.1[4] (2017) | 435.37 $tCO_2eq$ |
| **Indonesia** | 18.2 (2020) | 5,168.25 $tCO_2eq$ |
| **Japan** | 770.12[5] (2020) | 110,548.14 $tCO_2eq$ |
| **Korea** | 1,094.60[6] (2019) | 199,885.56 $tCO_2eq$ |
| **Malaysia** | 10.67 [7](2018) | 2,278.31 $tCO_2eq$ |
| **Mexico** | 2,015 [8](2021) | 467,002.63 $tCO_2eq$ |
| **New Zealand** | 126.73[9] (2021) | 4,671.75 $tCO_2eq$ |
| **Papua New Guinea** | 14[10] (2021) | 3,467.50 $tCO_2eq$ |

[4] For estimation, figure refers to only known solar installation that is in Hong Kong Disneyland Park

[5] For estimation, figure refers to residential solar PV installation with <10 kW capacity

[6] For estimation, figure refers to both grid-connected and distributed solar PV

[7] For estimation, figure refers to solar capacity connected to the low voltage distribution grid

[8] For estimation, figure refers to solar distributed generation

[9] For estimation, figure refers to total of solar panels (< 10kW and >10 kW) in the residential sector

[10] No data so figure was estimated based on PNG's plan to utilize 2% of Port Moresby's peak demand to come from rooftop solar PV. In an ADB report, peak demand by 2021 is estimated at 700 MW.

| APEC Economy | Rooftop Solar PV Installed Capacity (MW) | Annual GHG emissions that can be avoided |
|---|---|---|
| **Peru** | 10[11] (2022) | 2,541.65 $tCO_2eq$ |
| **The Philippines** | 100 (2019) | 24,951.40 $tCO_2eq$ |
| **Russia** | 15 (2018) | 1,446.28 $tCO_2eq$ |
| **Singapore** | 13.1[12] (2020) | 1,950.85 $tCO_2eq$ |
| **Chinese Taipei** | 4,537.42 (2020) | 665,113.17 $tCO_2eq$ |
| **Thailand** | 9.018 [13](2021) | 1,864.35 $tCO_2eq$ |
| **USA** | 19,961.80 [14](2021) | 5,163,573.07 $tCO_2eq$ |
| **Viet Nam** | 2,876 (2020) | 844,095.93 $tCO_2eq$ |

With the current solar rooftop PV installations, it is estimated that the APEC region is avoiding almost 32 million tonnes of carbon dioxide equivalent annually (32 million $tCO_2eq$) from power generation. Specifically and due to differences in units of grid emission factors, seven to nine tonnes $CO_2$ in Brunei Darussalam, 30,928.64 tonnes GHG in Canada, and 31.5 million $tCO2_{eq}$ in the rest of the APEC. This estimate comes from rooftop solar PV data gathered from extensive research and use of assumptions for economies such as PNG and Peru, where data is not readily available. For estimation purposes, the solar PV capacity data in the residential sector was assumed to be rooftop system. The data on grid emissions factor per economy was used to calculate for the equivalent GHG emissions.

[11] Figure was estimated based on Government's plan in 2018 to introduce net metering scheme for up to 10MW.

[12] For estimation, figure refers to solar PV installation in the residential sector

[13] Figure refers to installations in the residential sector only

[14] Figure refers to installations in the residential sector only

# 3 Impacts of Rooftop Solar PV & EV on Distribution Network

This report aims to review overall impacts of rooftop solar PV and EV on distribution networks and specifically on distribution transformers' performance, such as lifetime. The distribution network is expected to experience a higher degree of intermittency and uncertainty both in generation and demand sides due to increasing uptake of solar PVs and EVs, which may result in overloading of the distribution network and affect the grid stability, as well as the power quality. However, the coordinated operation of solar PV and EV charging can be complementary to each other. It can overcome the grid stability and power quality issues that may arise due to individual integration of these devices. Several research works have investigated and reported the individual impact of PV system and EV charging on the grid operation. However, very few studies have been reported in the literature that investigates the combined impacts of PVs and EVs on grid stability, power quality, and energy economics.[15]

Summarized in Table 3-1 are possible impacts on distribution network and distribution transformers owned by utilities. Findings from desk research works on PV and EV integration in distribution networks are subsequently discussed in this section.

*Table 3-1: Possible Impacts on Distribution Network and Transformer*

| Technology | Possible Impacts on Distribution Network | Possible Impacts on Distribution Transformer |
|---|---|---|
| **Solar PV** | • increased spinning reserve at the generation level<br>• less stable system arising from the inability to support system frequency management<br>• voltage change/ voltage stability<br>• decrease in daytime loading<br>• line overloading<br>• power quality issues<br>• system loss<br>• reverse power flows | • transformer overloading<br>• power quality issues<br>• voltage change |
| **EV** | • voltage drop, deviation, and instability<br>• overloading of lines<br>• system instability<br>• harmonics and system losses<br>• short-circuit currents are higher | • accelerated aging<br>• overheating<br>• overloading |

## 3.1 Impacts of PV on Distribution Network

The intermittency of solar PV systems affects stability and power quality of distribution network. With the increasing amount of grid integration of PVs, the impact of this intermittent energy source on the

[15] Impacts of grid integration of solar PV and electric vehicle on grid stability, power quality and energy economics: a review, the Institution of Engineering and Technology (IET) Journals, 2019 2019

grid is becoming more significant. The impacts of grid integration of PV system from the aspects of grid stability and power quality are discussed as follows.

### 3.1.1 Impacts of PV Integration on Grid Stability

The lack of reactive power support and system inertia can impose significant challenges on grid stability with the high penetration of PV in the power grid. Several studies have been carried out over the years to study the impacts of high penetration of PV system on grid stability. The aspects of voltage and frequency stability are discussed in this subsection.

- **Impacts on voltage stability:** With the increased penetration of PV systems into the power grid, several studies have been carried out over the years to investigate the grid voltage stability in both distribution system and transmission networks. A thorough study on the impact of PV penetration to the distribution network voltage profile shows that the intermittency of a PV system can result to voltage rise and fluctuations, and these negative impacts become worse as the number of PV system increases. This effect is more prominent when a large-scale PV system is connected near the end of long, lightly loaded feeders. Similar studies also show that intermittency in PV power generation can cause voltage fluctuation in the low voltage distribution network and affect the voltage stability of the distribution network. Especially during fault conditions, the intermittency in PV power generation can cause short-term voltage instability in the distribution system.

- **Impacts on frequency stability:** Grid integration of large-scale PV systems can potentially impact the grid frequency stability. With the increased PV penetration into the power grid and the conventional synchronous generators undergoing retirement, the grid inertia decreases and the reduction in system inertia makes the grid highly sensitive to grid disturbances such as faults, sudden change in load demand and/or generation; and the rate of change of frequency becomes very high. This can significantly increase the risk of grid frequency instability. In the worst case, this may lead to cascading failures and blackouts. Battery storage with appropriate control can be used to emulate the synthetic inertia to negate the arising frequency stability issues due to the high penetration of PV system into the power grid.

### 3.1.2 Impacts of PV Integration on Power Quality

Power quality is one of the major concerns in integrating inverter-connected distributed energy resources such as solar PV. The main power quality parameters regarding PV integration involve voltage and power fluctuations and harmonic distortions. Many studies have been conducted to evaluate the impacts of high PV deployment on power quality issues. The impacts are categorized as follows:

- **Impacts on network voltage:** Grid integration of PV systems can cause voltage fluctuation that may potentially impact the lifetime of the network equipment. Studies show that grid integration of PV impacts the following aspects of grid voltage: (a) voltage unbalance, (b) voltage rise, (c) voltage sag and swell, and (d) flicker. Several studies have also indicated that high penetration of single-phase rooftop PV integration can cause the voltage to unbalance in within the distribution network. It has been identified through simulation studies that the unbalance voltage due to single-phase rooftop PV installations has a relationship with PV size, PV connection point, and load amount. Voltage rise has been identified as another impact resulting from reverse power flow. Studies also revealed that the high impedance between the PV and LV transformer causes a voltage rise in the distribution network. As rooftop PV installations are connected to different phases of a distribution network, voltage unbalance and voltage rise might exceed the standard boundary.

- **Impacts on network power:** Due to irradiance and temperature variability, output power of a PV system fluctuates. This fluctuating nature of PV output can cause grid frequency fluctuation with high penetration of PV systems.

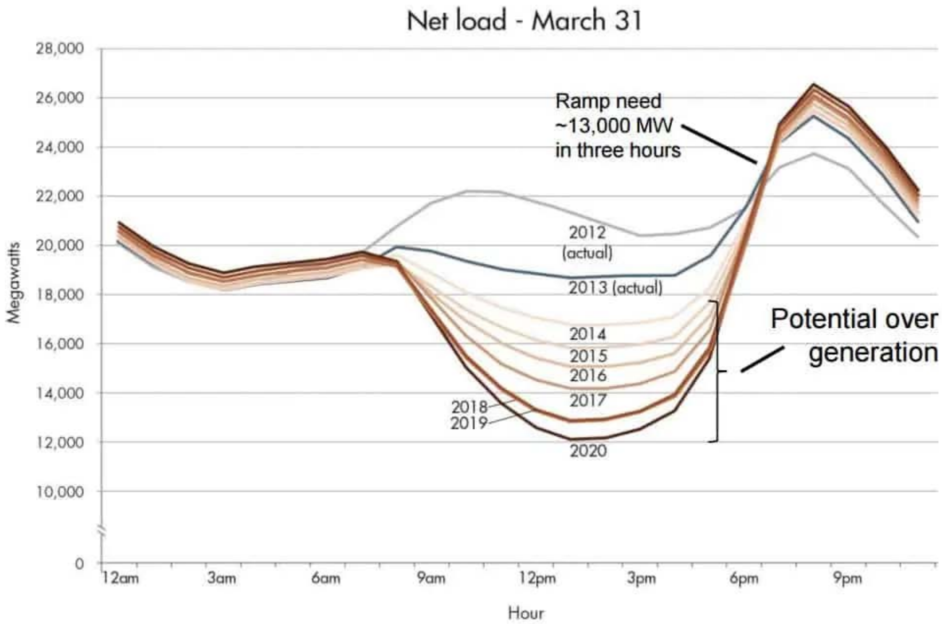
- **Impacts on network harmonics:** PV systems are sources of harmonics because of semiconductor switches in the inverter. The total harmonic distortion is dependent on the inverter technology, solar irradiation, temperature, and network characteristics. The current harmonics in an LV network with high impedance can result in significant voltage distortions. Many approaches have been proposed to mitigate the impacts of harmonics produced by PV systems. The passive and active filters are the traditional solutions to eliminate the harmonics in the system. Another method is to apply control strategies for inverters to compensate harmonics.

### 3.1.3 Impacts of PV Integration on Distribution Transformer

#### 3.1.3.1 Distribution Transformer Load Profiles with PV Integration

The distribution transformers owned by utilities and customers will be subject to different load variation patterns. In a 2013 report by the California Independent System Operator (CAISO), they predicted the impacts of an increasing intermittent renewable energy, predominantly solar, when connected to the grid and presented the chart now commonly known as the "Duck Curve" shown in Figure 3-1. The salient features of the chart are the mid-day drop in net load, then the increase between 3 and 7 pm. The mid-day drop is due to a high volume of energy from solar, and when solar is no longer a source of energy, then there is an increase in energy demand.

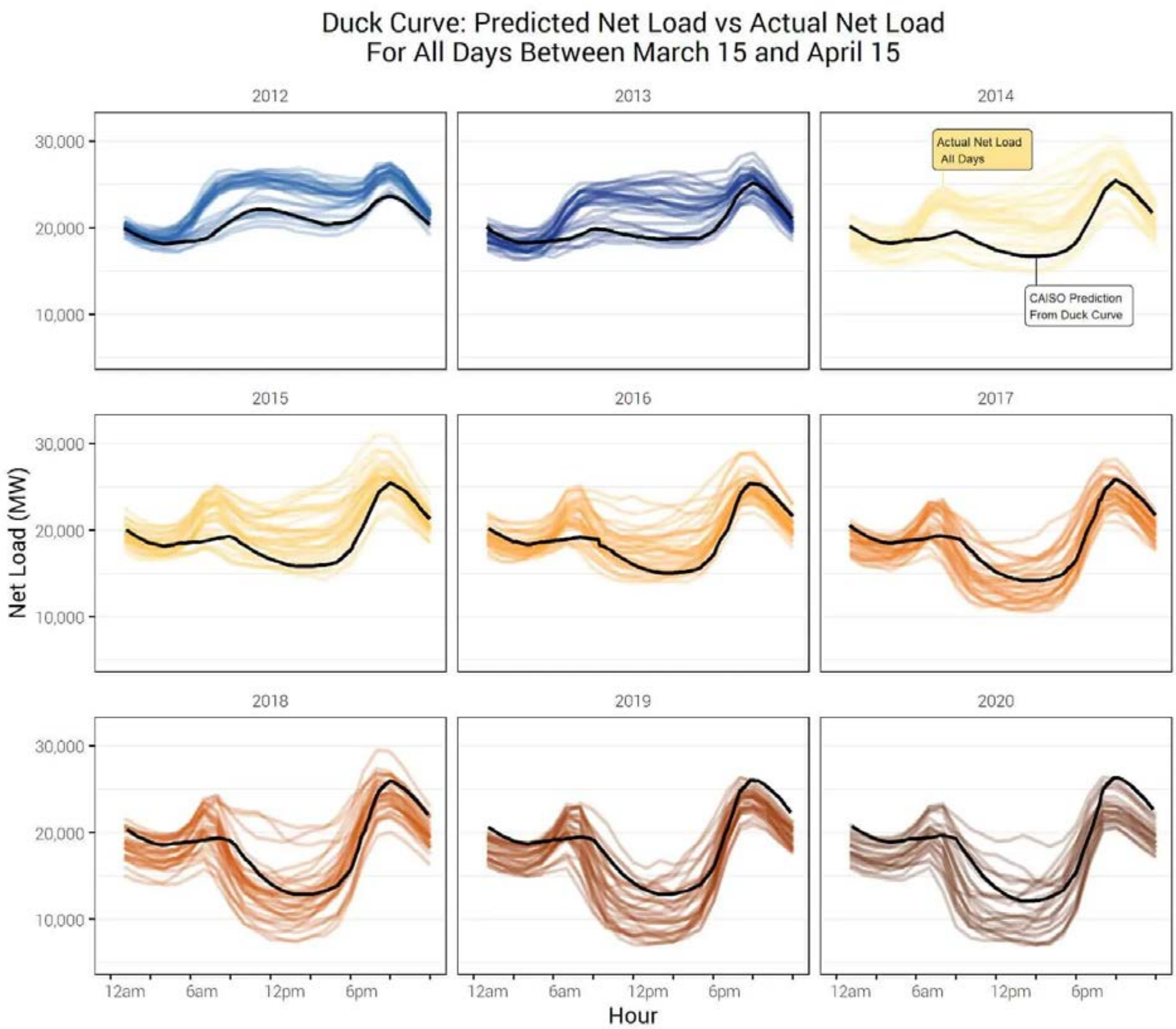
***Figure 3-1: Original Duck Curve predicted by CAISO in 2013***




Source: CAISO

Comparison of the CAISO's 2013 predictions with the actual net load from 2012 to 2020 found that the predictions were close to the actual net load. It was also found that starting in 2017, the actual load has begun to dip lower than CAISO's predictions, and the duck curve has also begun to include a morning peak (see Figure 3-2).

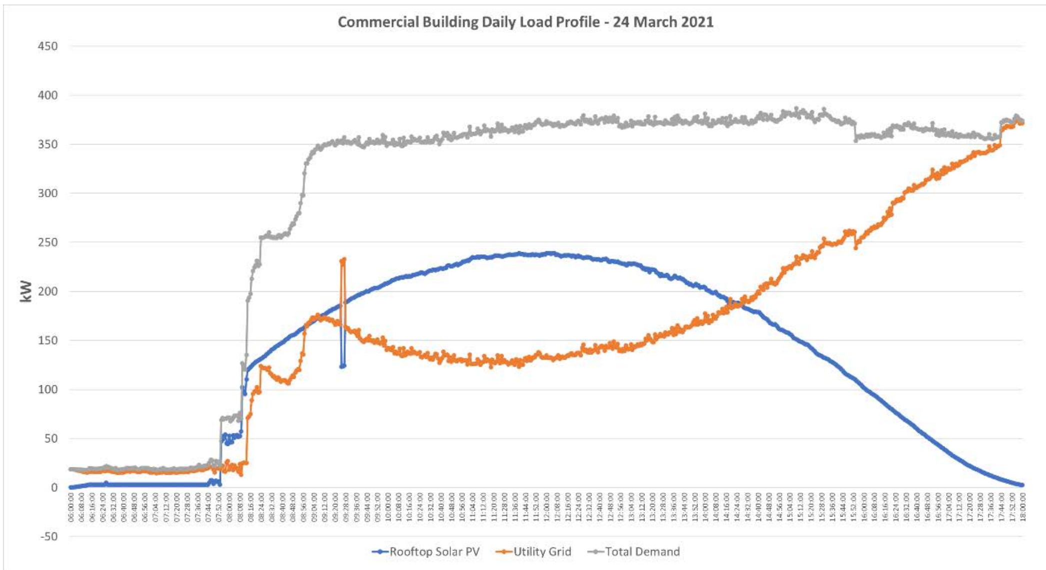
***Figure 3-2: Predicted Net Load vs Actual Net Load 2012 - 2020***




Source: https://www.aurorasolar.com/blog/the-duck-curve-a-review-of-californias-daily-load-predictions/

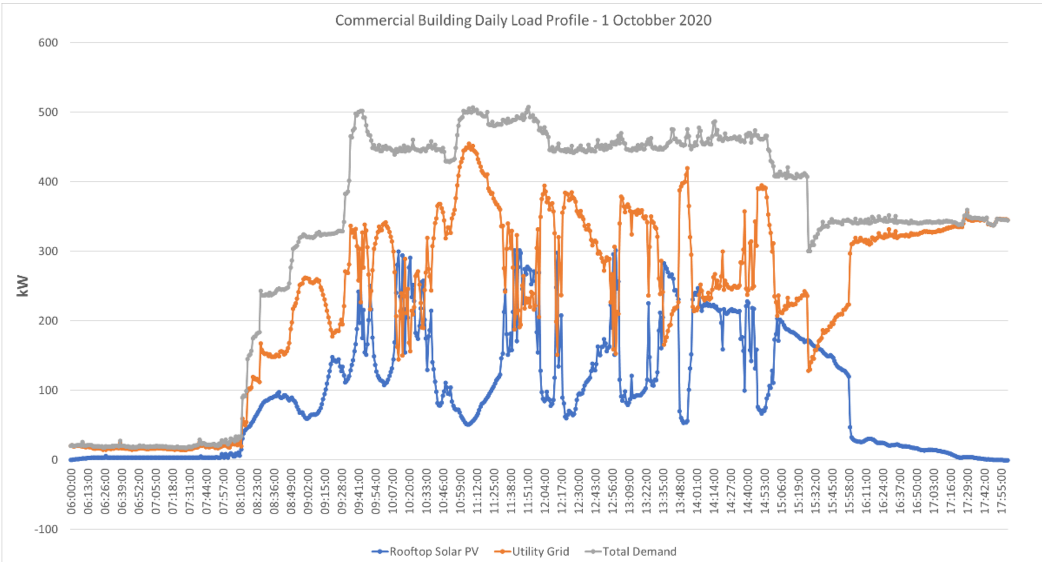
Although the Duck Curve cannot represent the daily load profile of each individual distribution transformer owned by the utilities, it shows that, with PV integration, the overall daily loading of distribution transformer is reduced, hence the total distribution transformer losses. As for the distribution transformers owned by non-residential consumers e.g., commercial and industrial, variations of daily load profile depend on the operating hours of the facilities. However, the mid-day dip and evening peak can be clearly seen in the daily load profiles (see Figure 3-3 and Figure 3-4), and the overall load factor is also reduced due to PV integration.

***Figure 3-3: Sunny Day Load Profile – Hypermart Building with Rooftop Solar PV***




Source: Measurement data compiled by IIEC

***Figure 3-4: Cloudy Day Load Profile – Hypermart Building with Rooftop Solar PV***




Source: Measurement data compiled by IIEC

#### 3.1.3.2 Distribution Transformer Lifetime with PV Integration

Lower load factor generally extends the lifetime of distribution transformer, however high penetration of PV could develop power quality problems such as current and voltage unbalance, and these could reduce distribution transformers' useful lifetime. The lifetime of a distribution transformer is mainly determined by insulation life, which is affected by loading, ambient temperature, moisture, and oxygen content of the oil. A paper on the analysis of distribution transformer lifetime with different levels of PV penetration in a distribution network in Australia shows that PV integration can extend lifetime of distribution transformers while the introduction of demand response can further improve distribution transformers' lifetime. The paper concluded that inclusion of PV and demand response in the feeder of the case study reduces the Loss of Life (LOL) of a distribution transformer by 90%. (Behi, Arefi, Pezeshki, & Shahnia, 2017)

## 3.2 IMPACTS OF EV ON DISTRIBUTION NETWORK

From the utility's perspective, EV charging loads are non-linear loads with different characteristics from other usual loads. Several efforts have been made to study the impact of grid integration of EVs. This section summarizes impacts of EV integration into distribution networks in terms of grid stability and power quality.

### 3.2.1 Impacts of EV Integration on Grid Stability

Uncertainties in EV connection points, time, and period of charging cause challenges to predict the behavior of this new load. Therefore, a large number of EV charging might cause concerns about power system stability. Since characteristics of load can significantly impact power system stability, different types of EV load models have been considered in various research studies; for example, a constant power load (P) model of EV independent of voltage level and a constant current load (I) model of EV. It has been reported in many studies that grid integration of EV can significantly impact the grid stability. The impacts on voltage stability and frequency stability due to EV integration are summarized below:

- **Impacts on voltage stability:** Most impact studies are based on EV load modelling. A study on the impact of EVs on voltage stability in the residential networks in Australia showed that voltage stability indices of the distribution network are affected significantly by the location of integration and the size of the EV load.

- **Impacts on frequency stability:** With high penetration of EVs, the charging load demand in the grid will increase dramatically. Moreover, uncertainties in the number of EV connections and the period of connection and disconnection is likely to impose an increased level of uncertainty on the load demand. By regulating the time and rate of charging or discharging, EVs can be operated as controllable loads. Recent studies have demonstrated that EVs can be utilized to balance load demand and power generation in the grid, and they can be used to regulate the grid frequency. EVs have also been investigated as frequency controller to maintain the grid frequency.

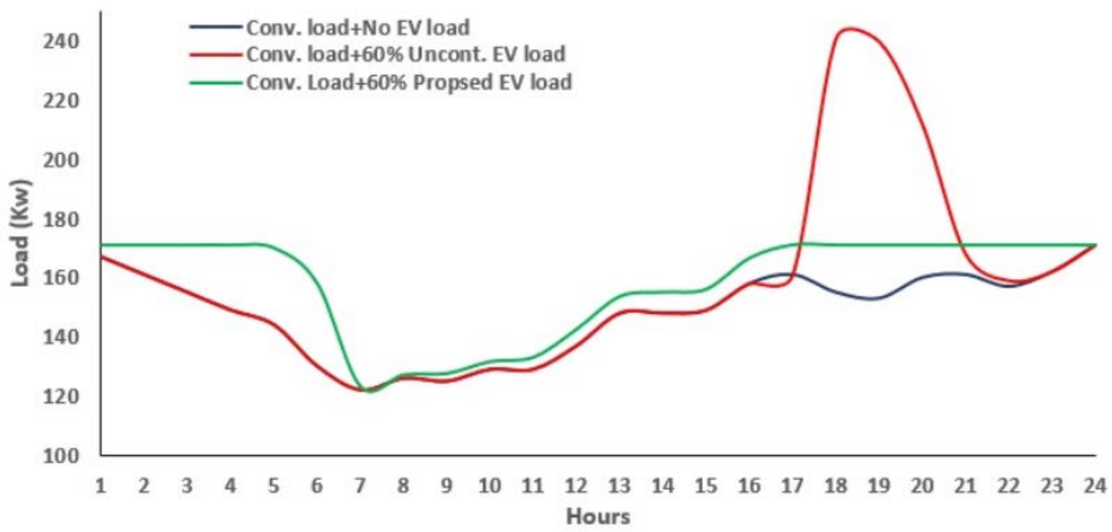
### 3.2.2 Impacts of EV Integration on Power Quality

Grid integration of EVs can affect the power quality of the power system. The impact of EV integration on the power quality (e.g., voltage fluctuation, voltage unbalance, harmonic, etc.) depends on the characteristic of EV charging, network features, and the number of EVs. Impacts on voltage fluctuation and harmonic depend on the integration level and charging rate of EVs. As the penetration and charging rate increase, the impacts increase. Impact on voltage unbalance increases with the increased EV single-phase charging. The harmonics increases with random unregulated EV charging.

### 3.2.3 Impacts of EV Integration on Distribution Transformer

Overloading and losses in distribution transformer increase with high penetration of EVs. If a distribution transformer is overloaded due to EV charging, it can either be replaced with a larger unit or the EV load can be managed with financial incentives and smart charging technology. A study by Hilshey et. al. (2013) suggests that EV charging is likely to introduce enormous uncertainty in transformer aging, particularly in hot climates. The paper also found that smart charging can also reduce uncertainty in the transformer's life. Smart charging can actually increase rather than decrease transformer aging over the uncontrolled case. Shown in Figure 3-5 are simulated load profiles of a low voltage feeder in Jordan, based on a real distribution system's load, and it can be seen that the uncontrolled charging behaviours based on typical drive distance, arrival time, and departure time in Jordan cause high evening peak demand in this particular feeder. However, a coordinated charging scheme for EVs with dynamic response will be able to better manage the load profile and remove the evening peak demand.

***Figure 3-5: Low Voltage Feeder Load Profiles with/without EV Load***




Source: (Obeidat, et al., 2021)

## 3.3 Potential Benefits of Coordinated PV and EV Integration

Individually, PVs and EVs can deliver negative impacts to grid stability and power quality due to the intermittent nature of PV power generation and the uncertain EV load characteristics, unpredictable EV connection point, and charging period of EVs. With the increased penetration of PV and EV, the electricity grid is expected to experience a higher degree of intermittency and uncertainty both in the generation and load. With high penetration of EVs with fast charging rates, the grid might not be able support the high-power demand of EV charging.

However, coordinated and combined control/management of PVs and EVs may enhance grid stability and power quality. Several papers recently studied on control approaches to coordinate PV and EV operation and utilize them to enhance grid stability, power quality, and economic benefits to name a few. EV charging stations are recommended to be assisted with PV energy sources to negate the uncertainties associated with EV charging. The Australian National Electricity Market (NEM) case study results show that EV charging management in coordination with a PV system can also minimize cost and $CO_2$ emissions.

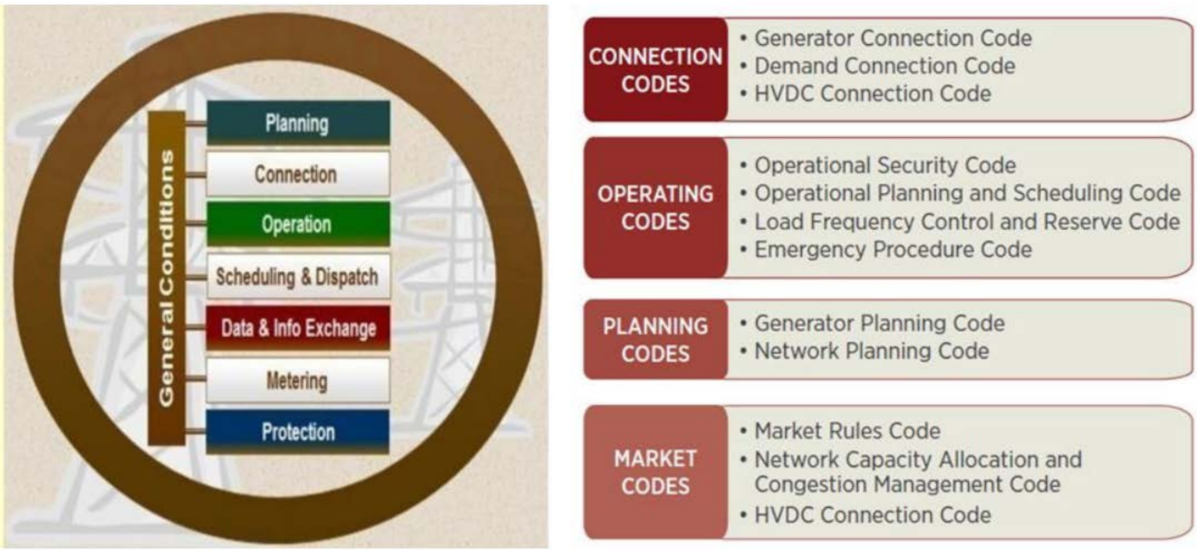
# 4 Grid Connection Requirements for Rooftop Solar PV

Installations of rooftop solar PV in APEC economies can generally be categorized into the following groups:

1. Rooftop solar PV installations/projects that sell all or part of electricity production to electric utilities;
2. Rooftop solar PV installations/projects for self-consumption, but connected to a utility's grid to supplement shortfalls in solar electricity production; and
3. Stand-alone rooftop solar PV installation/projects.

This section specifically focuses on rooftop solar PV installations/projects which are connected to utility's low voltage (LV) and medium voltage (MV) distribution networks. Local utilities require all rooftop solar PV installations/projects to be approved before connecting into the electricity grid to ensure stability of distribution power system and quality of power supply. With excessive electricity production by solar PV in a local distribution network, the voltage can exceed regulated limits, and the reversed power flow on the low voltage power line may then exceed line or transformer capacity limits. The grid connection requirements for rooftop solar PV or "grid codes," help regulate quality of the local distribution networks.

***Figure 4-1: Grid Code Structure and Type of Codes***




Source: (Abt Associates Inc., 2021)

As shown in Figure 4-1, grid codes encompass a much larger scope other than connecting rooftop solar PV installations/projects to electricity grids. There are rules and criteria in every grid code dealing with electricity generation by conventional and other renewable power plants, as well as for transmission, distribution, protection, metering, maintenance, buying and selling of power, ancillary services, etc. The development of a grid code involves multiple elements: preparation of technical studies, data collection and assessment of economy-specific aspects, experts' drafting of the grid code, stakeholder consultation on the draft, grid code endorsement, implementation, revision based on policy changes, and experience after employing the grid code. (IRENA, 2016)

Note that these grid connection codes for rooftop solar PV systems are typically part of the connection codes/guidelines for DER, which cover utility-scale and small-scale DER including solar PV, battery energy storage, backup generators, combined heat and power (CHP), wind turbines, small-scale hydro, or demand response such as EV charging. Distinction between utility-scale and small-scale DER is generally based on generating capacity. However, the generating capacity thresholds can be different from economy to economy. The regulatory framework review in this report focuses on the connection codes for rooftop solar PV and EV and their relevant requirements for distribution transformers.

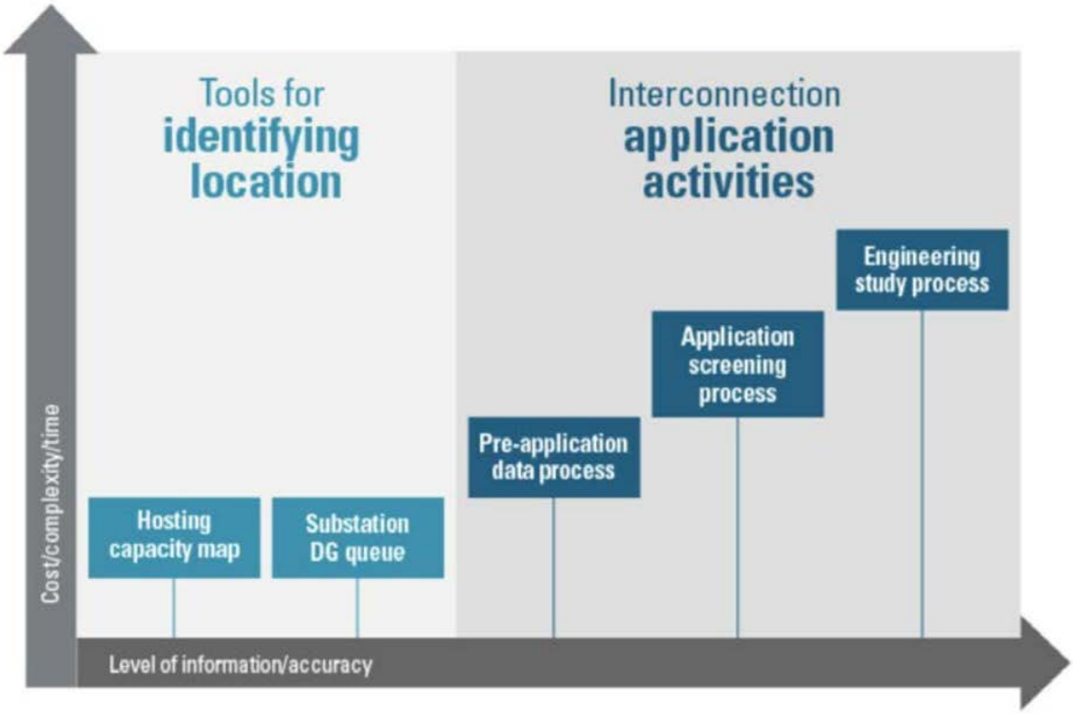
## 4.1 Current Practices and Standards

Grid connection codes/requirements for solar PV have constantly been evolving to respond to changing in DER behaviors and development of technologies for solar PV systems, e.g., inverter technologies.

Technical screening of systems that apply for interconnection is the important part of the grid connection codes/requirements as it helps ensure safe, reliable, and cost-effective interconnection within the electricity grid. Once a utility receives a complete interconnection application, the technical screening process will be carried out and the approval may be granted immediately. If the application did not pass this screening test, a supplementary review to determine the need for a detailed impact study involving modeling and mitigation measures is conducted. In general, the technical screening limits contribution of small generators, including rooftop solar PV (through grid-tied inverters), through maximum installed capacity per rooftop solar PV system, percentage of annual peak load most recently measured at the substation, percentage of distribution circuit's maximum fault current, maximum generating capacity per feeder, etc. Similar technical screening approaches have been applied across APEC economies with different sets of limits determined by local regulatory authorities and utilities.

Shown in Figure 4-2 is the relationship between level of information/accuracy and interconnection application activities. Utilization of available data, such as hosting capacity maps, appears to be effective in reducing the number of non-viable projects that seek to interconnect, and this available data can be used as part of the application screening and engineering study processes.

***Figure 4-2: Relationship Between Different Tools and Application Activities***




Source: (Horowitz, et al., 2019)

In 2018, the Institute of Electrical and Electronics Engineers (IEEE) published an updated version of IEEE 1547 standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. IEEE 1547-2018 provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection. It also includes general requirements, response to abnormal conditions, power quality, islanding, as well as test specifications and requirements for design, production, installation evaluation, commissioning, and periodic tests. The stated requirements are universally needed for interconnection of DER, including synchronous machines, induction machines, or power inverters/converters and will be sufficient for most installations. The criteria and requirements are applicable to all DER technologies interconnected to electric power systems (EPS) at typical primary and/or secondary distribution voltages. Installation of DER on radial primary and secondary distribution systems is the main emphasis of this document, although installation of DERs on primary and secondary network distribution systems is considered. This standard was developed considering that the DER is a 60 Hz source (IEEE, 2018). IEEE Std 1547-2018 requirements cover multiple areas including safety, power quality, protection, testing and certification, voltage regulation, interoperability, and support for bulk system (ride-through).

In addition to IEEE 1547-2018, PV interconnection standards/requirements have been developed internationally, with examples[16] as follows:

- Germany: BDEW/VDE 4105 for MV and LV connections, which provides key guidelines on feed-in management, active power reduction during over frequency, provision of reactive power and dynamic grid support (fault ride through).

[16] Greening the Grid - Best Practices for Grid Codes for Renewable Energy Generators Presentation, Adarsh Nagarajan, Ph.D., October 2018

- Regional level (Europe): European Network of Transmission System Operators for Electricity (ENTSO-E)
- Italy: CEI 0-21 standard governing the connection of power generation and consumption plants in the LV grid was published in Italy in December 2011 also, AEEG 084-12 from March 8, 2012.
- Spain: Royal decree RD 1565/2010, dynamic grid support is already mandatory for all PV plants exceeding two megawatts in Spain today.
- India: Best Practices Guide, Implementation of State-Level Solar Rooftop Photovoltaic Programs in India published by the Ministry of New and Renewable Energy (MNRE) in 2016, and the Central Electricity Authority (CEA) issued the CEA regulation on Technical Standards for Connectivity of the distributed generation resources in 2018.

As for the APEC member economies in Southeast Asia, most of the power utilities are government owned with single buyer market environment. The power utilities are responsible for grid code development with or without supervision of the regulator, depending on the legislation of each economy. Grid codes are developed based purely on practical experience and reflect the current grid conditions.

## 4.2 Grid Connection Requirements in APEC Economies

This section summarizes basic grid connection requirements in APEC economies based on desk research.

***Table 4-1: Summary of Grid Connect Requirements in APEC Economies***

| APEC Economy | Maximum Capacity | Hosting Capacity and Export Limit Requirement | Power Quality & Standard |
|---|---|---|---|
| **Australia** | • Single phase connection (most homes): Up to 5 kW (or 5 kVA)<br>• Three-phase connection (some homes and many businesses): Up to 30kW (or 30kVA) | Connection and export limit requirement to be evaluated by utilities | The inverter shall comply with the requirements of AS/NZS 4777.2 |
| **Chile** | 100 kW | N/A | N/A |
| **Hong Kong, China** | 1 MW | Connection and other requirement to be evaluated by utilities | Various IEC standards for safety and other performance of inverter and PV system referenced |
| **Indonesia** | 100% of Customer's Connected Power | Connection and other requirement to be evaluated by utilities | N/A |

| APEC Economy | Maximum Capacity | Hosting Capacity and Export Limit Requirement | Power Quality & Standard |
|---|---|---|---|
| **Japan** | 1 MW | Connection and other requirement to be evaluated by utilities | N/A |
| **Malaysia** | • Single-phase Domestic Consumer: not more than 4 kW<br>• Three-phase Domestic Consumer: not more than 10 kW<br>• Government agency, Commercial, Industry and agricultural building: up to 1,000 kW and subject to the following: requirements:<br>- MV Consumer - 75% of consumer's maximum demand<br>- LV Consumer - 60% of fuse rating for direct meter or 60% of CT rating | Any rooftop solar PV system with installed capacity more than 75 kW is required to conduct the Net Energy Metering Assessment Study (NEMAS).<br><br>For self-consumption rooftop solar PV system, no export is allowed, a device that will prevent the export shall be installed. | Inverters shall comply with international and Malaysian standards (IEC, and IEEE), and provide appropriate functionality within the inverter or use of external power limiting device. The following requirements are also specified:<br>• Normal voltage operating range<br>• Voltage fluctuation<br>• Harmonic<br>• Inverter power factor<br>• Reactive power compensation<br>• DC injection<br>• Flicker<br>• Voltage unbalance<br>• Short circuit level |
| **New Zealand** | Not specified with residential installations divided into two main groups: 10 kW or less and above 10 kW | Utilities may provide information on congestion management policy and congestion areas, allowing utilities to curtail output/operation and interrupt connection to ensure the power quality standards are met. | The inverter shall comply with the requirements of AS/NZS 4777.2. Utilities also provide the list of approved inverters. |
| **Singapore** | Not specified but three groups of install capacity for electricity licensing purpose:<br>1) < 1 MW<br>2) 1 MW to <10 MW<br>3) ≥ 10 MW | Connection and other requirement to be evaluated by the utility (SP PowerGrid - SPPG) | N/A |
| **Chinese Taipei** | Not specified but FiT rates divided into four groups:<br>1) 1 kW to <20 kW<br>2) 20 kW to <100 kW<br>3) 100 kW to <500 kW<br>4) ≥500 kW | All grid-connected rooftop solar PV systems are subject to evaluation and approval by utility and relevant authorities prior to connection to the grid. | Technology guideline references IEC, IEEE, ANSI, UL, VDE, and CNS standards |
| **Thailand** | • Single-Phase LV: 10 kW (MEA), 5 kW (PEA)<br>• MV: Not specified | LV consumers: Maximum cumulative installed capacity of solar PV systems | Relevant IEC and IEEE standards (including IEEE 1547) in specifying voltage, |

| APEC Economy | Maximum Capacity | Hosting Capacity and Export Limit Requirement | Power Quality & Standard |
|---|---|---|---|
| | | (in kW) shall not exceed 15% of rated kVA of the distribution transformer being connected<br><br>Maximum cumulative installed capacity of solar PV installations/projects (in kW) shall not exceed 75% of rated kVA of the substation transformer<br><br>MEA: 12kV - 4 MW/circuit, 24 kV - 8 MW/circuit<br><br>PEA: 22 kV - 8 MW/circuit, 33 kV - 10 MW/circuit,<br><br>115 kV - 120 MW/single-conductor circuit,<br><br>230 MW/double-conduct circuit | frequency, safety and power quality performance of grid-tied inverters, and the lists of pre-approved grid-tied inverters are also published by MEA and PEA. |
| **USA** | States and local utilities have different requirements, e.g.:<br>• 120% – 125% of connected load<br>• Not larger than the highest monthly energy usage<br>• No maximum installed capacity but higher fee will be applied for larger installed capacity | Connection and other requirement to be evaluated by States and local utilities guided by the Federal Energy Regulatory Commission's (FERC) Small Generator Interconnection Procedures (SPIG) | Various IEEE, UL, and ANSI standards as well as NEC (electrical building code) referenced. The IEEE 1547 family of standards provides the critical foundation for interconnecting DERs to electric utility distribution grids. |
| **Viet Nam** | 1 MW (per PPA) | Connection and other requirement to be evaluated by Viet Nam Electricity (EVN) | N/A |

Note: N/A = information not accessible during the preparation of this report. This does not mean such requirements on maximum installed capacity, hosting capacity, export limit, power quality and standards do not exist.

More details on grid connection requirements for rooftop solar PV systems in selected APEC economies are described in the following sub-sections.

### 4.2.1 Australia

Each distribution network and region have local interconnection requirements for DER, which may be based on Australian or international standards and legislation (such as AS/NZS 4777 or IEEE

1547:2018) (EPRI, 2019). For rooftop solar PV, most networks in Australia will allow system sizes for low voltage network as per the below:

- Single phase connection (most homes): Up to 5 kW (or 5 kVA)
- Three-phase connection (some homes and many businesses): Up to 30kW (or 30kVA)

Some networks in Australia allow up to 10 kVA single phase connection by inverter. In some networks, an export limit is imposed for each rooftop solar PV installation and an export limiting device must be installed (either via inverter or additional devices) to ensure that output from the system never exceeds the limit. Rooftop solar PV systems with capacity larger than 30 kVA can be installed but technical studies will be required before approval is granted.

### 4.2.2 Brunei Darussalam

According to the Guidebook on Solar PV Rooftop and Net-metering Programme published in March 2022 by the Sustainable Energy Division of the Ministry of Energy, no size of rooftop solar PV system is specified, but the guidebook provides estimation for rooftop solar PV system of up to 20 kW. The guidebook also highlights that the 100kWp system at Temburong District Office is known as the first and the largest solar rooftop installed at Government building in Brunei Darussalam.

### 4.2.3 Chile

The Chilean "net billing" law lays out a detailed process for approving distributed generation systems under 100 kW to inject into the grid. Although many stakeholders agree that the process is clear and straightforward, completing each step in the process is cumbersome, often requiring detailed and expensive engineering diagrams. Not only is each step in the process cumbersome, but delays in response time between stakeholders have been a factor in driving up the overall processing time. Moreover, there is no simplified process for smaller systems (e.g., <10 kW), which drives up the cost per watt as developers must put the same amount of time and effort into the lengthy process as a 100 kW system. In addition, the process is offline, requiring developers to manually fill out forms and return them to the proper address, resulting in processing errors and missed forms. These combined factors have led to processing times ranging from 3 to 6 months and increased installation costs. (Barrett, Dabrowski, Deo, Rahman, & Selle, 2016)

### 4.2.4 Hong Kong, China

According to the guidance notes for solar PV system installation issued by the Electrical and Mechanical Services Department (EMSD) in January 2019, all customers of the power companies, except for government bodies, who plan to install solar PV systems with a generating capacity of up to 1 MW at their premises are eligible for prescribed FiT rates from that power company based on the units of electricity generated and as long as the distributed RE systems are connected to the grid of the relevant power company subject to FiT Terms and Conditions. Solar PV (and other RE) systems with a generating capacity exceeding 1 MW will be considered on a case-by-case basis (EMSD, 2019). Customers who wish to connect the solar PV system to the grid are required to submit applications to the power company (i.e., CLP Power Hong Kong Limited and HK Electric Investments Limited). The design, technical specifications, operation procedure, testing, and cost data of the system should be submitted along with the application for grid connection. Shown in Figure 4-3 is the flowchart on key application procedures involved in applying for FiT.

***Figure 4-3: Key Application Procedure in Applying for Feed-in Tariff (FiT) in Hong Kong, China***


### 4.2.5 Indonesia

The Ministry of Energy and Mineral Resource enacted the new MEMR 26/2021 regulation in August 2021 governing "Rooftop Solar Systems" that are connected to the networks of the domestic electric utility, PLN (PT Perusahaan Listrik Negara) and other license holders of the electricity supply business. The capacity of rooftop solar systems is limited to a maximum of 100% of the connected power of the customers, which is calculated based on the total capacity of the inverters. The network operators in private business areas can set up the capacity limits and report such declaration to the Directorate General of New and Renewable Energy and Energy Conservation (DGNREEC) under MEMR. The customers who wish to install rooftop solar PV must submit an application for the construction and installation of the rooftop solar PV system to their respective utilities to obtain approval. (Ashurst, 2021)

### 4.2.6 Japan

The FiT system was first introduced in Japan in 2012. On June 2020, the act was amended and the feed-in premium (FIP) system was added under the amended law, which will come into effect with some exceptions on 1 April 2022. The FIT system applies for solar PV systems with capacity less than 50kW, and the FIT and FIP can be selected for the systems with capacity from 50 kW to less than 1,000 kW. For the FIT or FIP system to apply to a project, a business operator must prepare a renewable energy power generation project plan and obtain a certification from the Ministry of Economy, Trade and Industry. The project plan must meet all certification criteria, including project site and solar system design. If an environmental assessment is required, the procedures need to be initiated before applying for the certification.

It is also necessary to apply for the relevant transmission and distribution utility for a connection study, and then obtain their consent for the grid connection before applying for certification. The utilities may instruct the business operators to curtail output if the electricity supply is expected to exceed the demand, even after taking the prescribed avoidance measures. Solar power projects in any area in Japan for which a grid connection agreement is entered into on or after 1 April 2021 are subject to output control without restriction and compensation. (Asia Business Law Journal, 2021)

### 4.2.7 Malaysia

According to the updated Guidelines for Solar Photovoltaic Installation Under the Net Energy Metering (NEM) Programme issued by the Energy Commission in February 2021, rooftop solar PV systems for domestic consumers shall comply with the following maximum capacity requirements:

- Single phase domestic consumer, not more than 4 kW; and
- Three phase domestic consumer, not more than 10 kW.

The NEM Programme also covers government agency buildings as well as commercial, industrial, and agricultural consumers with the maximum installed capacity up to 1,000 kW. Note that the levels of grid supply voltage are also used to determine the maximum rooftop solar PV installed capacity for each public building. For medium voltage connected buildings, the maximum installed capacity shall not exceed 75% of maximum demand. As for low voltage connected buildings, the maximum installed capacity shall not exceed 60% of fuse rating or current transformer (CT) rating.

Any rooftop solar PV system with installed capacity more than 75 kW is required to conduct the Net Energy Metering Assessment Study (NEMAS). The NEMAS shall be conducted by qualified consultants and submit to the utility prior to approval of the NEM application. The NEM consumer will be responsible for the costs related to the NEMAS and any works required for the connection of rooftop solar PV system into the utility's grid. Although no analysis is required for the rooftop solar PV systems with capacity not more than 75 kW, the NEM consumer shall ensure that the exported power shall be less than the existing capacity of the feeder and consumer’s equipment. To ensure compliance of the exported power, the NEM consumer shall provide appropriate functionality within the inverter or use of external power limiting device. Inverters to be paralleled to the grid shall comply to the following standards and references, in terms of design, operation, and maintenance:

- MS 1873 Connection scheme of grid connected inverter
- IEC 61727 Photovoltaic systems – characteristics of utility interface

- IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems - This standard describes the connection requirements of various Distributed Resources to the utility network
- Suruhanjaya Tenaga "Distribution Code For Peninsular Malaysia, Sabah & F.T. Labuan"
- TNB *Tenaga Nasional Berhad* – Technical Guidelines for Interconnection of Distributed Generator to Distribution System, 2018
- Suruhanjaya Tenaga "Guideline for Solar Photovoltaic Installation on Net Energy Metering Scheme
- TNB "Technical Guideline for Connection of Indirect Solar PV Power Generation for Net Energy Metering"
- TNB "Electricity Supply Application Handbook"

### 4.2.8 Mexico

Information on the regulatory frameworks to govern installation and operation of grid-connected rooftop solar PV is not available. However, in April 2020, CENACE —the Mexican electricity grid operator— issued an administrative Decision ordering the suspension of all preoperative tests for wind and solar PV plants for an indefinite period of time to allegedly "protect the efficiency, quality, and security of the National Electric System" amid the COVID-19 pandemic. In the Decision, CENACE stated that the COVID-19 health emergency poses a major challenge to the grid due to a significant decrease in energy consumption. In this context, CENACE underscored its responsibility to guarantee the reliability of electricity supply and its ability to undertake all necessary actions to strengthen the system in accordance with the principles of "energy sovereignty and security." In a Technical Annex to the Decision, CENACE listed a series of recent, temporary electrical failures that took place in relation to certain solar PV plants and wind farms, concluding that due to their intermittent supply, these renewable energy sources "*affect the reliability of the domestic electric system and the quality and continuity of electricity supply*." It further noted that wind and solar PV plants "*do not contribute with physical inertia to the stability*" of the electricity system. Based on these statements, CENACE ordered the suspension, as of May 3, 2020, of all preoperative tests for wind and solar PV plants for an indefinite period of time. (King & Spalding, 2020)

### 4.2.9 New Zealand

Grid-connected rooftop solar PV systems in New Zealand require consent from electric utilities. Similar to Australia, inverters shall comply with AS/NZS 4777 standard. Utilities provide a list of pre-approved inverters for connection to the grid. The grid connection application process divides the maximum capacity of distributed generation equipment, including grid-tied inverter for rooftop solar PV, for residential installation into two main categories, 10 kW or less and above 10 kW. Utilities may provide information on congestion management policy and congestion areas, allowing utilities to curtail output/operation and interrupt connection to ensure the power quality standards are met.

### 4.2.10 The Philippines

Net-Metering is a program under RA 9513 also known as the Renewable Energy Act of 2008. It allows customers to install an RE facility within their premises up to a capacity of 100kW. Any excess electricity not consumed in the home or business is exported to the distribution utility. The 100kW limit is the ceiling established under the RE Act's Net-Metering Rules; any RE installation above 100kW is no longer covered by the Net-Metering program and these will fall under the Zero-Export program, which does not allow the export of energy to the grid. (MERALCO, 2018) Any electricity consumer who wishes to install a rooftop solar PV system under the Net-Metering program is required to submit the Net-Metering Application form with supporting documents to the distribution utility serving their area (DOE, n.d.).

### 4.2.11 Singapore

The installation of solar PV systems in Singapore may require electricity license, depending on the aggregate of the Alternating Current (AC) inverter capacities ("installed generation capacity") at the point of connection to the grid, as shown in theTable 4-2. Residential rooftop solar PV systems usually fall in the below 1 MWac category and license is exempted.

***Table 4-2: Type of License for Solar PV System in Singapore***

| Installed Capacity of Solar PV System | Connected to the Power Grid? | Type of Licence* |
|---|---|---|
| Below 1 MWac | Yes | Exempted |
| | No | |
| 1 MWac or more but less than 10 MWac | Yes | Wholesaler (Generation) Licence |
| | No | Exempted |
| 10 MWac or more | Yes | Generation Licence |
| | No | |

* An Electrical Installation Licence may still be required.

Source: (SP Group, 2018)

Any residential electricity customer who intends to install a rooftop solar PV system has to engage a Licensed Electrical Worker (LEW) to complete the online Application Form and to submit the required documents to SP PowerGrid to evaluate and discuss with LEW on the technical requirements and specifications of the solar PV system.

### 4.2.12 Chinese Taipei

The Bureau of Energy under the Ministry of Economic Affairs announced the 2022 FiT rates for renewable energy projects in March 2022. According to the official announcement, installed capacities of rooftop solar PV systems in Chinese Taipei can be categorized by the FiT rates into four groups as follows:

1) 1 kW to <20 kW
2) 20 kW to <100 kW
3) 100 kW to <500 kW
4) ≥500 kW

All grid-connected rooftop solar PV systems are subject to evaluation and approval by Taipower, the electric utility in Chinese Taipei and relevant authorities prior to connection to the grid. In addition, a wholesale contract must be signed with Taipower, along with equipment evaluation after completion. The time frame of installation will take one to three months, depending on the scale of construction. An additional three to six months will be required after contracting to having the system fully operational. After three more months of administrative process, the electricity will be ready for sale. (Initial Solar, n.d.) Taipower also publishes a technology guideline (in Chinese) that provides requirements for grid-tied inverters. The technology guideline references IEC, IEEE, ANSI, UL, VDE, and CNS standards.

### 4.2.13 Thailand

Rooftop solar PV installations in Thailand require consents from the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA). MEA and PEA specify different requirements for the maximum installed capacity of residential rooftop solar PV systems, i.e., up to 10 kW for MEA's single-phase connection, and up to 5 kW for PEA's single-phase connection. MEA and PEA also limit cumulative installed capacity of rooftop solar PV in low-voltage and medium-voltage feeders as percentage of distribution transformer rated capacity. MEA and PEA reference relevant IEC and IEEE standards (including IEEE 1547) in specifying voltage, frequency, safety and power quality performance of grid-tied inverters, as well as publish the lists of pre-approved grid-tied inverters. Summarized in Table 4-3 are basic grid connection requirements of MEA and PEA. Note that MEA and PEA may revise the below basic requirements to maintain power quality and stability of their networks.

***Table 4-3: Maximum Installed Capacity of Residential Rooftop Solar PV in Thailand***

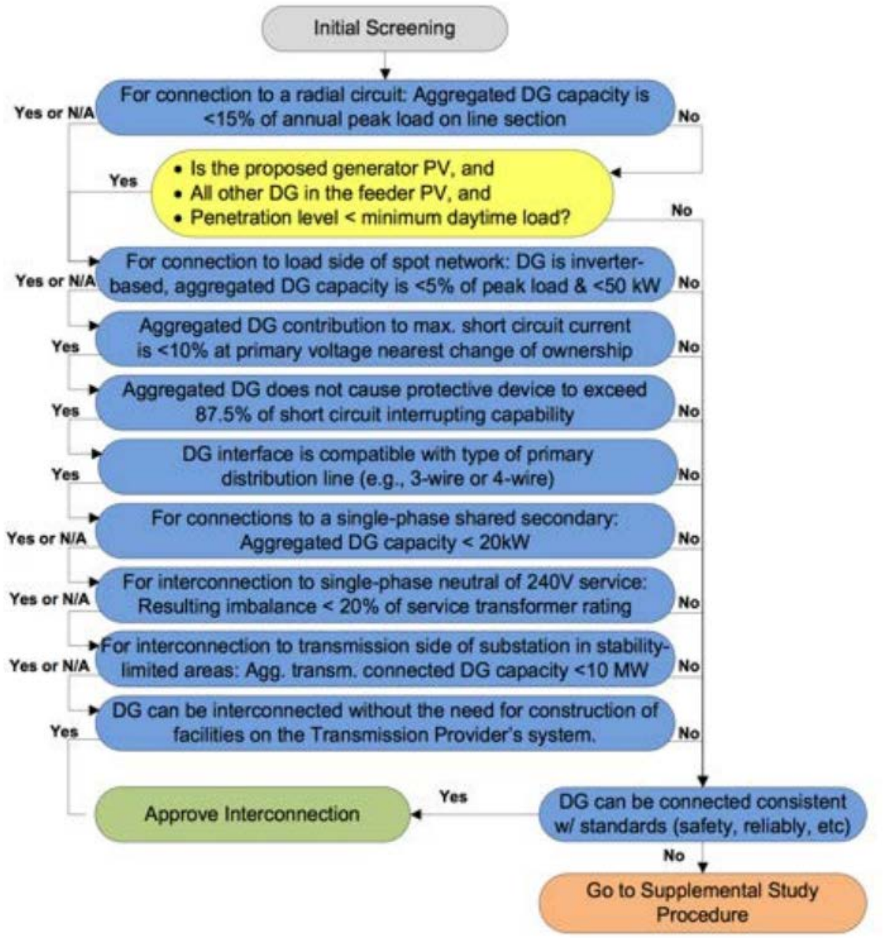
| Requirement | MEA | PEA |
|---|---|---|
| **Maximum installed capacity per system** | Single-Phase: 10 kW | Single-Phase: 5 kW |
| **Maximum cumulative installed capacity per distribution transformer** | Low Voltage 400/230 $V_{ac}$: Maximum cumulative installed capacity of solar PV installations/projects (in kW) shall not exceed 15% of rated kVA of the distribution transformer being connected | Low Voltage 380/220 $V_{ac}$: Maximum cumulative installed capacity of solar PV installations/projects (in kW) shall not exceed 15% of rated kVA of the distribution transformer being connected<br><br>Medium Voltage 22/33 kV: Maximum cumulative installed capacity of solar PV installations/projects (in kW) shall not exceed 75% of rated kVA of the substation transformer being connected |
| **Maximum cumulative installed capacity per circuit** | Medium Voltage 12 kV: 4 MW/circuit<br><br>Medium Voltage 24 kV: 8 MW/circuit<br><br>Cumulative installed capacity shall not generate reverse power flow back to | Medium Voltage 22 kV: 8 MW/circuit<br><br>Medium Voltage 33 kV: 10 MW/circuit |

| Requirement | MEA | PEA |
|---|---|---|
| | the Electricity Generating Authority of Thailand (EGAT). | High Voltage 115 kV: 120 MW/single-conductor circuit; 230 MW/double-conduct circuit |

### 4.2.14 United States

In the US, the FERC published an updated version of the Small Generator Interconnection Procedures (SGIP) in 2018. In general, the technical screening limits contribution of small generators, including rooftop solar PV (through grid-tied inverters) as percentage of annual peak load most recently measured at the substation, percentage of distribution circuit's maximum fault current, maximum generating capacity per feeder, etc. Illustrated in Figure 4-4 is the summary of the technical screen under the FERC's SGIP.

***Figure 4-4: FERC SGIP Technical Screen Summary***

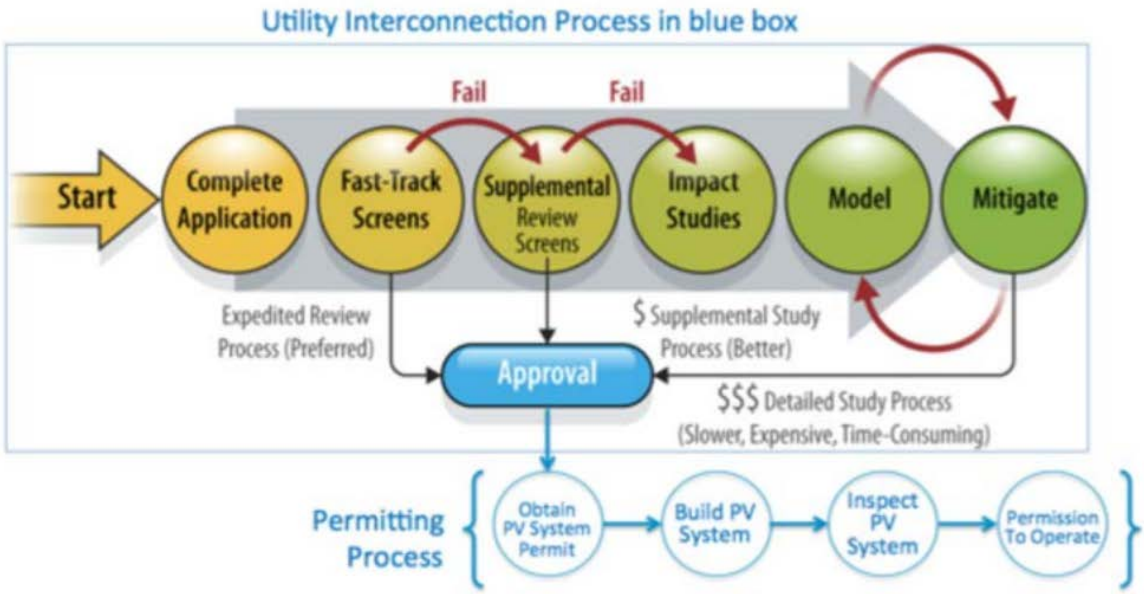



Guided by the FERC SGIP, states and local utilities usually set limits on how much each power rooftop solar PV system is allowed to generate. Utilities may set a maximum system size limit as percentage of customer's total connected load. Some examples of the maximum installed and generation capacity of rooftop solar PV systems in the US are given below. (Freedom Forever LLC, 2019)

- Arizona sets a maximum system size limit of 125% of the customer's total connected load.
- California does not set limits on the maximum size of the solar system. However, a system over 15 kW will be subject to higher permitting fees.
- Colorado's largest electricity provider, Xcel Energy, allows the generation of up to 120% of the total usage from the previous 12 months. Having an EV will add up to 250 kWh per month to generation capacity.
- Nevada requires that the solar system be no larger than the highest monthly energy usage recorded at the home in the last 24 months.

Shown in Figure 4-5 is the typical interconnection process for rooftop solar PV system. First, an application for interconnection is submitted; if the system size is below a specified size threshold, the utility then conducts a series of technical screens to evaluate the potential impact of the PV on its system. If any negative system impacts—for example on voltage, power quality, or protection—are identified during the screening process, strategies for mitigating those impacts are identified by the utility. There is a variety of options for mitigating these impacts, including, but not limited to, downsizing the PV system using advanced inverter functions or upgrading the distribution network.

***Figure 4-5: Typical Utility Interconnection Process***




## 4.2.15 Viet Nam

In Viet Nam, Decision No. 13/2020/QD-TTg (Decision 13) was approved on 6 April 2020, which provides the mechanism for the regulation and encouragement of the development of solar power projects. It also provides classification of rooftop solar power system (RTS system) as follows:

- Solar power system with solar energy panels installed on the rooftop of a construction work.
- Capacity of an RTS system ≤ 1MW.

- Directly or indirectly connected to the power grid of the power purchaser (EVN).
- Voltage of an RTS system ≤ 35kV.
- Solar cells having an efficiency greater than 16% and the module efficiency must be greater than 15%.

Any rooftop solar power system directly or indirectly connected to the grid must register their grid connections with EVN or its authorized entities. In addition to Decision 13, the Ministry of Industry and Trade (MOIT) issued Official letter No. 7088/BCT-DL dd (MOIT Letter No. 7088) on 22 September 2020, providing further guidance for Decision 13 and Circular No. 18 for comments on the permissibility of having more than one 1MW rooftop solar power system installed on the same rooftop. MOIT advises that more than one RTS system on the same rooftop/location with a combined capacity greater than 1MW is permitted, provided these have separate meters and separate EVN PPAs. With separate meters and separate PPAs, and each RTS system having an individual capacity ≤ 1MW, each RTS system will qualify under Decision 13 and other regulations as a rooftop solar power system.

# 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

Solar PV is one of the mature renewable energy technologies. Its adoption has increased significantly in recent years because of favourable government policies and incentives, as well as lower costs of solar PV panels and inverter technologies. The APEC EWG expects solar power to be the fastest source of energy to grow under a business-as-usual scenario in the APEC region. China is the most significant player in the solar industry, having the largest solar power installed capacity of 253 GW as of 2020. However, majority of the economy's solar energy is on the utility scale. The United States and Australia are also the leaders in rooftop solar PV adoption among the APEC economies and globally. California and Hawaii have been in the forefront in integrating solar energy into distribution networks and implementing various measures to ensure grid stability and power quality. In Australia, approximately 30% of households have rooftop solar PV, and there are around 3 million installations as of November 2021.

Viet Nam has only recently started promotion of solar PV energy through Feed-in-Tariff, which was very generous during its initial phase and spurred the solar PV boom in the economy. Just between 2018 and 2019, solar PV installed capacity in Viet Nam increased from 134 MW to 5.5 GW, making it the top solar PV energy producer in Southeast Asia. Although many of solar PV systems installed in Viet Nam to date are large-scale solar farms, the rooftop solar power systems (RTS systems) with the maximum installed capacity of 1 MW have been an important component of the solar PV industry in the economy. In contrary, Russia and PNG need to scale up their efforts to fully utilize solar energy within their areas. As of 2019, Russia is still drafting a net metering scheme for rooftop solar PV while PNG has recently allowed power generation from rooftop solar PV as previously, it was illegal to generate own energy from solar PV at the household level.

In the APEC, it is forecasted that BEV and PHEV will have a combined share of 18% in the total vehicle fleet in 2050, while hybrid EV is 6.4% of the vehicle fleet in the same year. The United States and China are currently the largest EV users globally. China is also investing in the research and development of EV and EV manufacturing. Similarly, Korea was among the earliest to release an institutional framework to promote the development of the EV manufacturing in the economy. Meanwhile, it is estimated that EV sales in Southeast Asia will increase by almost 25% by 2022. Some APEC economies in Southeast Asia also aim to be an EV manufacturing hub such as Indonesia and Thailand. In terms of policies on EV adoption, among the common strategies being adopted by APEC economies to introduce EVs is to have such technology within their government and public transport fleet first or provide tax exemptions for EV users. However, economies such as the Philippines, Brunei Darussalam, and PNG are yet to develop their own EV policy while Malaysia lacks a clear EV programme despite tax exemptions for EV. It must be noted that PNG's unique transport system is dependent on water transport and the Pacific Island economy has a very low road density, so a different approach on EV adoption may be needed.

PV and EV deliver different impacts on distribution network equipment. As for the distribution transformers, PV integration generally reduces load factor, and this can extend the lifetime of distribution transformer. However high penetration of PV could develop power quality problems such as current and voltage unbalance and these could reduce distribution transformers' useful lifetime. Various studies predicted increased overloading and losses in distribution transformers with high penetration of EVs with uncontrolled charging behaviors based on typical drive distance, arrival and departure times. EV charging is also likely to introduce enormous uncertainty in transformer aging, particularly for those in hot climates. These negative impacts of EVs on distribution transformers can be mitigated through coordinated smart charging schemes with dynamic response. Some studies and simulations also suggested that coordinated or combined operational strategies of PV systems and EVs can mitigate negative impacts on power quality and grid stability.

It is evident that uncontrolled penetration of PV systems and EVs individually can negatively impact the grid stability and power quality due to the intermittent nature of PV energy sources and uncertain load characteristics of EVs. With massive PV integration, distribution networks have become less resilient and grid connection requirements or "grid codes" for DERs, which include rooftop solar PV, have been the common preventive measures for utilities in APEC economies to ensure stable grid operation and power quality. Grid connection requirements in most APEC economies generally involve technical screening (which generally limits penetration of rooftop solar PV system in a distribution feeder through a screening checklist) and a detailed engineering and impact study involving modeling and mitigation measures. It should be noted that grid connection requirements do not aim at protecting specific equipment (e.g., distribution transformers or conductors), but rather maintain grid stability and power quality within the system.

## 5.2 RECOMMENDATIONS

Based on the extensive literature reviews of the impacts of rooftop solar PV and EV connections to distribution networks, recommendations for policymakers and utilities to sustain the electricity distribution system performance and reliability when integrating combined rooftop solar PV systems and EVs are summarized below.

- **Establishment of a platform for sharing information on requirements and best practices for rooftop solar PV and EV integration:** It is evident that some APEC economies are more advanced than others in handling PV and EV integration in the electricity grid. Knowledge, experience, and lessons learned in managing PV and EV integration, implementing grid code requirements to mitigate negative impacts on grid stability and power quality, and implementing cost-effective measures to correct problems in voltage/frequency stability and power quality should be compiled and made available to all APEC economies. It is strongly recommended for the APEC EWG to explore the existing cooperation platforms under APEC to facilitate knowledge sharing of experiences and lessons learned for policymakers and utilities in APEC economies and beyond. In case such appropriate information sharing platform is not available, a new dedicated information sharing platform should be considered. In addition, development of an outreach and communication program to create awareness on PV and EV integration for policy makers should be part of the platform establishment.

- **Utilization of demand-side management (DSM) and demand response (DR) to improve distribution network performance:** With ongoing and planned EV strategies in APEC economies, uncontrolled EV charging loads will soon add more stress in low voltage distribution networks, especially during the evening peak demand. It is recommended for the utilities in APEC economies to collaborate with EV manufacturers and encourage integration of a demand response (DR) feature in the EV charger, enabling the utilities to directly control EV charging during peak demand periods. The time of use (TOU) electricity tariffs specifically designed to address the EV charging loads should be explored by the utilities to proactively move these EV loads away from the peak demands. As for the rooftop solar PV systems, utilization of smart inverters in accordance with IEEE 1547-2018 standard, which requires inverters to provide grid supportive functions such as voltage and frequency ride-through, voltage and frequency regulation, and communications and control functionality will enable greater deployment of solar PV in the long term. With these DR and smart features, utilities can introduce coordinated operation of PV systems and EV chargers to ensure stability and power quality in the distribution network.

- **Development of PV and EV resilient specifications:** The limited lifetime of a distribution network equipment raises the need for replacement at its end-of-life. Therefore, procurement of new network equipment, such as distribution transformer should consider future integration of rooftop solar PV systems and EV charging loads in each feeder. For example, higher rated current conductors can mitigate voltage and power problems due to PV integration. Lower loss distribution transformers will ensure lower carbon footprints of the distribution networks when load factors are getting higher. To determine the overall carbon footprint, it is recommended to conduct a lifecycle analysis of the equipment.

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# 7 Annexes

## 7.1 Annex A: Assumptions used in GHG Accounting

The table below summarizes the assumptions made and factors used to estimate for the GHG emissions avoidance. With data on installed capacity, the team needed to determine the equivalent electricity that it can produce, which is then assumed to represent the amount of electricity that it can displace from other sources in the grid. The grid emissions factor was then used to determine the equivalent GHG emissions avoidance as a result of solar PV use.

***Figure 7-1: Assumptions and factors used for GHG accounting***

| APEC Economy | Assumptions made | | Grid emission factor ($tCO_2eq/MWh$) |
|---|---|---|---|
| | Average hours of sunlight per day | Solar panel efficiency | |
| **Australia** | 6 | 0.20 | 0.8100 (2020) |
| **Brunei Darussalam** | 5 | 0.20 | 0.2020 *if replacing NatGas*<br><br>0.2668 *if replacing gasoline/ oil (2017)* |
| **Canada** | 4 | 0.20 | 0.0400 (2018) |
| **Chile** | 6 | 0.20 | 0.6330 (2018) |
| **China** | 4 | 0.20 | 0.8510 (2022) |
| **Hong Kong, China** | 4 | 0.20 | 0.7100 (2021) |
| **Indonesia** | 5 | 0.20 | 0.7780 (2022) |
| **Japan** | 4 | 0.20 | 0.4916 (2017) |
| **Korea** | 4 | 0.20 | 0.6254 (2022) |
| **Malaysia** | 5 | 0.20 | 0.5850 (2017) |
| **Mexico** | 6 | 0.20 | 0.5291 (2022) |
| **New Zealand** | 5 | 0.20 | 0.1010 (2018) |
| **Papua New Guinea** | 5 | 0.20 | 0.6786 (2022) |
| **Peru** | 6 | 0.20 | 0.5803 (2022) |
| **The Philippines** | 5 | 0.20 | 0.6836 (2017) |

| APEC Economy | Assumptions made | | Grid emission factor ($tCO_2eq/MWh$) |
|---|---|---|---|
| | Average hours of sunlight per day | Solar panel efficiency | |
| **Russia** | 4 | 0.20 | 0.3302 (2017) |
| **Singapore** | 5 | 0.20 | 0.4080 (2020) |
| **Chinese Taipei** | 4 | 0.20 | 0.5020 (2021) |
| **Thailand** | 5 | 0.20 | 0.5664 (2017) |
| **USA** | 5 | 0.20 | 0.7087 (2019) |
| **Viet Nam** | 5 | 0.20 | 0.8041 (2020) |

## 7.2 Annex B: Workshop Report

Asia-Pacific
Economic Cooperation

# EWG 03 2020A
# Integrating Electrical Vehicles and Solar Rooftop PV in Electricity Distribution Systems with Continued Performance of Distribution Transformers

**Workshop Summary Report**

**Energy Working Group**

**May 2022**

## Table of Contents


1 OBJECTIVE ........ 1
2 WORKSHOP ORGANIZATION ........ 2
3 PARTICIPANTS ........ 3
4 WORKSHOP SUMMARY ........ 4
Introduction ........ 4
Session 1: Solar Rooftop PV Integration in Electricity Distribution Systems ........ 5
Session 2: EV Adoption in Electricity Distribution Systems ........ 6
Session 3: Case Studies Presentation ........ 6
Session 4: Recommendations and Discussions ........ 7
5 WORKSHOP EVALUATION SURVEY ........ 9
6 APPENDIX ........ 11
6.1 Workshop Agenda ........ 11
6.2 List of Participants ........ 13
6.3 Workshop Evaluation Form ........ 17
6.4 Workshop Evaluation Responses ........ 19

## Table of Figures

Figure 2-1: Virtual workshop group photos ........ 4

Figure 4-1: Respondents - Level of Agreement on Workshop Contents ........ 9

Figure 4-2: Relevance of the Workshop Topic to the Participants ........ 10

Figure 4-3: Level of Knowledge and Skill prior to and after the workshop ........ 10

## Table of Tables

Table 2-1: Workshop Time ........ 2

Table 3-1: Summary of Participants List by Economies and Type of Organizations ........ 3

# Acronyms

| | |
|---|---|
| APEC | Asia-Pacific Economic Cooperation |
| DEDE | Department of Alternative Energy Development and Efficiency |
| DIS | Distribution Impact Study |
| DT | Distribution Transformer |
| EV | Electric vehicle |
| EWG | Energy Working Group of the APEC |
| EWG | Energy Working Group |
| GHG | Greenhouse Gas |
| GW | Gigawatts |
| HKC | Hong Kong, China |
| kW | kilowatts |
| MW | Megawatts |
| PEA | Provincial Electricity Authority |
| PV | Solar Photovoltaic |
| QE | Qualified End-Users |
| RE | Renewable energy |
| USA | United States |
| V2B | Vehicle to building |
| V2G | Vehicle to grid |
| V2H | Vehicle to home |
| V2X | Vehicle to everything |
| ZEV | Zero Emission Vehicle |

# 1 OBJECTIVE

This workshop report is an output of the project "Integrating Electrical Vehicles and Solar Rooftop PV in Electricity Distribution Systems with Continued Performance of Distribution Transformers". The workshop was organized by International Institute for Energy Conservation with support from Asia-Pacific Economic Cooperation (APEC), the Department of Alternative Energy Development and Efficiency (DEDE), Thailand, in collaboration with International Copper Association (ICA). The workshop specifically aims to:

- Allow productive interactions between public and private stakeholders of the APEC and other regions, as a mean to facilitate future cooperation;

- Build awareness and knowledge through sharing of experience and lessons learned from APEC and non-APEC economies regarding impacts of integrating rooftop solar PVs and EVs into distribution networks;

- Disseminate project findings on review of common practices and measures to mitigate impacts on distribution systems from high penetration of rooftop solar PVs and EVs;

- Solicit comments and suggestions on best practices and regulatory frameworks to ensure quality of distribution networks with high penetration of rooftop solar PVs and EVs.

Comments and recommendations from the workshop will be incorporated into the Technical and Policy Recommendation Report.

# 2 WORKSHOP ORGANIZATION

The workshop was planned to organize as hybrid, however, due to the prolonged COVID-19 pandemic in Thailand and other APEC economies, the Zoom virtual workshop was organized on 22nd April 2022 at 9:00 (UTC +7). The workshop time in each APEC member economies is shown in Table 2-1.

***Table 2-1: Workshop Time***

| Cities | UTC | Time |
|---|---|---|
| **Wellington** | UTC+13 | 15:00 - 18:00 |
| **Canberra** | UTC+11 | 13:00 - 16:00 |
| **Port Moresby** | UTC+10 | 12:00 - 15:00 |
| **Seoul/ Tokyo** | UTC+9 | 11:00 - 14:00 |
| **Bandar Seri Begawan/ Beijing/ Hong Kong/ Kuala Lumpur/ Manila/ Singapore/ Taipei** | UTC+8 | 10:00 - 13:00 |
| **Bangkok/ Hanoi/ Jakarta** | UTC+7 | 09:00 - 12:00 |
| **Moscow** | UTC+3 | 5:00 - 8:00 |
| **Ottawa/ Santiago/ Washington DC (21st April 2022)** | UTC-4 | 22:00 - 01:00 |
| **Lima/ Mexico City (21st April 2022)** | UTC-5 | 21:00 - 24:00 |

During March and April 2022, the workshop participants were nominated by APEC EWG members; and directly invited by the Project Overseer, ICA and IIEC. Target participants of the workshop are:

- Utilities: especially notably procurement officers as they will be instrumental in applying the recommendations for selection of more resilient distribution transformers;
- Distribution Transformer Industry Representatives: including both individual distribution transformers manufacturers as well as regional or economy industry association representatives;
- Policy-makers: agencies responsible for the promotion of both renewable energy and energy efficiency will be engaged;
- Non-Governmental Organizations (NGOs): including groups of organizations such as energy efficiency advocacy groups, universities, and other stakeholder groups;
- Women's participation (cross-cutting all above categories of stakeholders): Throughout the project duration, particular attention will be paid to allow participation and expression of women.

# 3 PARTICIPANTS

Refer to the list of participants in Appendix 6.2, there were 59 participants in the workshop, including: 7 speakers, 49 participants, and 3 organizers. As shown in Table 3-1, 54% of the participants were policy-makers, followed by 32% from other sectors (Academic Institutions, Not-for-profit Organizations, International Organizations), 8% from utilities, and 5% from Industry representative of Solar PV/ EV/ DT. 11 representatives from APEC economies (i.e. China, Japan, Mexico, New Zealand, Peru, Philippines, Singapore, Thailand, Chinese Taipei, HKC, and USA) participated in the workshop. In terms of gender participants, there were 37 (63%) male, and 22 (37%) female.

***Table 3-1: Summary of Participants List by Economies and Type of Organizations***

| Economies | Policy-makers | Utilities | Industry Representatives of Solar PV/ EV/ DT | Others | Total |
|---|---|---|---|---|---|
| **China** | | | 1 | 2 | **3** |
| **Japan** | | | 1 | 1 | **2** |
| **Mexico** | 1 | | | | **1** |
| **New Zealand** | | | 1 | | **1** |
| **Peru** | 2 | | | | **2** |
| **Philippines** | 12 | 2 | | 2 | **16** |
| **Singapore** | | 1 | | | **1** |
| **Thailand** | 7 | 2 | | 9 | **18** |
| **Chinese Taipei** | 1 | | | 4 | **5** |
| **Hong Kong, China** | 8 | | | 1 | **9** |
| **United States of America** | 1 | | | | **1** |
| **Total** | **32** | **5** | **3** | **19** | **59** |

# 4 Workshop Summary

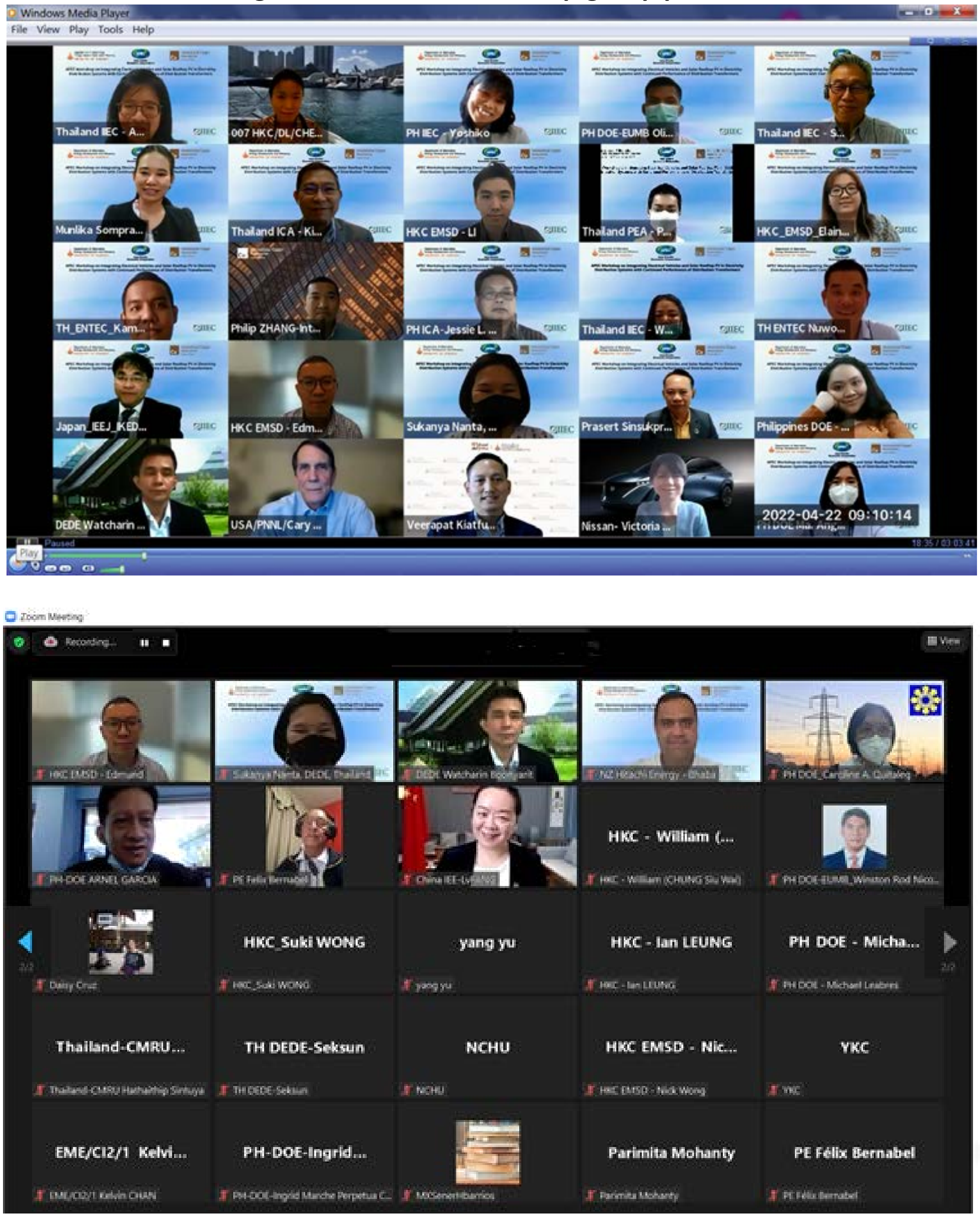
The virtual workshop was separated into 5 sections, Introduction, Solar Rooftop PV, EV Adoption, Case Studies; and Recommendations and Discussions, as shown in Appendix 6.1. Workshop summary is as follows:

## Introduction

The workshop welcome remark was delivered by Dr. Prasert Sinsukprasert, Director General from Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy of Thailand.

After the welcome remark, the group photos were taken, as shown in Figure 2-2.

***Figure 4-1: Virtual workshop group photos***



After the group photo session, a representative from International Copper Association (ICA) introduced the project, including project rationale, objectives and workshop agenda.

Following the project introduction, Mr. Sommai Phon-Amnuaisuk, Director, Asia-Pacific of International Institute for Energy Conservation (IIEC), and as the project consultant, delivered the presentation on **Impacts of PV & EV on Distribution Network**. He summarized key statistics of solar PV and EV and the key drivers of Solar PV and EV adoption in APEC economies. Furthermore, the review of more than 100 reports found that individually, uncontrolled penetration of PV systems and EVs can negatively impact the grid stability (voltage and frequency) and power quality due to the intermittent nature of PV energy sources and uncertain load characteristics of EVs. However, PV integration generally reduce DTs' load factor, and many studies and papers found that the general trend of DT's lifetime is improved by PV integration. Various studies predicted increased overloading and losses in DTs with high penetration of uncontrolled EV charging. Mr. Sommai explained the impacts of solar PV on network load profiles through the "Duck Curve". He also explained the impacts of EVs on load profiles through a Simulation of EV Charging Loads on a Low Voltage Feeder.

After Mr. Sommai's presentation, the 6 resource speakers delivered their presentations on the Adoptions of Solar Rooftop PV and EV, and Impacts on Electricity Distribution System and Transformers, as follows:

## SESSION 1: SOLAR ROOFTOP PV INTEGRATION IN ELECTRICITY DISTRIBUTION SYSTEMS

**China – Distributed Solar Rooftop PV market and Trend:** Ms. Lyu Fang, Senior Engineer from Electrical Engineering Institute, Chinese Academy of Science highlighted that the global PV installation increased every year, and the total cumulative installed capacity at the end of 2021 is 942 GW. Of which, China has shared the highest installed capacity of 308 GW. According to the China Five-Year plan (2021-2025), the annual installed of solar PV will be 30 – 40 GW. From 2002 to 2021, the distributed PV policies scheme roadmap outlines multiple supporting policies for PV, including the Rural Township Electrification Program, FIT Subsidy, Utility Scale PV Subsidy Limited, Distributed Subsidy Tailing Off; and the current scheme in 2021 - 2023, "County Rooftop Distributed PV Pilot Program". Moreover, in the China's Building Energy Efficiency & Green Building Development Nation Planning (2021-2025), the Building-Integrated Photovoltaics has been adopted, and at least 50GW of solar PV will be installed in the building. Moreover, China has launched the National Carbon Market and Green Certification. The cumulative trading volume in the National Carbon Market exceeded 19 million tons of carbon in October 2021, with the transaction price of listing agreement from 61.07 to 41 Yuan/ton.

**Philippines – MERALCO's Net Metering Program** delivered by Mr. Gerard Anthony Lim, Product Manager from Manila Electric Company (MERALCO). Mr. Lim explained that the Net Metering Program in the Philippines is under the Renewable Energy Act of 2008 (RA 9513) which applied to the installation of renewable energy (RE) facilities with a capacity of up to 100kW. Any excess RE electricity produced is exported to a distribution utility (DU), and its corresponding value will be given as credits to the electricity bill. Applying for Net Metering will ensure that the solar installation is compatible with the power grid; and that it can be properly monitored. MERALCO will evaluate the Qualified End-Users (QE) application and requirements through a field study called the Distribution Impact Study (DIS) which is free of charge. After that, MERALCO will inspect the facility and service entrance to ensure compliance to standards, and will install a Bi-directional and REC meter for testing. Once all required documents and testing completed, the Net Metering will be successfully installed.

## SESSION 2: EV ADOPTION IN ELECTRICITY DISTRIBUTION SYSTEMS

**Thailand – Plans and Program, with focus on EV Infrastructure**: Dr. Veerapat Kiatfuengfoo, Deputy Director General of Energy Policy and Planning office (EPPO), Ministry of Energy informed about the Long-term Low Greenhouse Gas Emission Development Strategy of Thailand. Thailand aims to reduce the Greenhouse Gas Emission by 40% by 2030. The government has set the target of carbon neutrality by 2050, and net GHG emissions by 2065. According to the National Energy Plan 2022, 30% of vehicle total production will be Zero Emission Vehicle (ZEV) in 2030. To be a global major production base for EVs and parts, Thailand has set the National Electric Vehicle Policy committee. The committee has 4 sub-committees to promote the EVs manufacturing industry; to support infrastructure and battery development; to assess the impact of fuel and GHGs from promotion of EVs; and to promote EVs adoption. The National EV Committee has approved the target for domestic sale and production of ZEV to be more than 500,000 units in 2025 and around 1 million unit in 2030. The committee has also set the target for EVs charging stations as 2,200 – 4,400 stations in 2025, and more than 12,000 stations in 2030. As for the promotion of EVs Adoption, the Ministry of Finance will have policies on tax and non-tax measures, and supporting government EVs fleet. In terms of the Charging Station Infrastructure Development, the Ministry of Energy will promote the development of an adequate charging station networks; establish the regulations, standard and guidelines to develop charging stations; and promote the smart grid technology to support connectivity and management of integrated electric charging stations. Dr. Veerapat also briefed the meeting on the Smart Grid Plan to support EVs.

**Japan – EV as Energy Infrastructure in Society**: Ms. Victoria Chiu, Senior Manager, Global EV, External & Government Affairs from Nissan Motor, Japan informed the meeting that Nissan is currently working on establishing a comprehensive EVs ecosystem as part of the circular economy and achieving carbon neutrality by 2030. She illustrated Nissan's "Perfect Circle" in which today's topic is a part of this circle -– Utilize EVs as an Energy Solution. Nissan uses EVs as the energy storage to balance electricity supply and demand through bi-directional energy flow. Regarding this, Nissan applies the technology called Vehicle to everything (V2X) which comprises Vehicle to load (V2L), Vehicle to home (V2H), Vehicle to building (V2B), and Vehicle to grid (V2G). The basic concept of V2L is transferring the stored energy from EVs to electrical devices at camping/construction sites, or in case of emergency. Whereas, V2H, V2B, and V2G are to charge EVs battery during off-peak hours and to provide electricity during peak demand. Nissan has initiated a program called "Blue Switch" since 2018. The program is to promote the use of EVs to help communities from disaster relief efforts by providing energy management solutions. For example, Nissan has utilized EVs as backup electricity from blackout due to a typhoon in Chiba, reduced peak power demand in Yamaguchi Prefecture, and verified tests of energy management system in Namie, Fukushima. Nissan has done research on estimation V2X contribution to domestic power system with Tokyo Universities. The research result is that V2X can reduce renewable curtailment by 19.3% and reduce annual operating cost of power generation by 66.3 billion yen.

## SESSION 3: CASE STUDIES PRESENTATION

**Impact of Electric Vehicles on Distribution Transformers** presented by Dr. Bhaba Das, Lead Digital Business Developer from Hitachi Energy, New Zealand. Dr. Bhaba shared experience on the research and common impact of EV on DT; and the social cost of carbon for DT. He evaluated the impact of EVs on a 1,000kVA distribution transformer with 1.1 kW no load loss and 9.5 kW load loss, which is compliant with the Australian MEPS standard measured at 50% loading. Currently, the penetration of EVs is low, DT loading is around 20% and % efficiency of DT is still higher than MEPS. However, if EVs penetration is higher, loading of DT will be higher and % efficiency of DT will be lower than MEPS. Moreover, high EVs penetration will also increase the environmental impact in terms of $CO_2$

equivalents and global warming potential. He recommended to have sustainable design of DT which is to focus on the whole life cycle analysis – quantification of the environmental impact in tonnes $CO_{2e}$ of the selected transformer throughout its life cycle from raw material acquisition through production, transportation, use and disposal.

**Impacts of Solar Rooftop PV on the Distribution Grid and Its Transformers:** Mr. Prakal Inthaphat, Assistant Chief, Electricity Industry Operator Encouragement Division of the Provincial Electricity Authority (PEA), Thailand introduced the PEA distribution system; and regulation on the power network system interconnection code B.E. 2559 (2016) or grid code. Mr. Prakal also explained the impacts of rooftop solar PV on the voltage level, power loss and generation system. In conclusion, he highlighted that the utility should keep a balance between a load profile and rooftop solar PV hosting capacity in the feeder to avoid the over voltage and reverse power flow problem in the distribution system. However, according to PEA's grid code, the total installed capacity of all circuits in 22/33 kV distribution system must not exceed 75% of distribution transformer load. Excessive rooftop solar PV installations may cause the reverse power flow problem; therefore, PEA is going to consider the appropriate percent of distribution transformer load to mitigate the problem.

## SESSION 4: RECOMMENDATIONS AND DISCUSSIONS

**Grid Connection Requirements & Recommendations:** Mr. Sommai informed the workshop that Solar PV interconnection is part of the generator connection code, while connection of EV charging load is part of the demand connection code. Regarding standards referenced solar PV connection, many APEC economies apply IEEE 1547 ("a standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces") which provides universal requirements needed for interconnection of Distributed Energy Resources (DER). Based on reviewing grid connection requirements in 15 APEC economies, he found that virtually all grid connection requirements are part of ongoing Feed-in-Tariff (FIT) or Net-Metering programs backed by regulatory frameworks. All grid connection requirements focus on quality of voltage and frequency, limits of disturbance (e.g., harmonics) and degree of safety protections required from solar inverters and EV chargers. Most grid connection requirements limit penetration of rooftop solar PV through maximum kW installed per connection (or customer) with supplementary requirements.

In conclusion, most utilities in APEC have adopted various preventive measures to manage adverse impacts from the intermittent nature of PV energy and uncertainty of EV load. Most of these preventive measures focus on imposing requirements on solar PV generation and EV load (e.g., limits of power generation and disturbance), and utilization of smart grid technologies (e.g., smart inverter) rather than developing new specifications for network components. Some APEC economies (e.g., Australia, China, USA) are more advanced than others in handling PV and EV integration in electricity grid.

Mr. Sommai recommended the APEC economies to establish a platform for sharing information on requirements and best practices for rooftop solar PV and EV integration; utilize appropriate demand-side management (DSM) and demand response (DR) strategies for EV charging loads to improve distribution network performance; and upgrade procurement technical specifications of distribution network equipment to enhance grid's resiliency of under high PV and EV integration scenarios.

**Open Discussion:**

- PEA, Thailand, will manage the increased uptake of rooftop solar PV or EV in distribution network through load shading and change to other feeders to balance between load and RE generation systems. When PEA has problem about over voltage from RE power producers, PEA may invest the energy storage in the system in order to improve the voltage level.

- The key challenge for MERALCO, the Philippines, is to encourage the electricity consumers to register their "guerrilla" solar PV systems with the utility because these guerrilla systems have caused inconsistent behaviours to the distribution network. MERALCO will ensure the grid stability by using a machine learning system to detect guerrilla installations.

- A representative from China updated the workshop that the Chinese government issued law/regulation about the solar rooftop last year, and it limits the installed solar PV capacity for one roof (or one point) not exceeding 6 MW. However, if the roof has more than one point, the government allows to install more than 6 MW solar rooftop PV.

- A representative from China further elaborated that the EV charging load in China will reach about 30GW by 2025. The energy storage resources are expected to exceed 150 billion kilowatt-hours per year. The low-valley charging and peak discharge will promote the consumption of new energy and will improve the overall efficiency of energy system.

Lastly, the closing remark was officially delivered by Mr. Watcharin Boonyarit, Director of Strategy and Planning Division of the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy, Thailand.

The workshop was officially closed at noon (UTC +7), and the presentation slides were shared to all participants after the workshop. Copies of the presentation materials in the workshop can be found **here**.

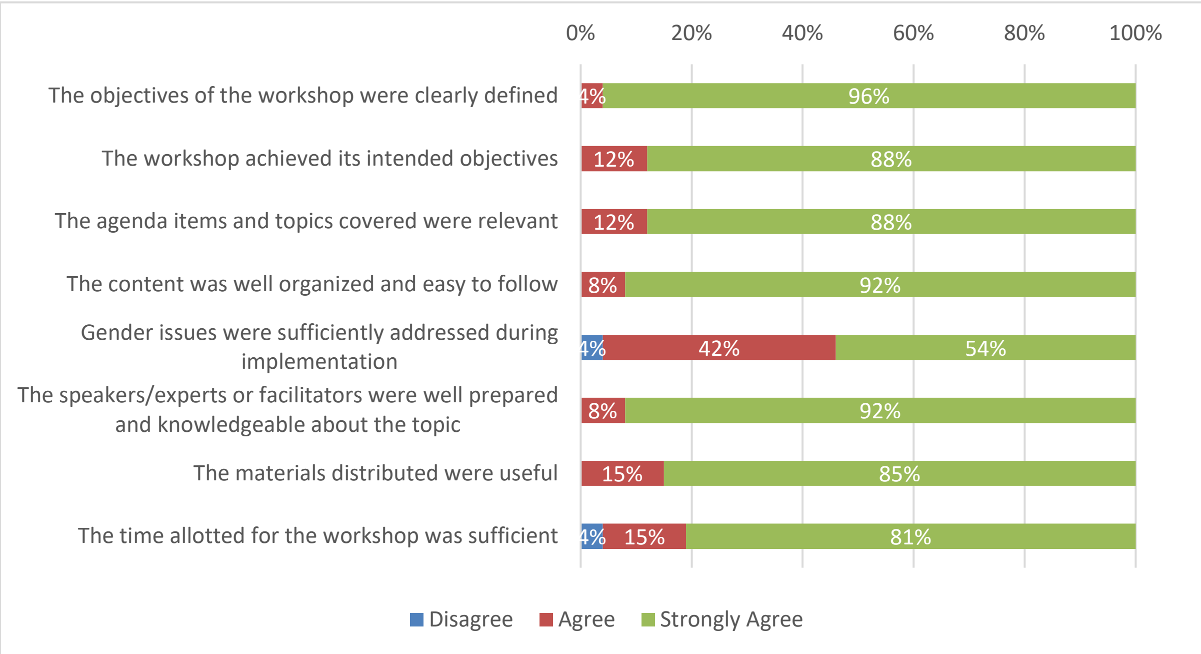
# 5 Workshop Evaluation Survey

Once the participants left the virtual workshop, all participants were requested to complete the workshop evaluation survey. The survey evaluation form is in Appendix 6.3.

26 participants (44%) completed the workshop evaluation survey. Summary of the survey responses is enclosed as Appendix 6.4.

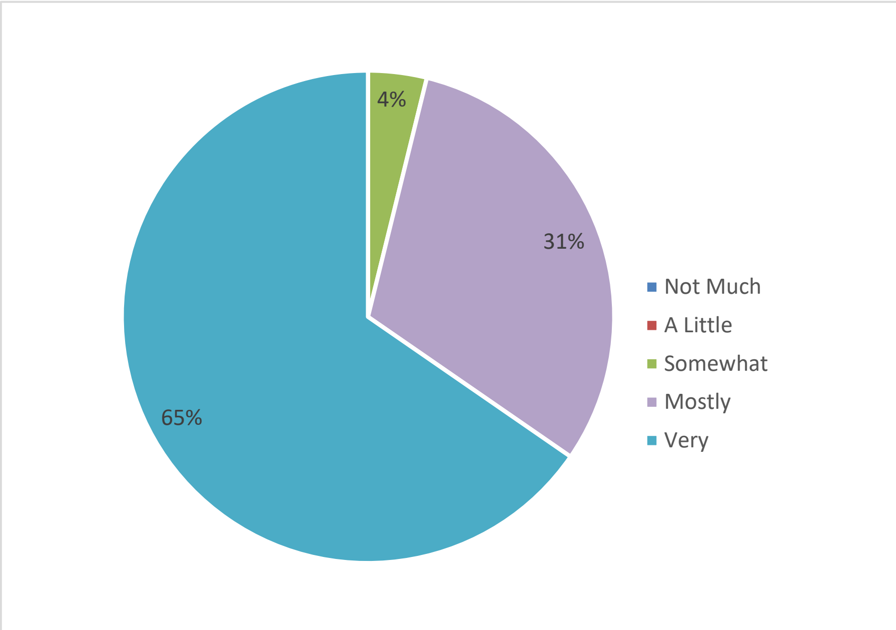
Based upon the evaluation survey conducted as part of the workshop, the workshop is estimated to have been a success, notably in terms of contents, objectives, preparations, materials, and time management; as shown in Figure 5-1.

***Figure 5-1: Respondents - Level of Agreement on Workshop Contents***



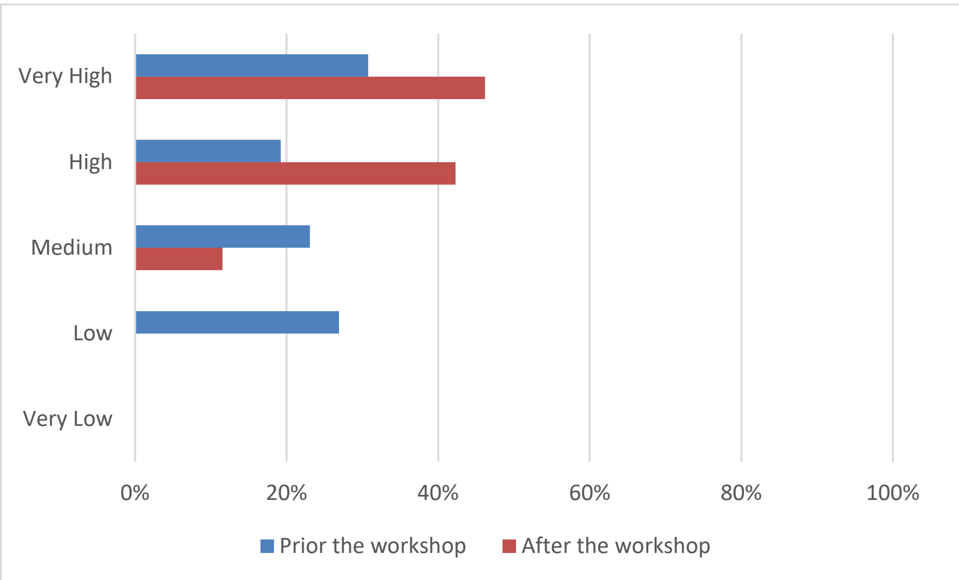

As shown in Figure 5-2, the workshop topic on "Integrating Electrical Vehicles and Solar Rooftop PV in Electricity Distribution Systems with Continued Performance of Distribution Transformers" is highly relevant to most respondents and their economies.

*Figure 5-2: Relevance of the Workshop Topic to the Participants*




The workshop participants were requested to compare their level of knowledge and skill of the workshop topic, before and after workshop. Most respondents improved their knowledge and skill on the workshop topic, as shown in Figure 5-3.

*Figure 5-3: Level of Knowledge and Skill prior to and after the workshop*



# 6 APPENDIX

## 6.1 WORKSHOP AGENDA

| Time (AM) | Duration (minute) | Presentation Title | Speaker |
|---|---|---|---|
| 8:30 | 30 | Registration and Test run | |
| Introduction: | | | |
| 9:00 | 5 | Welcome Remarks | *Dr. Prasert Sinsukprasert,* Director General Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy, Thailand |
| 9:05 | 10 | Project introduction, workshop objectives, outline agenda | *Mr. Pierre Cazelles*, Director – Global Partnerships International Copper Association (ICA) |
| | | Group Photo | |
| 9:15 | 10 | Impacts of PV & EV on Distribution Network | *Mr. Sommai Phon-Amnuaisuk*, Director, Asia-Pacific International Institute for Energy Conservation (IIEC) |
| Session 1: Solar Rooftop PV Integration in Electricity Distribution Systems | | | |
| 9:25 | 15 | China – Distributed Solar Rooftop PV market and Trend | *Ms. Lyu Fang*, Senior Engineer Electrical Engineering Institute, Chinese Academy of Science |
| 9:40 | 15 | Philippines – MERALCO's Net Metering Program | *Mr. Gerard Anthony Lim*, Product Manager Manila Electric Company (MERALCO) |
| 9:55 | 5 | Q&A for Session 1 topics | |
| Session 2: EV Adoption in Electricity Distribution Systems | | | |
| 10:00 | 15 | Thailand – Plans and Program, with focus on EV Infrastructure | *Dr. Veerapat Kiatfuengfoo*, Deputy Director General Energy Policy and Planning office (EPPO), Ministry of Energy |
| 10:15 | 10 | BREAK | |
| 10:25 | 15 | Japan – EV as Energy Infrastructure in Society | *Ms. Victoria Chiu*, Senior Manager, Global EV, External & Government Affairs Nissan Motor, Japan |
| 10:40 | 5 | Q&A for Session 2 topics | |
| Session 3: Case Studies Presentation | | | |
| 10:45 | 15 | Impact of Electric Vehicles on Distribution Transformers | *Dr. Bhaba Das*, Lead Digital Business Developer Hitachi Energy, New Zealand |

| **Time (AM)** | **Duration (minute)** | **Presentation Title** | **Speaker** |
|---|---|---|---|
| 11:00 | 15 | Impacts of Solar Rooftop PV on the Distribution Grid and Its Transformers | *Mr. Prakal Inthaphat*, Assistant Chief, Electricity Industry Operator Encouragement Division Provincial Electricity Authority (PEA), Thailand |
| 11:15 | 10 | Q&A for Session 3 topics | |
| Session 4: Recommendations and Discussions | | | |
| 11:25 | 10 | Grid Connection Requirements & Recommendations | *Mr. Sommai Phon-Amnuaisuk*, Director, Asia-Pacific International Institute for Energy Conservation (IIEC) |
| 11:35 | 20 | Open Discussion | All Participants |
| 11:55 | 5 | Closing Remarks: Closing message and way forward to officially end the workshop | *Mr. Watcharin Boonyarit,* Director of Strategy and Planning Division Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy, Thailand |

## 6.2 List of Participants

| # | Name | M/F | Email Address | Participant | Economies | Organization |
|---|---|---|---|---|---|---|
| 1 | Yang YU | F | yuyangceline@mail.iee.ac.cn | Participant | China | China ECOPV Alliance |
| 2 | Fang LYU | F | purple@mail.iee.ac.cn | Speaker | China | China ECOPV Alliance/IEE, CAS |
| 3 | Lingyu ZHANG | M | philip.zhang@copperalliance.org | Participant | China | International Copper Association |
| 4 | Yang-Ming TARNG | M | ymtarng@moea.gov.tw | Participant | Chinese Taipei | Bureau of Energy |
| 5 | Yu-Hsuan HUNG | F | minataiwan@gmail.com | Participant | Chinese Taipei | Chung Hsing University |
| 6 | Ching-Ming LAI | M | pecmlai@gmail.com | Participant | Chinese Taipei | Chung Hsing University |
| 7 | Yu-Hsuan CHIANG | M | chiangyu2022@gmail.com | Participant | Chinese Taipei | Chung Hsing University |
| 8 | Iu-suan KHOO | M | i.s.khoo@itri.org.tw | Participant | Chinese Taipei | Industrial Technology Research Institute |
| 9 | William Siu Wai CHUNG | M | mswchung@cityu.edu.hk | Participant | Hong Kong, China | City University of Hong Kong |
| 10 | Jovian Man Chit CHEUNG | F | joviancheung@emsd.gov.hk | Participant | Hong Kong, China | Electrical and Mechanical Services Department |
| 11 | Wai Ling YIP | F | yipwailing@emsd.gov.hk | Participant | Hong Kong, China | Electrical and Mechanical Services Department |
| 12 | Suki Sze Ki WONG | F | sukiwong@emsd.gov.hk | Participant | Hong Kong, China | Electrical and Mechanical Services Department |
| 13 | Chun Yin LI | M | lichunyin@emsd.gov.hk | Participant | Hong Kong, China | Electrical and Mechanical Services Department |
| 14 | Kai Chung LAU | M | edmundlau@emsd.gov.hk | Participant | Hong Kong, China | Electrical and Mechanical Services Department |

| # | Name | M /F | Email Address | Participant | Economies | Organization |
|---|---|---|---|---|---|---|
| **15** | Ian LEUNG | M | leungian@emsd.gov.hk | Participant | Hong Kong, China | Electrical and Mechanical Services Department |
| **16** | Chi Kin CHAN | M | chanchikin@emsd.gov.hk | Participant | Hong Kong, China | Electrical and Mechanical Services Department |
| **17** | Wai Ching WONG | M | wongwaiching@emsd.gov.hk | Participant | Hong Kong, China | Electrical and Mechanical Services Department |
| **18** | Victoria CHIU | F | chiu@mail.nissan.co.jp | Speaker | Japan | Nissan Motor CO., Ltd |
| **19** | Takao IKEDA | M | ikeda@tky.ieej.or.jp | Participant | Japan | The Institute of Energy Economics, Japan |
| **20** | Heberto BARRIOS CASTILLO | M | jlhernandeze@energia.gob.mx | Participant | Mexico | Ministry of Energy of Mexico |
| **21** | Bhaba DAS | M | bhaba.das@hitachienergy.com | Speaker | New Zealand | Hitachi Energy |
| **22** | Carlos BONILLA | M | cbonilla@minem.gob.pe | Participant | Peru | Ministry of Energy and Mines |
| **23** | Felix BERNABEL | M | fbernabel@minem.gob.pe | Participant | Peru | Ministry of Energy and Mines |
| **24** | Arnel Mathew C. GARCIA | M | arnelgarciadin@yahoo.com | Participant | Philippines | Department of Energy (DOE) – Energy Utilization and Management Bureau (EUMB) |
| **25** | Oliver L. DESAMITO | M | odesamito@doe.gov.ph | Participant | Philippines | Department of Energy (DOE) – Energy Utilization and Management Bureau (EUMB) |
| **26** | Peter SABLAY | M | psablay@doe.gov.ph | Participant | Philippines | Department of Energy (DOE) – Energy Utilization and Management Bureau (EUMB) |
| **27** | Winston Rod R. NICODEMUS | M | wnicodemus@doe.gov.ph | Participant | Philippines | Department of Energy (DOE) – Energy Utilization and Management Bureau (EUMB) |
| **28** | Caroline QUITALEG | F | caroline715@gmail.com | Participant | Philippines | DOE – ECCD – Environmental Cooperation |
| **29** | Kristine Ross Welsh LACBAYO | F | klacbayo@doe.gov.ph | Participant | Philippines | DOE – ECCD – Project Monitoring and Evaluation Section (PEMS) |

| # | Name | M /F | Email Address | Participant | Economies | Organization |
|---|---|---|---|---|---|---|
| 30 | Ingrid Marche Perpetua C. CALAPIT | F | icalapit@doe.gov.ph | Participant | Philippines | DOE – Energy Cooperation and Coordination Division (ECCD) |
| 31 | Daisy D. CRUZ | F | dcruz@doe.gov.ph | Participant | Philippines | DOE – Planning Division (PD) |
| 32 | Angelica Eunice R. PERALTA | F | mperalta@doe.gov.ph | Participant | Philippines | DOE – Planning Division (PD) |
| 33 | Michael S. LEABRES | M | mleabres@doe.gov.ph | Participant | Philippines | DOE – Planning Division (PD) |
| 34 | Lilibeth T. MORALES | F | lmorales@doe.gov.ph | Participant | Philippines | DOE- Policy Formulation and Research Division (PFRD) |
| 35 | Marietta M. QUEJADA | F | mquejada@doe.gov.ph | Participant | Philippines | DOE- Policy Formulation and Research Division (PFRD) |
| 36 | Jessie TODOC | M | jessie.todoc@copperalliance.org | Participant | Philippines | International Copper Association Southeast Asia |
| 37 | Yoshiko DE VILLA | F | ydevilla@iiec.org | Organizer | Philippines | International Institute for Energy Conservation |
| 38 | Gerard Anthony LIM | M | gajblim@meralco.com.ph | Speaker | Philippines | Manila Electric Company |
| 39 | Bryan NAVARRO | M | bbnavarro@meralco.com.ph | Participant | Philippines | Manila Electric Company |
| 40 | Isaac CHOONG | M | isaac.choong.yk@gmail.com | Participant | Singapore | SP Group |
| 41 | Parimita MOHANTY | F | mohantyp@un.org | Participant | Thailand | United Nations Environment Programme |
| 42 | Hathaithip SINTUYA | F | hathaithip.nin@g.cmru.ac.th | Participant | Thailand | Chiang Mai Rajabhat University |
| 43 | Minta POOWATANAVONG | F | minta_p@dede.go.th | Participant | Thailand | Department of Alternative Energy Development and Efficiency, Ministry of Energy |
| 44 | Sukanya NANTA | F | sukanya_n@dede.go.th | Participant | Thailand | Department of Alternative Energy Development and Efficiency, Ministry of Energy |
| 45 | Munlika SOMPRANON | F | munlika_s@dede.go.th | Participant | Thailand | Department of Alternative Energy Development and Efficiency, Ministry of Energy |

| # | Name | M /F | Email Address | Participant | Economies | Organization |
|---|---|---|---|---|---|---|
| **46** | Prasert SINSUKPRASERT | M | prasert_s@dede.go.th | Participant | Thailand | Department of Alternative Energy Development and Efficiency, Ministry of Energy |
| **47** | Watcharin BOONYARIT | M | watcharin_b@dede.go.th | Participant | Thailand | Department of Alternative Energy Development and Efficiency, Ministry of Energy |
| **48** | Seksun HORMNUAN | M | seksun_h@dede.go.th | Participant | Thailand | Department of Alternative Energy Development and Efficiency, Ministry of Energy |
| **49** | Veerapat KIATFUENGFOO | M | veerapat@eppo.go.th | Speaker | Thailand | Energy Policy and Planning Office |
| **50** | Pierre CAZELLES | M | pierre.cazelles@copperalliance.org | Participant | Thailand | International Copper Association |
| **51** | Kittisak SUKVIVATN | M | kittisak.sukvivatn@copperalliance.org | Participant | Thailand | International Copper Association Southeast Asia |
| **52** | Aungsanant THIPTHAWEECHARN | F | athipthaweecharn@iiec.org | Organizer | Thailand | International Institute for Energy Conservation |
| **53** | Wilaiwan KUNCHANSOMBUT | F | wkunchansombut@iiec.org | Organizer | Thailand | International Institute for Energy Conservation |
| **54** | Sommai PHON-AMNUAISUK | M | sphonamnuaisuk@iiec.org | Speaker | Thailand | International Institute for Energy Conservation |
| **55** | Nuwong CHOLLACOOP | M | nuwong.cho@entec.or.th | Participant | Thailand | National Energy Technology Center |
| **56** | Kampanart SILVA | M | kampanart.sil@entec.or.th | Participant | Thailand | National Energy Technology Center |
| **57** | Prakal INTHAPHAT | M | prakarn.int@pea.co.th | Speaker | Thailand | Provincial Electricity Authority |
| **58** | Tadsakorn THONGBOR | M | thatsakorn.tho@pea.co.th | Participant | Thailand | Provincial Electricity Authority |
| **59** | Cary BLOYD | M | cary.bloyd@pnnl.gov | Participant | United States of America | Pacific Northwest National Laboratory |

## 6.3 Workshop Evaluation Form

APEC Project Name/Number: ______________________________________________

Date:____________________________

**Instructions:** Please indicate your level of agreement with the statements listed in the table below.

| | Strongly Agree | Agree | Disagree | COMMENTS (Continue on back if necessary) |
|---|---|---|---|---|
| The objectives of the workshop were clearly defined | | | | |
| The project achieved its intended objectives | | | | |
| The agenda items and topics covered were relevant | | | | |
| The content was well organized and easy to follow | | | | |
| Gender issues were sufficiently addressed during implementation | | | | |
| The speakers/experts or facilitators were well prepared and knowledgeable about the topic | | | | |
| The materials distributed were useful | | | | |
| The time allotted for the training was sufficient. | | | | |

1. How relevant was this project to you and your economy?

| 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|
| Very | mostly | somewhat | a little | not much |

*Explain:*______________________________________________________________________________

________________________________________________________________________________________

2. In your view what were the project's results/achievements?

*Explain:*______________________________________________________________________________

________________________________________________________________________________________

3. What new skills and knowledge did you gain from this event?

*Explain:*______________________________________________________________________________

________________________________________________________________________________________

4. Rate your level of knowledge and skills in the topic prior to participating in the event:

| 5 | 4 | 3 | 2 | 1 |
| --- | --- | --- | --- | --- |
| very high | high | medium | low | very low |

5. Rate your level of knowledge and skills in the topic after participating in the event:

| 5 | 4 | 3 | 2 | 1 |
| --- | --- | --- | --- | --- |
| very high | high | medium | low | very low |

*Explain:*___________________________________________________________________________
________________________________________________________________________________

6. How will you apply the project's content and knowledge gained at your workplace? Please provide examples (e.g. develop new policy initiatives, organise trainings, develop work plans/strategies, draft regulations, develop new procedures/tools etc.).

*Explain:*___________________________________________________________________________
________________________________________________________________________________

7. What needs to be done next by APEC? Are there plans to link the project's outcomes to subsequent collective actions by fora or individual actions by economies?

________________________________________________________________________________
________________________________________________________________________________

8. How could this project have been improved? Please provide comments on how to improve the project, if relevant.

________________________________________________________________________________
________________________________________________________________________________

**Participant information (identifying information is optional):**

Name:

Organisation/Economy:

Email:

Gender: M / F

***Thank you. Your evaluation is important in helping us assess this project, improve project quality and plan next steps.***

## 6.4 WORKSHOP EVALUATION RESPONSES

Survey Scale (No.1-8): 1=Disagree 2=Agree 3=Strongly Agree
Survey Scale (No.9): 1=Not Much 2=A Little 3=Somewhat 4=Mostly 5=Very
Survey Scale (No.12-13): 1=Very Low 2=Low 3=Medium 4=High 5=Very High

| Workshop Evaluation Survey | # 1's | #2's | #3's | #4's | #5's | comments |
|---|---|---|---|---|---|---|
| Q1: The objectives of the workshop were clearly defined | 0 | 1 | 25 | | | - very informative<br>- It is very important that the energy for electrical vehicles comes from renewable energy, so it is necessary to know the barriers for that purpose order ya |
| Q2: The project achieved its intended objectives | 0 | 3 | 23 | | | - APEC not fully represented and participants did not have much to share<br>- The pronunciation of the English were not good in some cases. |
| Q3: The agenda items and topics covered were relevant | 0 | 3 | 23 | | | Specially the case studies. |
| Q4: The content was well organized and easy to follow | 0 | 2 | 24 | | | Apparently some speakers were not present. |
| Q5: Gender issues were sufficiently addressed during implementation | 1 | 11 | 14 | | | - I'm not sure<br>- not explicitly shown<br>- The presentations didn't focus on gender issues directly. |
| Q6: The speakers/experts or facilitators were well prepared and knowledgeable about the topic | 0 | 2 | 24 | | | The English pronunciation of some speakers were not good. |
| Q7: The materials distributed were useful | 0 | 4 | 22 | | | - Please share the presentations<br>- wish can get the materials<br>- It will be useful for projects in our economies. |
| Q8: The time allotted for the workshop was sufficient | 1 | 4 | 21 | | | I agree. |
| Q9: How relevant was this project to you and your economy? | 0 | 0 | 1 | 8 | 17 | - The Philippines is increasingly deploying rooftop solar PV and EVs.<br>- My economy has not implemented yet the rooftop PV, so the information will be useful for that purpose. |
| Q10. In your view what were the workshop results/ achievements? | | | | | | |
| - Increased awareness and knowledge on impacts of rooftop solar PV and EVs on distribution systems.<br>- Learning from APEC Economies on the development of EV and Solar rooftop PV in their economies<br>- Recommendations on the way forward, esp. for DU's and private sector companies, in accounting for the increase uptake of EV combined with solar PV<br>- To understand that electric vehicles must be powered by solar energy, for which smart grids are required.<br>- Capacity building | | | | | | |
| Q11: What new skills and knowledge did you gain from this event? | | | | | | |
| - Solar and EV integration<br>- Social benefits of EVs.<br>- EV status update | | | | | | |

<table>
<tr><th>Workshop Evaluation Survey</th><th># 1's</th><th>#2's</th><th>#3's</th><th>#4's</th><th>#5's</th><th>comments</th></tr>
<tr><td colspan="7">- Information on grid connection requirements for rooftop solar PV<br>- The existence of regulations and standards which implies the integration of information so that the charging infrastructure operates efficiently.<br>- Impact of EV on grid</td></tr>
<tr><td>Q12: Rate your level of knowledge and skills in the workshop topic prior to participating in the event</td><td>0</td><td>7</td><td>6</td><td>5</td><td>8</td><td>- not very familiar with the topics<br>- I have a basic level of knowledge on electrical vehicles.</td></tr>
<tr><td>Q13: Rate your level of knowledge of and skills in the topic after to participating in the event</td><td>0</td><td>0</td><td>3</td><td>11</td><td>12</td><td>- I was involved in the implementation of Renewable Energy projects in my previous office at the DOE Philippines, with my new office that implements Energy Efficiency and Conservation as well as renewable energy technologies, I was able to connect the topics in my current job<br>- now more familiar, but still many things to learn<br>- I understand the barriers for the implementation of charging infrastructure inside smart grids.</td></tr>
<tr><td colspan="7">Q14: How will you apply the project’s content and knowledge gained at your workplace? Please provide examples (e.g. develop new policy initiatives, organise trainings, develop work plans/strategies, draft regulations, develop new procedures/tools etc.).</td></tr>
<tr><td colspan="7">- Policy enhancement, integration in the energy efficiency and conservation and renewable energy projects, and will serve as reference in future related projects<br>- Develop work plans/strategies<br>- Incorporate in the rooftop solar PV training<br>- We can apply the project's content in conducting studies or developing new policies regarding emerging technologies<br>- Develop new policy initiatives<br>- Benchmarking the EV and solar rooftop PV policies of other APEC economies with government policies, and also adopt the best practices to environment<br>- Program development and planning<br>- Whitepaper publications<br>- It has open new issues for public discussion and the possibility to include in energy policies.<br>- Organise trainings</td></tr>
<tr><td colspan="7">Q15: What needs to be done next by APEC? Are there plans to link the project’s outcomes to subsequent collective actions by fora or individual actions by economies?</td></tr>
<tr><td colspan="7">- Implementation of EVs and establishment of strategic EV charging stations and EV market<br>- Maybe this workshop is the starting point for future projects.</td></tr>
<tr><td colspan="7">Q16: How could this workshop have been improved? Please provide comments on how to increase the impact of the project, if relevant.</td></tr>
<tr><td colspan="7">- The meeting should be organized as a physical meeting rather than a virtual meeting<br>- More budget for more concrete and realistic results<br>- it is convenient that the speakers have a good pronunciation of English.</td></tr>
</table>

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Produced by
Watcharin Boonyarit (Project Overseer)
Department of Alternative Development Energy Development and Efficiency
Ministry of Energy
17 Rama I Road, Kasatsuk Bridge,
Pathumwan, Bangkok 10330 Thailand
Telephone: +66-2129-3344
Fax: +662 226 1416
Email: munlika_s@dede.go.th

In partnership with
Pierre Cazelles
Director - Global Partnerships
International Copper Association
Email: pierre.cazelles@copperalliance.org

Developed by
Sommai Phon-Amnuaisuk
Director, Asia-Pacific
International Institute for Energy Conservation
Email: sphonamnuaisuk@iiec.org

For
Asia Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org



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