Asia-Pacific
Economic Cooperation

Advancing Free Trade
for Asia-Pacific Prosperity

The Role of Integrated Distribution System Planning in Maximizing Resiliency in the APEC Region

APEC Energy Working Group

March 2022

Asia-Pacific
Economic Cooperation

The Role of Integrated Distribution System Planning in Maximizing Resiliency in the APEC Region

APEC Energy Working Group

March 2022

APEC Project: EWG 03-2020S

Report prepared for the APEC Energy Working Group by:
Pacific Northwest National Laboratory
902 Battelle Blvd
Richland, WA 99354
USA

Authors:
Sarah H Davis
Xueqing Sun
Cary Bloyd
Juliet S Homer
Md Jan E Alam

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

APEC#222-RE-01.4

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <https://www.ntis.gov/about>
Online ordering: http://www.ntis.gov

FOREWORD

There is an urgent need in the Asia-Pacific Economic Cooperation (APEC) region to enhance the resilience of energy infrastructure to reduce the impact from natural and man-made disasters, as well as climate change. APEC economies face 70 percent of all global natural disasters. Energy systems are further stressed by exploding growth and urbanization across the APEC region. In recognition of the importance of energy resiliency, the APEC energy ministers instructed the APEC Energy Working Group (EWG) to establish the Energy Resiliency Task Force at the 12th Energy Ministers' Meeting (EMM12) held in Cebu, Philippines, on October 13, 2015. This project is being carried out in support of the APEC Energy Resiliency Task Force, which operates under the APEC EWG. This project also directly supports the EWG's 2019–2023 Strategic Plan stated goal to enhance energy resiliency and energy access and advance clean energy through improvements in the electric distribution systems.

ACKNOWLEDGEMENTS

This U.S. self-funded APEC project was supported by the U.S. Department of Energy's Office of Asian Affairs. The authors would like to acknowledge and thank Ariadne BenAissa, deputy director of the U.S. Department of Energy's Office of Asian Affairs for her support and guidance throughout this project. The APEC project overseer was Cary Bloyd, and the Pacific Northwest National Laboratory (PNNL) project manager was Jan Alam.

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

This report examines the role of integrated distributed system planning in maximizing the use of distributed energy resources (DERs) in the APEC region. Electrical distribution systems also have a critical linkage to energy resiliency in that 80 to 90 percent of customer outages originate in the distribution system. Additionally, increasing desirable DER technologies, including electric vehicles, energy storage, and consumer photovoltaic generation, relies heavily on the distribution system to link the consumer to the power grid.

This report shares recommendations, tools, techniques, and best practices from grid modernization efforts in the APEC region. The report demonstrates how cutting-edge distribution system planning techniques and new technologies can enhance reliability, resilience, and DER utilization in the region, at a high level.

Six key integrated distribution system planning elements for grid modernization are highlighted in this report.

Key Integrated Distribution System Planning Elements

- Implementing Integrated Distribution System Planning
- Leveraging Distributed Energy Resources for Reliability & Resilience
- Planning for Electric Vehicles & Their Potential
- Increasing Situational Awareness
- Allowing for Microgrids
- Establishing Equitable Recovery Strategies

For each one of these elements—their value and importance, implementation, technology and application readiness, and their varying levels of implementation in APEC member economies—are explored in this report. This exploration reveals recommendations and suggested prioritization that all APEC member economies can benefit from. These recommendations are summarized in Table 6-1 and Table 6-2.

Table 6-1 summarizes the resulting high-level recommendations for policy and regulating entities, as well as distribution system planning entities in the APEC region. Whether an APEC economy is designated as developed or developing, these recommendations are applicable to all. Some APEC regions are already adopting many of these recommendations to some extent. All these recommendations are essential to the success of distribution grid modernization and operational reliability and resiliency; therefore, listing in terms of prioritization is challenging. These recommendations should be pursued in parallel to keep up with the quickly changing characteristics of the distribution system.

Table 6-2 summarizes the technologies and applications highlighted in this report that are recommended for APEC economies to consider, if they have not yet already. Technologies and applications that can be prioritized by developing economies are noted in this table. Additionally, those that are considered emerging technologies that APEC economies should be actively aware of are also noted. As these technologies and applications are considered by policy makers and distribution planners, it is important to note that there are many distribution technologies that flaunt their ability to enhance system resilience; however, the cost of deploying such technologies remains a barrier to many. Grants to field test and demonstrate these technologies should be made available to distribution planning entities to help overcome these financial barriers.

Table 1-1. Recommendations matrix

	POLICY AND REGULATING ENTITIES	DISTRIBUTION SYSTEM PLANNING ENTITIES
Integrated Distributio n Planning	Develop rulings to require development of **integrated distribution system planning processes** that are also publicly available, transparent, and provide a balanced/fair opportunity for technology deployment/adoption.	Establish and document integrated system planning processes and needs assessments required for grid modernization and **allow these plans to be publicly transparent** and eligible for stakeholder feedback.
DERs	Develop rulings to require **planning for DERs in advance**, as well explore and field test technologies that can manage DER operation to improve reliability and resilience.	Identify and field test technologies and resources needed to **improve the management, coordination, and optimization of DERs** to improve reliability and resilience.
Electric Vehicles (EVs)	Develop rulings for transportation electrification industries, distribution planning entities, and other necessary stakeholders to require development of **rate structure mechanisms and technologies to better manage** EVs and field test technologies for future vehicle-to-grid (V2G) capability.	**Identify EV hosting capacity constraints and charge management techniques** for forecasted EV and field test technologies that can be utilized to managed EV charging that can also enable future V2G capability.
Situational Awareness	Develop rulings to require roll-out of advanced technologies (e.g., Advanced Metering Infrastructure [AMI], Distribution Management Systems [DMSs], Outage Management Systems [OMSs], etc.) that will **increase situational awareness on distribution systems,** all while ensuring customer engagement is upheld throughout planning and deployment stages.	Build a business case, with consumers in mind, to **roll-out advanced technologies (e.g., AMI, DMS, OMS, etc.)** to increase situational awareness considering how increased maintenance savings, reduction in restoration costs, and effective cost-savings can be achieved.
Microgrids	Develop technical and regulatory rulings and guidance for distribution planning entities and microgrid developers that will **enable safe and effective deployment and operation of microgrids,** including grid-connected and isolated microgrid configurations.	Allocate resources to improve planning and operational strategies for the deployment of microgrids that incorporate safety requirements and engagement with consumers to **identify essential/critical community resources** or regions needing improved reliability and resiliency.
Disaster	Develop requirements to **ensure fair and equitable disaster recovery strategies** are prepared by distribution system planning entities, requiring continuous improvement based on lessons learned from local and global extreme events.	Prepare publicly transparent recovery plans that incorporate classification and prioritization of critical loads, microgrid deployment, and performing annual trainings for staff to **ensure readiness for extreme events.**

Table 1-2. Recommended technologies & applications matrix

	TECHNOLOGIES & APPLICATIONS
Integrated Distributi	New Distribution Planning Approaches* Modern Grid Architecture & Distribution System Operator (DSO)** Peer-to-Peer Trading & Transactive Energy**
DER	DER Load Forecasting Tools* Energy Storage* Distributed Energy Resource Management System (DERMS)
EVs	EV Load Forecasting Tools* EV Load Management Tools Charging Infrastructure Vehicle-Grid-Integration (VGI)**
Situational Awareness	AMI* Supervisory Control and Data Acquisition (SCADA) & DMS OMS
Microgrids	Microgrid Tariffs* Microgrid Technical Specifications* Microgrid Interface Controller**
Disaster Recovery	Asset Management Systems* Geographic Information Systems (GISs) & Hazard Maps* Emergency Response Drills & Training Simulators* DMS

***Technologies and applications developing economies should consider prioritizing**
****Considered an emerging technology and not yet widely implemented**

This project directly supports APEC's goals to double the share of renewables in the APEC energy mix, including in power generation, from 2010 levels, by 2030 and decrease energy intensity by 45 percent by 2035. Per the energy ministers' instructions, this project is meant to promote energy resiliency in the APEC region, anchored on the four strategic priority sub-themes identified in the Cebu Declaration.

This report is prepared under the EWG's 2019–2023 Strategic Plan stated goal to enhance energy resiliency and energy access and advance clean energy through improvements in the electric distribution systems.

The key beneficiaries for this project are energy policy makers across APEC, especially in developing economies. Other beneficiaries include program managers, evaluators, non-government organizations, academics, students, and associated stakeholders involved in local, regional, and national disaster response activities. The beneficiaries will be engaged through existing APEC EWG and Energy Resiliency Task Force communication networks.

ACRONYMS AND ABBREVIATIONS

AESO	Alberta Electric System Operator
AMI	Advanced Metering Infrastructure
APEC	Asia-Pacific Economic Cooperation
CBM	condition-based maintenance
DER	distributed energy resources
CPUC	California Public Utilities Commission
DERMS	Distributed Energy Resource Management System
DMS	Distribution Management System
DOE	U.S. Department of Energy
DSO	Distribution System Operator
EV	electric vehicles
EWG	Energy Working Group
GDP	gross domestic product
GIS	Geographic Information Systems
GW	gigawatts
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
kWh	kilowatt hours
LDF	light-duty vehicle
LSRV	locational system relief value
NERC	North American Electric Reliability Corporation
NREL	National Renewable Energy Laboratory
NWA	Non-wires Alternative
OMS	Outage Management Systems
P2P	peer-to-peer
PEV	plug-in electric vehicle
PG&E	Pacific Gas & Electric
PNNL	Pacific Northwest National Laboratory
PSE	Puget Sound Electric
PV	photovoltaic
ROK	Republic of Korea
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition

SGI	Smart Grid Index
T&D	transmission and distribution
U.S.	United States
VGI	Vehicle Grid Integration
V2G	vehicle-to-grid

1.0 INTRODUCTION

The modern electric grid has often been described as the most complex machine of the 20th century. The availability of reliable and affordable electricity is necessary for sustainable economic development. The electric grid is also one of the largest infrastructure investments of both developed and developing economies. In total, investment in the U.S. grid is roughly US$2 trillion with an estimated replacement cost of US$5 trillion [1]. This investment supports the total annual electricity sales of just over US$400 billion in 2020, which amounts to about 2 percent of the US$20 trillion gross domestic product (GDP).

Electricity infrastructure can be loosely defined as a network of power plants and electricity infrastructure equipment to generate, transmit, and distribute electrical energy to various types of end-users (e.g., residential, commercial, industrial). It is generally discussed in terms of electric power generation, transmission, and distribution components. Generation resources consist of various power generating technologies (e.g., gas; nuclear; renewable energy, such as solar, wind, hydro; etc.). Electric power produced by generation resources is transmitted through long-distance high-voltage transmission lines for distributing among the end-users via medium and low voltage power distribution lines. An image illustrating the basic parts of electricity infrastructure is provided in Figure 1-1.

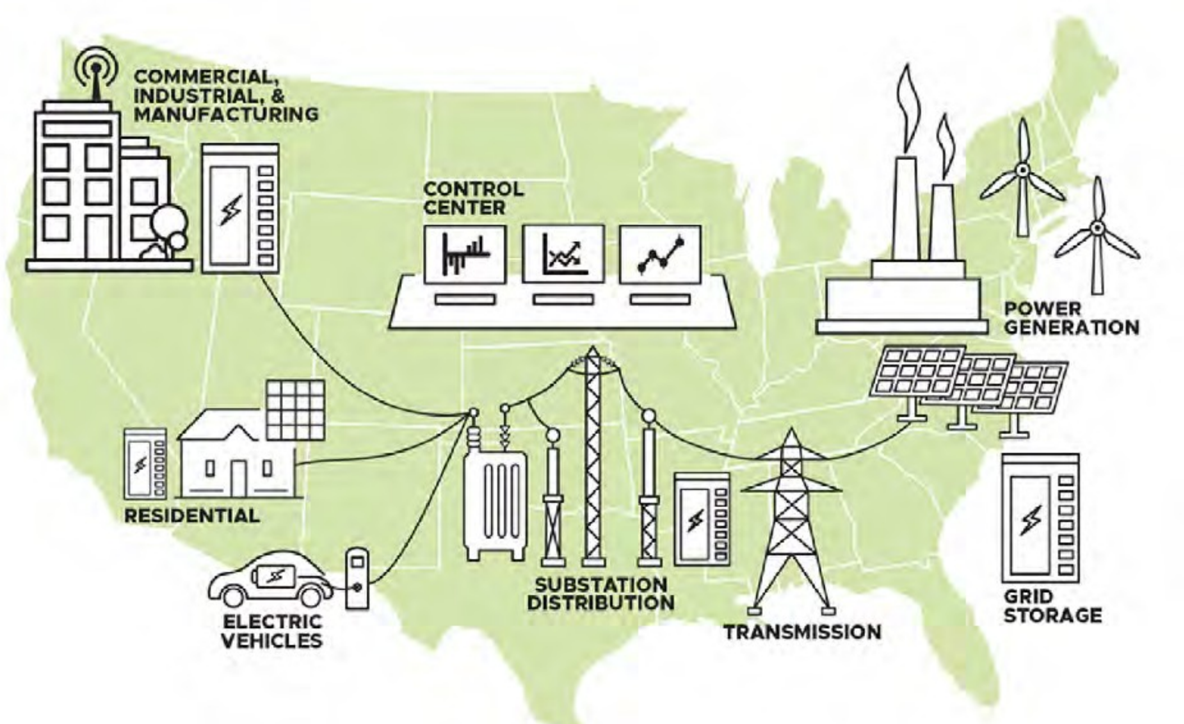


Figure 1-1. High-level illustration of components that make up the transmission and distribution power systems from a U.S. national laboratory perspective

Enhancements and considerations to the distribution system are the main scope of this report, but it is important to understand how this system is connected to the rest. As generation sources such as photovoltaic panels and large loads such as electric vehicles are added by the consumer, the role of the distribution systems has become more important. The local distribution system is now being asked to play a new role of handling bidirectional flow of electricity with the integration of DERs. The new role of monitoring the two-way flow of electricity was not envisioned when distribution systems were originally constructed.

It is increasingly recognized that the modern distribution system role is growing in importance as new distributed renewable resources and new categories of consumer loads, such as electric vehicles, are added to the grid. The objective of this project is to increase the use of DERs and increase the resiliency of the electric grid through integrated distribution system planning. This is an important topic of exploration, as APEC member economies are experiencing a significant increase in renewable energy deployments on both the high-voltage bulk power grid and at the lower-voltage distribution system levels. Electric loads on the distribution network are becoming more flexible and, when coordinated with nearby renewables, can help balance the power system with local, community-based resources. The project seeks to address the need to modernize electric distribution systems to enable them to better utilize DERs and strengthen electric distribution systems to be more resilient in the face of natural disasters. The project is applicable to all APEC economies.

Figure 1-2. Distribution system infographic showing various types of connected infrastructure and land zoning, with detailed annotation of this image in Appendix A [2]

This report comes at an important time, when renewable energy projects on the bulk system are increasing and new resources and technologies at the distribution system level are changing how the distribution and transmission systems interact to serve loads. We are seeing new trends in APEC member economies. These include

- Regulators requiring more stakeholder engagement and visibility into planning at distribution system level
- A need for increased usage of more granular forecasts (in space and time) to adapt and improve distribution system reliability and resilience
- Increased data access and utilization in distribution system planning practices
- Hosting capacity maps and non-wire alternative opportunities for addressing system upgrades to accommodate changes in load and increased penetration of DERs
- Concepts of resilience and equity taking on increasing attention in distribution planning considerations.

It is important to explore how these trends are being realized and what technologies and applications are readily available for APEC member economies to deploy. The intent of this report is to explore and summarize at a high level the most important elements APEC member economies should focus on to enhance distribution system planning practices to support carbon reduction, increased renewable energy deployments, and opportunities to modernize the distribution grid in preparation for a more reliable and resilient future.

The structure of this report was developed in such a way as to inform the reader, who may not come from a technical background, what the distribution power grid is, the value it provides, and what **key integrated distribution system planning elements** APEC member economies need to begin considering, if they have not yet already.

To identify what these elements are, some thoughts went into the selection criteria. It was decided that the key integrated distribution system planning elements must satisfy the three criteria listed below.

Selection Criteria for Key Integrated Distribution System Planning Elements

1. Elements that absolutely need to be planned for in advance
2. Elements that serve multiple benefits
3. Elements that are already being developed in APEC economies and demonstrate proven value

Utilizing this selection criteria, extensive literature review was performed on distribution grid modernization and trends. After reviewing the contents of these materials, what resulted were six key elements that distribution power system operators, planners, and regulators should be considering. These key elements are listed below.

Key Integrated Distribution System Planning Elements

- Implementing Integrated Distribution System Planning
- Leveraging Distributed Energy Resources for Reliability & Resilience
- Planning for Electric Vehicles & Their Potential
- Increasing Situational Awareness

- Allowing for Microgrids
- Establishing Equitable Recovery Strategies

In the attempt to identify the most important elements, there were many other topics that could have potentially been added to this list. However, for the purposes of preparing this high level and brief reporting material, the key elements identified above were determined to be the highest impact and most critical. Each one of these elements—their value and importance, implementation, technology and application readiness, and their varying levels of implementation in APEC member economies—will be explored in this report. This exploration will reveal recommendations and suggested prioritization that all APEC member economies can benefit from.

2.0 VALUE OF THE DISTRIBUTION GRID

Access to reliable and resilient electric power supply systems is an essential precondition for the functioning of modern economies, both in developed and developing economies. Current electricity consumption per unit of GDP is far lower in developing economies than in developed economies. For developing economies, additional growth in GDP requires much larger additions of electricity per unit of output because of the ongoing process of changing from traditional subsistence to modern commercial/industrial activities and lifestyle. At the same time, global climate change and limited energy resources impose new challenges on the developing economies to transition to a low-carbon energy system. Rapid increase in penetration of renewable energy resources, development, and integration of energy storage devices, EVs, and smart buildings in the distribution system emphasizes the importance and urgency for developing economies to invest in the grid of the future, leveraging the integrated distribution system planning experiences and lessons from developed economies and optimizing their decision-making process for power system planning. This section provides a comprehensive overview of the APEC economies and a discussion on the value of grid to the development of the economies.

2.1 APEC MEMBER ECONOMY PROFILES

The 21 economies in APEC are diverse, including some of the world's most energy-intensive (Canada, Korea, and Russia) and some of the least energy-intensive (Papua New Guinea, Peru, and Philippines) economies, as shown in Table 2-1. The group also has some of the world's fastest growing economies (Viet Nam and Papua New Guinea). For developing economies, analysis of energy use and the power sector based on the diversities provides significant opportunity to share and learn from other economies.

Table 2-1. Key energy statistics for APEC economies (in APEC order) [3]

APEC Economy	Total Primary Energy Supply (Mtoe)	Energy Production (Mtoe)	Electricity Consumption	Energy Intensity (toe/unit GDP)	Energy Intensity (toe/capita)
Australia	130	390	257	116	5.4
Brunei	3.2	15	4	102	0.076
Canada	282	475	667	173	7.8
Chile	38	12	79	89	2.1
China	2983	2359	6200	144.00	2.1
Chinese Taipei	110	11	263	100	4.7
Hong Kong, China	13	0.11	39	32	1.8
Indonesia	233	434	262	80	0.89
Japan	436	35	1072	86	3.4
Korea	285	51	560	153	5.6
Malaysia	83	96	138	100	2.7
Mexico	189	180	320	83	1.5

APEC Economy	Total Primary Energy Supply (Mtoe)	Energy Production (Mtoe)	Electricity Consumption	Energy Intensity (toe/unit GDP)	Energy Intensity (toe/capita)
New Zealand	22	17	43	124	4.6
Papua New Guinea	2.2	11	4	69	0.27
Peru	24	26	52	60	0.76
Philippines	55	28	91	70	0.53
Russia	731	1372	1089	196	5.1
Singapore	27	0.74	52	56	4.8
Thailand	138	79	191	122	2
USA	2174	1915	4306	121	6.7
Viet Nam	79	69	165	138	0.84
APEC	8043	7578	15854	123	2.8
World	13761	13764	24973	115	1.8

2.1.1 POPULATION DEMOGRAPHICS & GEOGRAPHIC FEATURES

The population of the APEC region increased by about 600 million people over the past three decades, to 2.9 billion in 2018, accounting for 38 percent of the global population. Among the developing economies, Indonesia has the third largest population, following China and the United States. Mexico overtook Japan and became the fifth most populous APEC economy. In total, developing APEC economies account for 26.33 percent of the APEC population. Population density varies largely in the APEC regions. Australia has only 3 people per square kilometer, while Singapore has the largest population density, with 7,953 people per square kilometer. In general, APEC economies in Asia have higher population density than other areas [4].

The geographic location is an important factor for power system planning, as well. Developing economies have their own specific locational opportunities and challenges. Examples of these developing economies are as follows:

- **Indonesia**, the world's largest archipelagic state, encompasses 17,504 large and small islands. The cost to generate and provide electricity in Indonesia varies greatly by location due to the remote locations of populations across its many islands.
- **Papua New Guinea** is an island economy located in the Pacific Ocean, with roughly 600 islands. It sits along the volcanically active "Ring of Fire" and faces frequent earthquake and tsunami risks. Papua New Guinea has the lowest population among the APEC economies with access to electricity. In 2018, the electricity access percentage in Papua New Guinea was only 58.97 percent.
- **Viet Nam**, located at the center of Southeast Asia, is in a tropical monsoon zone and profoundly affected by the East Sea, which gives it abundant renewable energy sources, such as solar energy. Viet Nam is endowed with diverse energy resources, such as oil, gas, coal, and renewables.

- **Chile**, with the longest and narrowest geographical footprint among the economies, has been dependent on energy imports, despite vast solar and wind energy resources and the rapid shift toward cleaner energy over the past decades.
- For **Thailand**, the domestic supply of energy resources will soon become depleted-oil resources within two years and natural gas within five years [4].

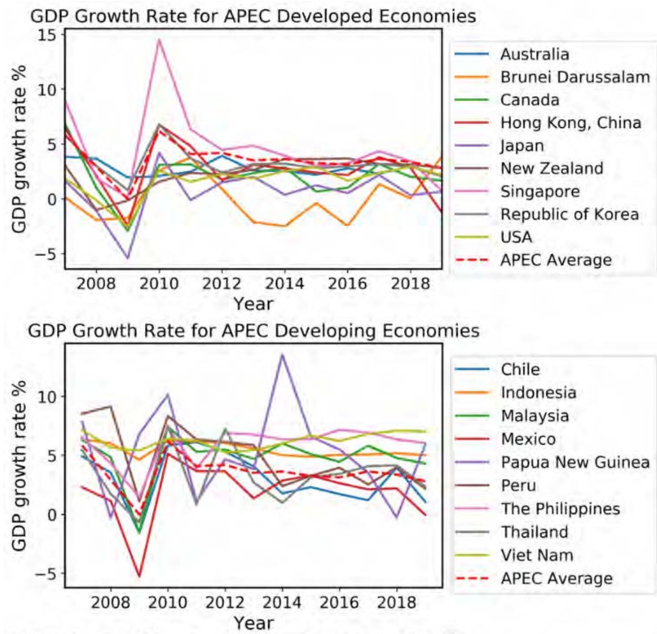
Despite the differences in demographic, geographic, and locational opportunities and challenges for each developing economy, all of them have the priority to expand and improve their power systems to ensure accessibility of reliable electricity to the whole population, while considering the decarbonization mission of the APEC region.

2.1.2 ECONOMIC DEVELOPMENT

In the last decade, the Asia-Pacific Region has been home to some of the fastest growing economies in the world [5]. Specifically, Viet Nam's GDP grew at an average of 6.25 percent per year in the period of 2007 to 2019. Its GDP growth was 7.08 percent in 2018 and 7.02 percent in 2019, its highest growth rate in 10 years. Indonesia, Papua New Guinea, and Philippines also experienced rapid GPD growth at an average annual rate higher than 5 percent. Other developing economies, such as Malaysia and Peru, also have rapid GDP growth rates at more than 4 percent.

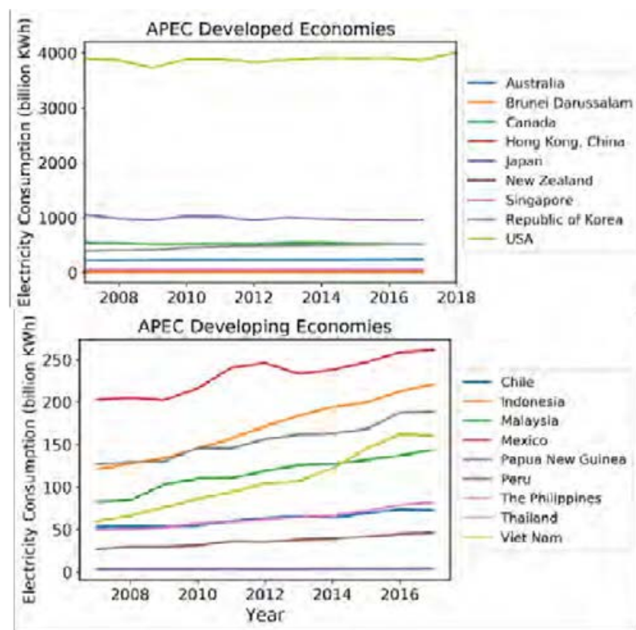
Figure 2-1 depicts the GDP growth of the APEC economies. The red dash line is the APEC average GDP growth rates for each year. For the last decade, developing economies have seen strong economic growths, with most of these economies having a growth rate higher than APEC average growth rates. The strong economic development has spurred significant growth in electricity demand, as shown in Figure 2-2.

For Viet Nam, the demand in electricity has grown at a compound annual growth rate of 13 percent since 2000 and is projected to continue at 8 percent through 2030 [6]. The energy demand for Indonesia has grown at 7 percent annually. Compared with the energy consumption in developed economies, the absolute value of electricity consumption has a large space to grow into. In 2017, the average electricity consumption in APEC developing economies was 130.87 billion kilowatt hours (kWh), while this number for APEC developed economies was 688.8 billion kWh.



* Chinese Taipei, China, and Russia are not included in this figure

Figure 2-1. GDP growth rates for APEC economies[1]



*Chinese Taipei, China, and Russia are not included in this figure

Figure 2-2. Electricity consumption for APEC economies[2]

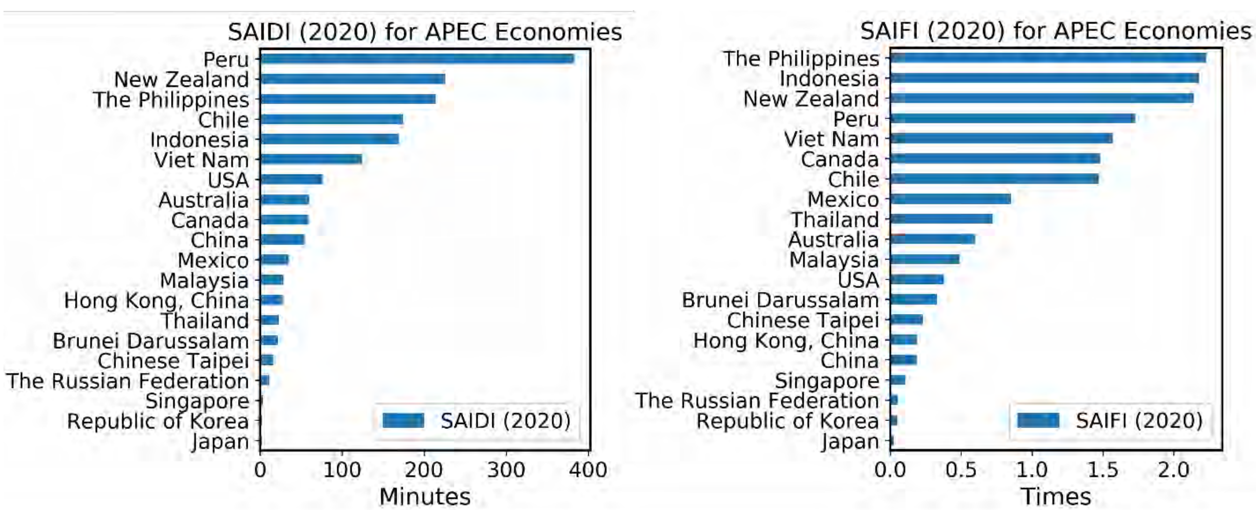
[1] Data source: World Bank, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD
[2] Data source: World Bank, https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC

2.1.3 POWER SECTOR IN APEC ECONOMIES

Power system planning in developing economies faces enormous challenges and problems, for example, the rapid growth of electricity demand with uncertainties, the aging power sector infrastructures that need upgrades and expansion, the constraints imposed on investment, the type and availability of energy resources for the generating units, and the need for consolidating the dispersed electric utilities in the isolated regions.

The development levels of power sectors vary in each of the developing economies. As of 2018, while the populations of all developed economies have had 100 percent access to electricity for decades, some economies, such as Chile, Malaysia, Mexico, Thailand, and Viet Nam, have just achieved 100 percent electricity access, and a small portion of population in other developing economies still have no access to electricity.

Power system reliability, resilience, and efficiency are important factors when evaluating a power system and must be taken into consideration during all phases of power system planning. The Institute of Electrical and Electronics Engineers (IEEE) has developed metrics to measure and monitor power system reliability from a customer perspective. The System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) are two commonly used reliability indicators. SAIDI is an aggregate measure of the number of minutes a customer is without power for each interruption. SAIFI is the average number of interruptions that a customer would experience. Power systems in developing economies are much less reliable compared with the developed economies. In 2017, the aggregate time a customer is without power (SAIDI) in Papua New Guinea is 211.33 hours, almost 18 times of that for Viet Nam, which has the second highest SAIDI at 12 hours. The average number of interruptions that a customer would experience (SAIFI) in Papua New Guinea is 134 times, while the second largest SAIFI is 6.72 for Viet Nam. Figure 2-3 is the SAIDI and SAIFI for APEC economies except Papua New Guinea.



* Papua New Guinea is not included in this figure

Figure 2-3. Reliability of the power sector in APEC economies[3]

[3] Data source: World Bank, WBG – Doing Business

Power supply efficiencies is another important metric indicating the transmission and distribution (T&D) infrastructure performance status and advancement of the power sector. Electric power T&D losses include losses in transmission between sources of supply and points of distribution and in the distribution to consumers. Most of the total T&D losses occur on the distribution system. Figure 2-4 is the T&D losses for APEC economies in 2014. In Mexico, 13.71 percent of energy was lost in the T&D system. The losses for developing economies were between 5.79 percent and 13.71 percent.

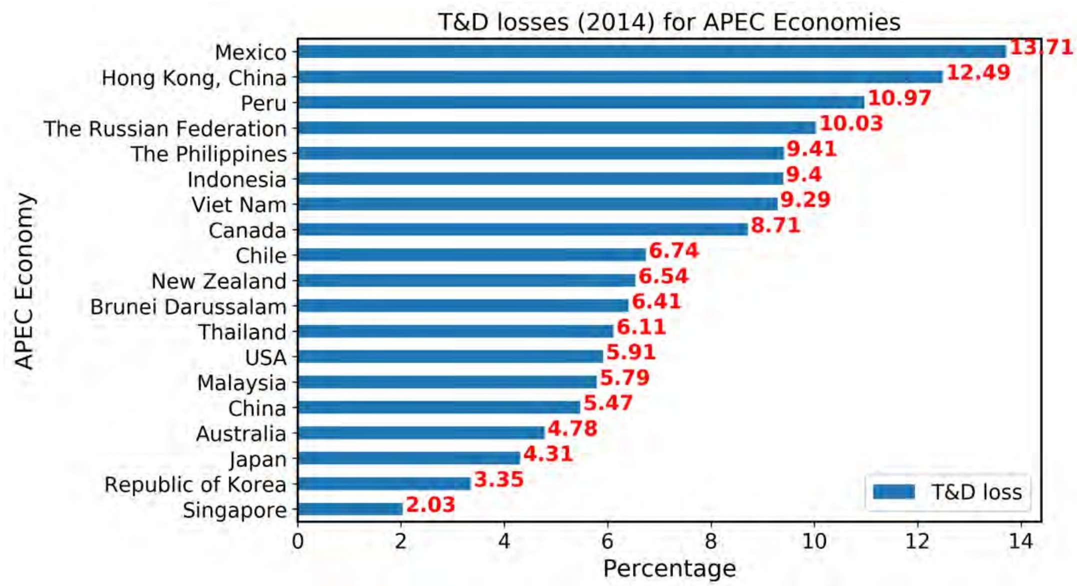


Figure 2-4. T&D losses for APEC economies[4]

The comparatively low level of reliability and efficiency of the power systems in the developing economies emphasizes the importance of wise investment in the grid, so that the grid can be reliable, efficient, and capable of integrating higher levels of versatile renewables, DERs, and demand-response end uses.

2.2 UNLOCKING THE VALUE OF THE GRID

A reliable and resilient power system is the backbone for any economy's development. Investing in the grid to maintain its reliability and resilience, and to adapt it for the future challenges is essential for any economy. This section first briefly discusses the importance of electricity use for economic activities, as well as the different phases of development for developing and developed APEC economies in section 2.2.1. Then section 2.2.2 discusses the investment in power sector infrastructure globally, showing that the distribution system has been the most heavily invested sector in power sector. Lastly, emerging new challenges that change the distribution system planning and should be considered for all planners and stakeholders are discussed in section 2.2.3.

2.2.1 ECONOMIC ACTIVITY AND ELECTRICITY USE

Historically, growth in economic activity (measured as GDP) has tended to be coupled with increases in electricity use as populations grow and more goods and services are produced. Short-term changes in

[4] Data source: World Bank, https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS

electricity use are often positively correlated with changes in economic output (measured by GDP) [7]. As economies shift their economic activity from lower-skilled manufacturing to services and higher-skilled advanced manufacturing, the relationship between electricity use and economic activity will be gradually decoupling [8].

Figure 2-5 shows electricity use per GDP. For less developed economies, the electricity use per GDP is still on an increasing path, while developed economies already started to show the decoupling of electricity and GDP productivity, depending on each economy's relative level of development, electrification, economic makeup, and income levels. On the one hand, for developing economies, electricity use will continue to increase as they increase development of industrial manufacturing activities, which highlights the importance of a reliable power grid. On the other hand, developed economies have started shifting toward advanced manufacturing and services, which is less electricity intensive.

Although at different stages of development, all APEC economies face the same contemporary energy and environmental challenges, such as emission reduction. For developing economies, experiences from developed economies provide them valuable insights into power system planning for accommodating their expanding economic development needs, as well as preparing for the rapidly increasing penetration of DERs and electrification (such as electric vehicles).

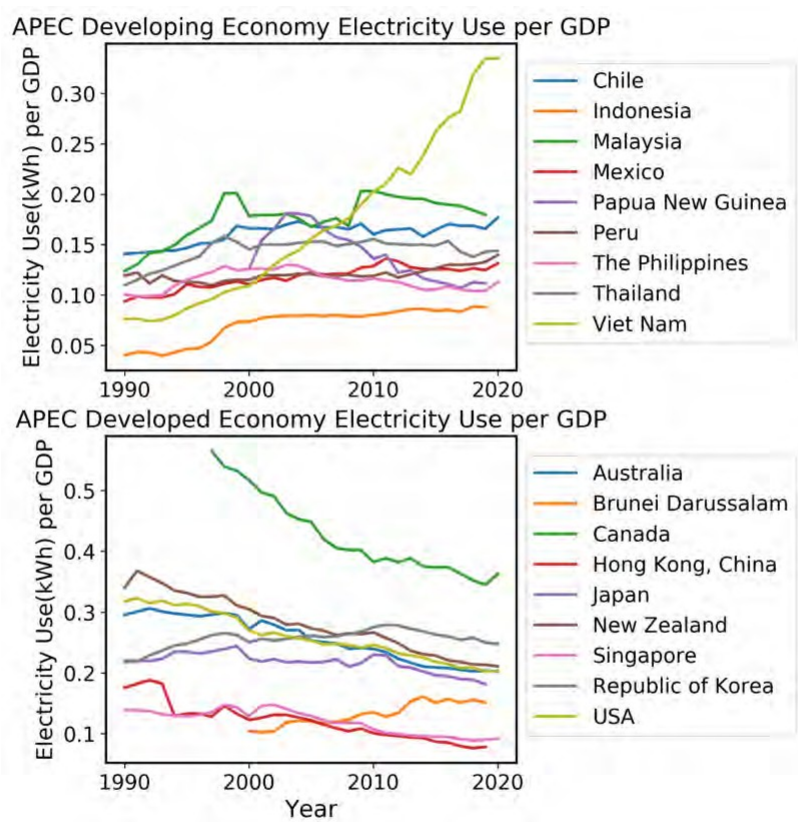


Figure 2-5. Electricity use per GDP for APEC economies[5, 6]

[5] Data source: World bank and Our World in Data

[6] Chinese Taipei, China, and Russia are not presented in this figure.

2.2.2 POWER SECTOR INFRASTRUCTURE INVESTMENT

The electric grid, as one of the greatest engineering achievements of the 20th century,[7] is very expensive. It would cost almost US$5 trillion to replace the U.S. electric grid, comprising power plants, wires, transformers, and poles [1]. Since the 20th century, the dominate model of a power network has been large, centralized generation resources with a sprawling distribution network delivering power to customers over a large territory. This model realized the value of economies of scale, as power produced in this way was much cheaper [9].

The electric infrastructure, especially for developed economies, has been aging and needs or will need significant ongoing investment just to keep things the way they are. U.S. utilities currently invest over US$20 billion per year replacing and modernizing their distribution infrastructure [10]. Figure 2-6 shows the annual costs for distribution systems for major U.S. utilities. In 2017, over US$20 billion was invested in distribution systems, and this number has been increasing since 1997.

On the other hand, in recent years, more and more distributed power has been generated, along the edge of the network, such as rooftop solar panels or wind farms. Electrification of vehicles, water heating, building heating, and other electrification also contributes to new customer needs and challenges to the grid, especially at the distribution level, which requires power system planning to change accordingly.

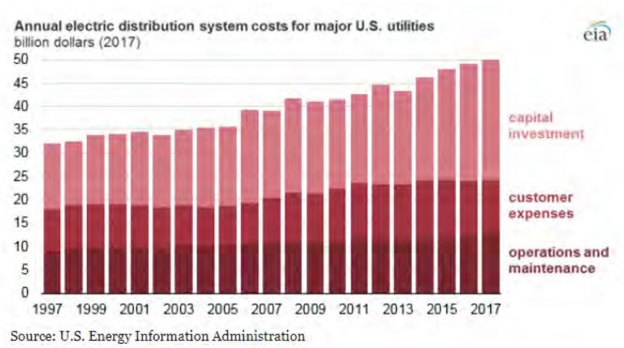
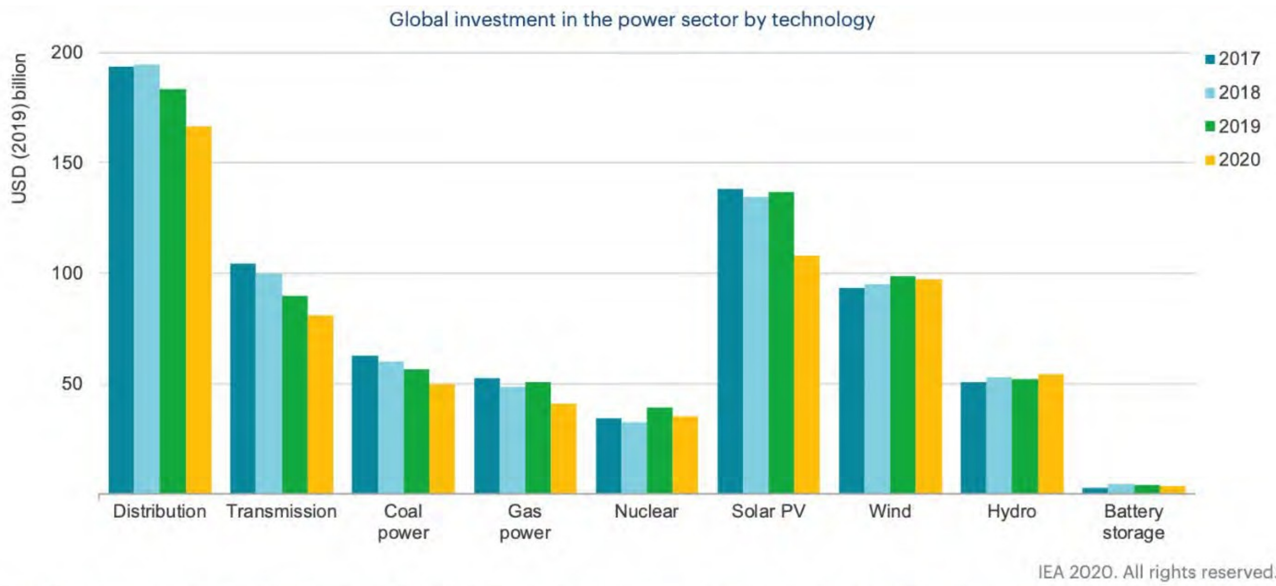


Figure 2-6. Annual electric distribution system costs for major U.S. utilities

Distribution systems, especially those in developing economies, often require substantial investment to upgrade and extend current networks. Global investment in the power sector has also echoed this point. Figure 2-7 shows that the distribution sector has had the largest share of investments. Much of the assets to transfer electricity (e.g., overhead lines, cables, switchgear, transformers, control systems, and meters) have long economic lives and require timely maintenance and upgrading to ensure long-term reliability and expansion of service [11]. For developing economies, while investing for expanding and upgrading electricity networks, identifying the key elements that should be considered when making investment decisions is critical, not only to meet the current needs, but also to prepare the grid for emerging challenges of low-carbon energy resources, increasing interactivity with customers, and new operational risks.

[7] The National Academy of Engineering has called the electric grid one of the greatest engineering achievements of 20th century.



Notes: Gas-fired generation investment includes large-scale plants as well as small-scale generating sets and engines. Hydropower includes pumped hydro storage.
Source: IEA analysis with calculations for solar PV, wind and hydropower based on costs from IRENA (2020).

Figure 2-7. Global investment in the power sector

2.2.3 NEW CHALLENGES FOR DISTRIBUTION SYSTEM PLANNING

Traditionally, distribution system planning has been centered on assessing current and planned infrastructure capacity, equipment conditions, and comparing that to the expected loads [12], to maintain safe, reliable, and affordable service. To identify where investments were needed to ensure adequate distribution system capacity and reliability, load forecasts were essential. Loads forecasts were based largely on historical data and information on known project developments (new customers and loads), for both short-term and long-term capital investment and operational change needs. DERs were largely considered as modifications to the load forecast, particularly when DER penetration levels were low. This situation is beginning to change with the rapid increase of DERs in the power system. Recent rapid technological advancements, policy initiatives, changing customer choices, and events such as COVID-19 have made the change more urgent.

- Rapidly increasing levels of DERs and other recent technologies put new pressure on the T&D grid. The grid planners, operators, and engineers face challenges in managing the complexity of the two-way power flow in the electric grid, as well as the opportunities of new capabilities provided by these technologies in enhancing the reliability and resilience of the grid.
- Evolving customer needs requires grids to enable consumers to have a greater control over energy costs and sources. The growth of DERs and their ability to be integrated into an increasingly intelligent grid is changing how customers meet their energy needs. The COVID-19 pandemic has accelerated the acceptance of working from home and access to reliable electricity services for customers has become paramount for consumers.
- Climate change and cyberattacks increase operational risks, which are changing the calculus for new investments. Climate change is expected to worsen the frequency, intensity, and impacts of some types of extreme weather events. In the United States, for example, wildfires have affected California's networks, blackouts have hit New York City, and coastlines have been battered by a

plethora of catastrophic hurricanes [13]. The frigid winter storms that swept across Texas in February 2021, caused the greatest forced power blackouts in U.S. history. In addition, across the Pacific Ocean, Zhengzhou, the capital of Henan province, experienced the most devastating floods in the history of the city in mid-July 2021.

- Grid-technology innovations are creating opportunities to drive value across T&D workflows [13]. Utilities in more advanced economies have already gone through several rounds of investments in grid modernization technologies, such as smart meters, grid management systems, asset-management platforms, and geospatial information systems. Crossing the boundaries of these systems by utilizing advanced cloud technology, software engineering models, and data-governance practices is the next step to maximize the value of the grid.

As a result of these shifts, distribution planning has become increasingly complex and is receiving more attention. Compared with traditional distribution system planning, the focus now is shifting to longer time horizons and a more holistic or integrated process, which requires more involvement by regulators, as well as other energy stakeholders, for identifying the key elements that should be considered when planning distribution systems to ensure the reliability and resilience of the grid.

3.0 THE NEED FOR RESILIENCE

A significant challenge APEC economies face are natural disasters; 70 percent of all global natural disasters occur within the APEC footprint. With this, there is an increased need for resilient electric distribution infrastructure. As APEC economies move toward modernizing their distribution systems, designing for improved resiliency along the way will be important, especially as climate change increases the frequency and intensity of severe weather [14]. This chapter discusses the concept of resilience in more detail, as well as how it relates to the distribution system.

Managing risk is an extremely important consideration for operating the electric grid successfully. When disruptions occur, power system operators try their best to reduce consequential impacts, as well as manage risks and acceptable consequences. Every grid operator wants to prevent or be prepared to bounce back from catastrophic damage that could cause outages for weeks or even months to reduce impact to societal burden. Being able to do so directly relates to the concept of power system resilience.

The National Infrastructure Advisory Council defines resilience as the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends on "the ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event" [16].

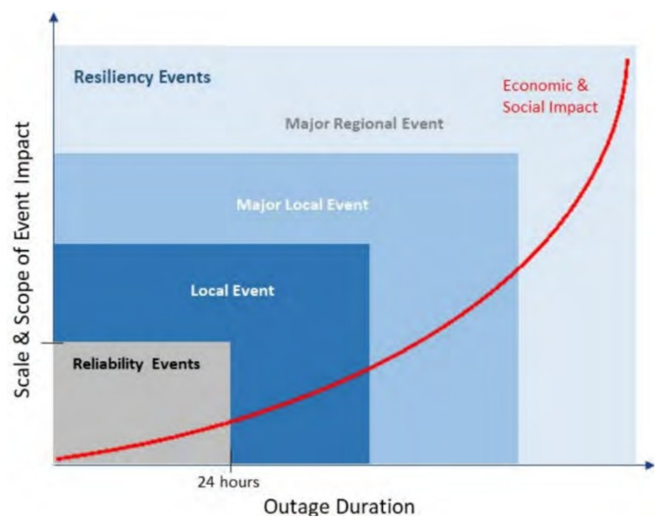


Figure 3-1. Economic and social impact with respect to type of event [15]

Resilience is the ability of the grid to resist degradation and to recover quickly from extreme natural or human-caused events [17]. It differs from the concept of reliability, which is a well-established component of electric grid planning, with metrics that are regularly used to measure reliability (e.g., SAIDI, SAIFI, etc.). Resiliency on the other hand, does not have metrics that are established or widely used. This is in part because there is not yet significant history or data on large-area, long-duration outages that can be used to guide system investments. A comparison of reliability and resiliency with respect to the scale and scope of event impact is shown in Figure 3-1.

When it comes to resilience, there is no one-size-fits-all solution, as every region has its own unique challenges, risks, and hazards. Electricity sector risks include weather-related emergencies, natural disasters, and becoming increasingly critical are cyberattacks. These different types of possible hazards and their approximated impact with respect to time to restore are shown in Figure 3-2. Another figure illustrating extreme events and their relation to the distribution network is shown in Figure 3-3.

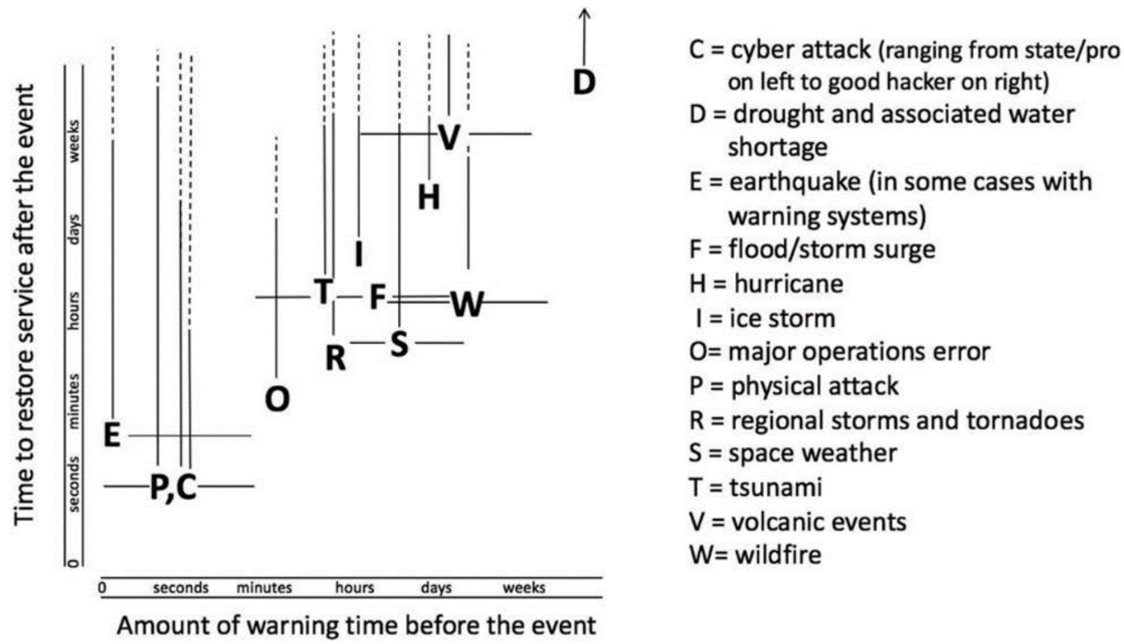


Figure 3-2. The many causes of grid failure, their approximate warning time before the event, and their approximate restoration time after the event [16]

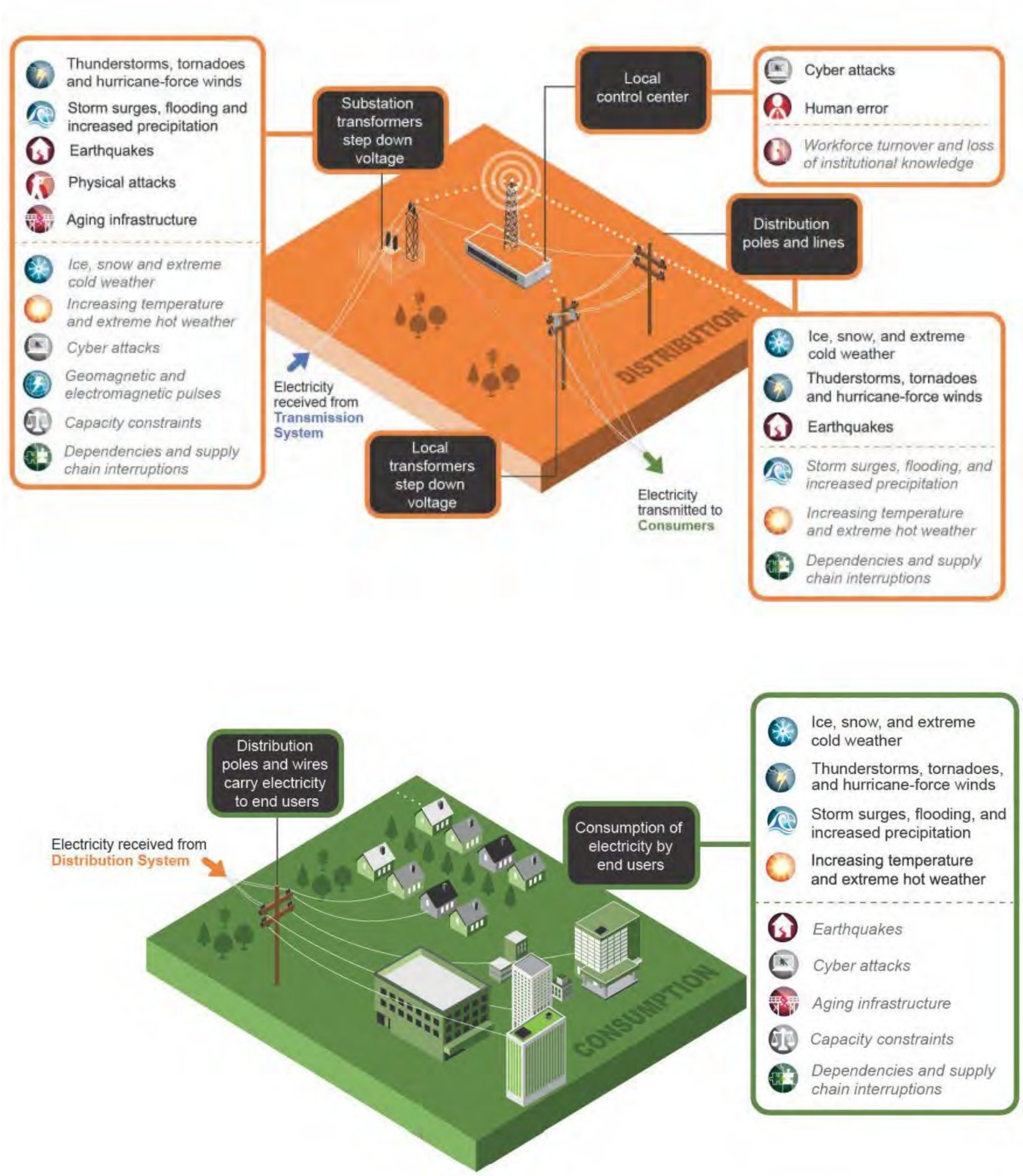


Figure 3-3. Extreme events that pose as threats, hazards, and vulnerabilities to the distribution system [18]

It is important for all APEC member economies to begin thinking about resilience and establishing critical infrastructure resilience goals. A framework to guide this effort is shown in Figure 3-4. This framework highlights the need to not only be robust, resourceful, and able to rapidly recover prior to and after a resiliency testing event, but to also grow from lessons learned and adapt practices to improve resiliency in preparation for the next extreme event.

Figure 3-4. A framework for establishing critical infrastructure resilience goals [19]

Lastly, the concept of resiliency is important to distribution networks and future grid modernization. Ways to increase resiliency in distribution systems are highlighted throughout this report, as improved resiliency is identified as a need for all APEC member economies. It is important to note that there can be many different resiliency solutions and scales of implementation. This is demonstrated in Figure 3-5.

Figure 3-5. A portfolio of resiliency solutions should be considered that compare solution to societal benefit [15]

4.0 KEY INTEGRATED DISTRIBUTION SYSTEM PLANNING ELEMENTS FOR RESILIENCE

Conducting distribution planning has become more complex as consumers and utilities adopt new technologies to manage the changes in consumer behavior and demand, as well as the increased need for resiliency.

This section will focus on key integrated distribution system planning elements APEC member economies need to begin considering. These elements were identified by applying the following criteria:

1. Elements that absolutely need to be planned for in advance
2. Elements that serve multiple benefits
3. Elements that are already being developed in APEC economies and demonstrate proven value.

Utilizing this selection criteria, extensive literature review was performed on distribution grid modernization and trends. After reviewing the contents of these materials, what resulted were six key elements that distribution power system operators, planners, and regulators should be considering. These key elements are listed below.

Recommended Key Integrated Distribution System Planning Elements

- Implementing Integrated Distribution System Planning
- Leveraging Distributed Energy Resources for Reliability & Resilience
- Planning for Electric Vehicles & Their Potential
- Increasing Situational Awareness
- Allowing for Microgrids
- Establishing Equitable Recovery Strategies

In the attempt to identify the most important elements, there were many other topics that could have potentially been added to this list. However, for the purposes of preparing this high-level and brief reporting material, the key elements identified above were determined to be the highest impact and most critical. Each one of these elements—their value and importance, implementation, technology and application readiness, and their varying levels of implementation in APEC member economies—are explored in the following sections. Each exploration reveals recommendations and suggested prioritization that all APEC member economies can benefit from.

4.1 IMPLEMENTING INTEGRATED DISTRIBUTION SYSTEM PLANNING

The purpose of electric distribution system planning is to assess needed physical and operational changes to the electric distribution system to maintain safe, reliable, and affordable service. Distribution planners must consider many factors and constraints as they work to forecast new growth, serve loads, and maintain reliability. While electric utilities have always engaged in some type of electric distribution system planning, it is becoming increasingly complex and receiving more attention due to the changing nature of the grid, increased interdependencies, and growing numbers of DERs.

Traditional distribution system planning has a short time horizon of one to three years and limited involvement by utility regulators; however, the focus is shifting to longer time horizons and a more holistic or integrated process, with greater transparency and more involvement by regulators and other energy stakeholders. It is becoming a more collaborative process whereby stakeholders can provide input and review projections, assumptions, and analysis results in a structured way. Integrated distribution system planning, in contrast to traditional distribution system planning, requires an evaluation of many interdependencies involving different aspects of planning. These interrelationships between planning for system resources, distribution, transmission, and operations are evolving.

> Integrated distribution system planning, in contrast to traditional distribution planning, requires the evaluation of many interdependencies between planning for system resources, distribution, transmission, and operations.

Regulatory bodies establish requirements or guidelines for distribution system planning, reporting requirements and frequency, and stakeholder engagement. Traditionally, regulators had minimal involvement in distribution system planning, as distribution system investments were relatively straightforward and included what was needed to address load growth and keep distribution systems operational. However, with integration of new technologies and an increase in DER penetration, the role of regulators in distribution system planning and the importance of transparency and stakeholder engagement have increased. Customers and other third parties can now be active participants in the distribution system by providing generation and/or managing loads in response to price signals or grid needs, so it is increasingly important that customers and third-party energy service providers be engaged in distribution system planning

Federal, regional, state/provincial, and local policy goals and utility business objectives set the context for distribution system planning and grid investments. Policies need to be considered in establishing goals for distribution system planning.

Figure 4-1 shows the stages of distribution system evolution and illustrates how complexity increases as distribution systems evolve from systems focused primarily on safety, reliability, and resilience to systems with DERs and customer microgrids, all the way to community microgrids and distribution markets. To address policy goals and move through the stages of evolution of the distribution system, a system view and structured approach are needed to address the layers of complexity, including enhancing grid architecture.

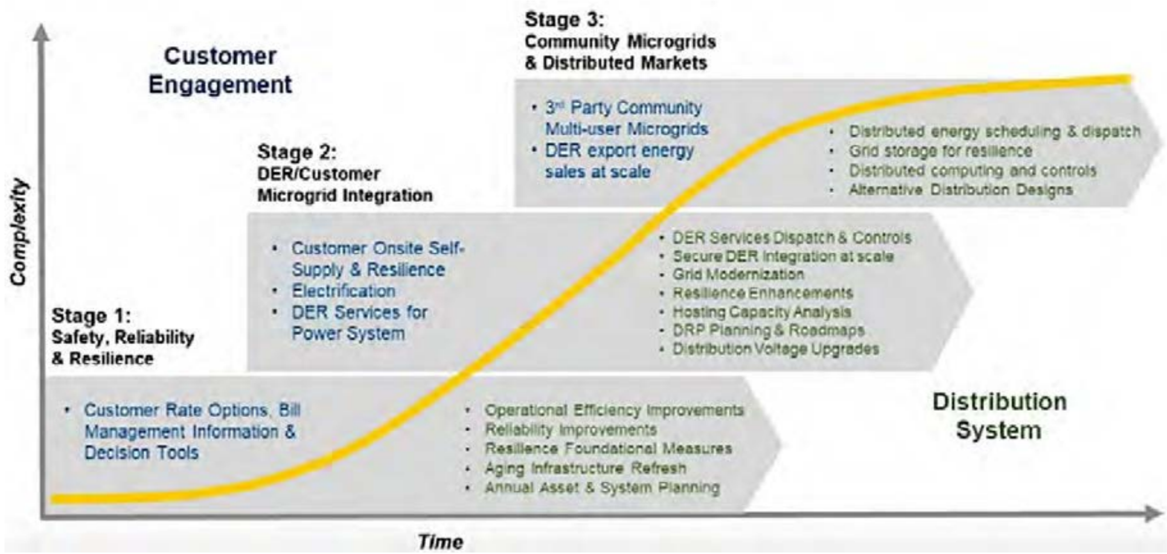


Figure 4-1. Stages of distribution system evolution [20]

4.1.1 VALUE & IMPORTANCE

Establishing transparent and integrated distribution system planning regulation and architecture will result in many new benefits and, therefore, makes this effort of great value and importance.

Distribution system investments are significant

In the United States, the Edison Electric Institute tracks and projects yearly spending by investor-owned utilities. Since 2018, distribution system investments have exceeded investments on generation and transmission. In 2020, distribution system spending was projected to be US$41 billion, or 30 percent of total spending by electric investor-owned utilities in the United States [21]. Given the size and importance of distribution system investments and the increase in customer and third-party alternatives, it makes sense that there is an increasing interest in improving focus on and transparency into utility distribution system investments and increasing regulatory and stakeholder engagement.

Reasons to take note of ***Integrated Distribution Planning:***

1. Distribution system investments are significant
2. Prioritization of investments is ensured
3. Regulators play an important role
4. Many new benefits will result
5. Improved grid architecture
6. Better management of DERs

Integrated planning ensures prioritization of investments

Transparent integrated distribution system planning and regulation can help ensure that prudent investments are made that leverage DERs and new technologies in a way that ultimately benefits customers equitably and helps achieve policy goals such as those associated with carbon reduction and deployment of renewables and enhancing resilience.

Regulators play an important role

Traditionally regulators supported electricity reliability through requiring utilities to report on reliability performance through measures such as SAIFI, SAIDI, and the Customer Average Interruption Duration Index. As carbon and renewable energy targets are applied and as jurisdictions are becoming increasingly interested in planning for system resilience, as well as reliability, regulators play an important role in ensuring utilities plan their grid systems, including their distribution systems, to meet those policy goals at the lowest cost and risk for customers.

Many new benefits will result

While integrated distribution planning may be more complex and time consuming to implement than traditional distribution system planning, it provides numerous benefits, including an increased and more granular understanding of the costs and benefits of DERs and grid modernization investments, while allowing utilities to accurately assess changing conditions and better evaluate future investments to maintain reliability, safety, and affordability. Specific benefits of transparent and integrated distribution planning guided through regulatory proceedings include

- Establishing the hosting capacity of circuits to identify the amount of DERs that can be managed on a feeder easily or where interconnection costs will be lower or higher.
- Allowing the utility to proactively identify and upgrade circuits that are likely to see DER growth to ease and speed deployment of distributed renewable resources.
- Providing information about the value of specific resources or services at various grid locations to guide developers and enabling utilities to develop incentives for customers and third parties to develop DERs in locations beneficial to the grid.
- Enabling the deferral of traditional infrastructure investments through non-wires alternatives (NWAs) that provide specific services at specific locations.
- Supporting emerging participation by consumers and third parties in proposing grid solutions and providing grid services.
- Helping support integration of utility or third-party-owned microgrids into distributions systems in a beneficial way.
- Helping utilities prioritize solutions and leverage third-party capital investments.
- Informing rates and tariffs.
- Increasing transparency around planned utility investments so regulators and energy stakeholders can weigh in before they are implemented and brought to the regulatory body for cost recovery.
- Providing opportunities for meaningful stakeholder engagement, which can improve outcomes.
- Allowing for the consideration of uncertainties under a range of possible futures.
- Supporting the consideration of both traditional and nontraditional supply- and demand-side solutions to minimize cost and risk.
- Providing an impetus for the utility to select and implement lowest cost/risk solutions.

Improved grid architecture

The importance of taking a holistic grid architecture approach to integrated distribution system planning is that it enables a systematic evaluation of customer needs and policy objectives and the required functionality, which serve as drivers for distribution system planning and investments. Through grid architecture, structural relationships can be determined, including between physical infrastructure; sensing, communication, control, computing, and information management systems; industry structure; market structure; and regulatory structure. Once these structural relationships are understood, processes and system designs can be developed that support holistic solutions and minimize unintended consequences [20]. Regulators play an important role in approving investments in enabling infrastructure build-out, such as two-way communication and control systems, metering, and safety equipment, which may not provide immediate financial benefit, but which can enable additional DER integration [22].

Recommendations for implementing ***Integrated Distribution Planning:***

1. Support regulating bodies in developing rulings
2. Start with integrated distribution system planning principles and objectives
3. Design grid architecture considering technology and utility analytics
4. Require utility stakeholder engagement
5. Require utility integrated distribution plan filings
6. Require utilities to conduct hosting capacity analysis and publish hosting capacity maps
7. Harmonize assumptions and projections between distribution, generation, and transmission planning
8. Address data privacy and data sharing

Better management of DERs

At higher levels of DERs, the net electricity demand and its characteristics can have material impact on the bulk power system operation. Distribution planning is performed outside the transmission planning process, and the aggregate impact of DERs may not be adequately studied. It is essential to align distribution system planning with generation planning and transmission planning as DER deployments increase.

4.1.2 IMPLEMENTATION

For APEC economies to increase focus on integrated distribution system planning and the importance of transparency, regulation, and architecture, the actions below should be considered.

Support regulatory bodies in developing rulings

Regulatory rulings, or dockets (a term used in the United States), are appropriate forums to explore needs and opportunities around integrated distribution system planning. Through a designated ruling, regulators can work with utilities and other stakeholders to 1) assess current practices for distribution system planning, 2) identify principles and objectives for an updated or advanced integrated distribution system planning process to achieve policy goals and/or address other discrepancies, 3) design a stakeholder engagement process for integrated distribution system planning, and 4) establish desired capabilities and functionalities for integrated distribution system planning and associated guidelines that support achieving the desired system requirements.

Start with integrated distribution planning principles and objectives

In a regulatory proceeding, start with principles and the objectives that integrated distribution system planning is being designed to support. Figure 4-2 shows a taxonomy proposed by the U.S. Department of Energy (DOE) for holistic grid planning and modernization. Principles and objectives drive capabilities, functionality, and system requirements. In regulatory proceedings on distribution system planning, it's important to start with principles and objectives rather than starting directly with system requirements or technologies. This foundational structure can support decision-makers at the onset of an integrated distribution system planning proceeding and can continue to provide benefits as parties consider the issues that arise during different phases of the planning process.

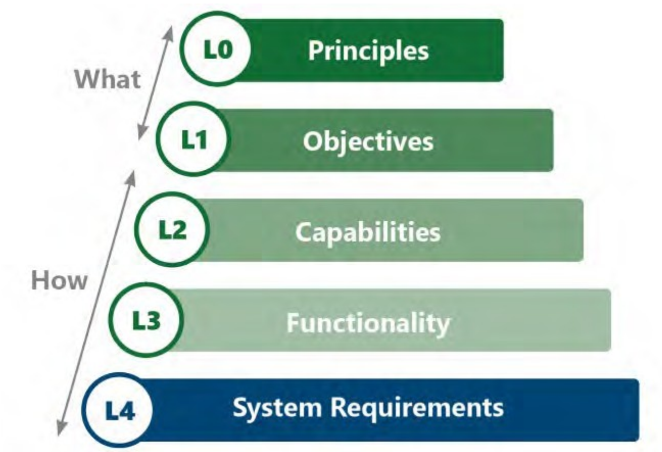


Figure 4-2. Integrated distribution planning framework [20]

Grid planning objectives and criteria are evolving, as shown in Figure 4-3. While, traditionally, distribution system planning objectives centered around reliability and cost, in many cases they are evolving to include integration of renewables, improving resilience, cybersecurity, climate change adaptation, and equity.

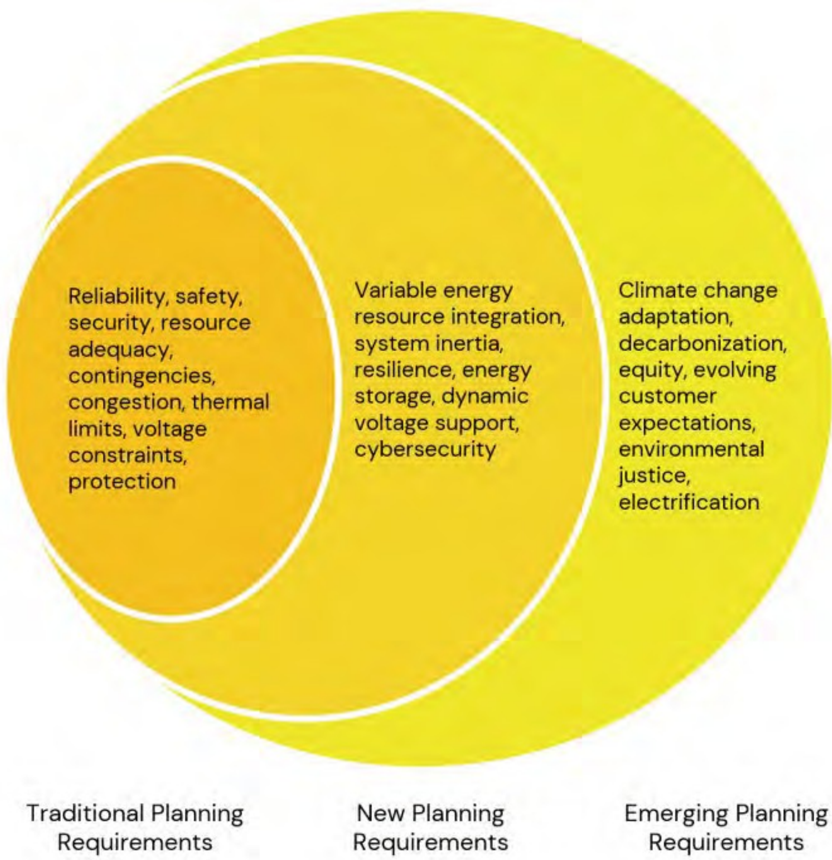


Figure 4-3. Evolving grid planning objectives

Design grid architecture considering advanced technology deployment and improved utility analytics

In grid architecture, it can be helpful to think about technologies as either core system components or applications. Figure 4-4 shows an architectural perspective of core components, which serve a supporting layer or platform for a variety of applications that can be built over time on the core components. In Figure 4-4, DER management, customer and market interactions, volt/VAR management and other advanced utility analytics are supporting applications that are enabled by core platform components of the physical grid, communication networks, sensing and control functions and data/information systems [20]. This report does not go into detail about all the potential functionality and applications described in Figure 4-4; however, it demonstrates the complexity and categorization of grid modernization technologies and applications. Regulators play a key role in approving investments in core system components, which may not pay for themselves, but may increase reliability and enable other capabilities that provide cost savings and support achieving policy goals, such as those associated with carbon and resilience.

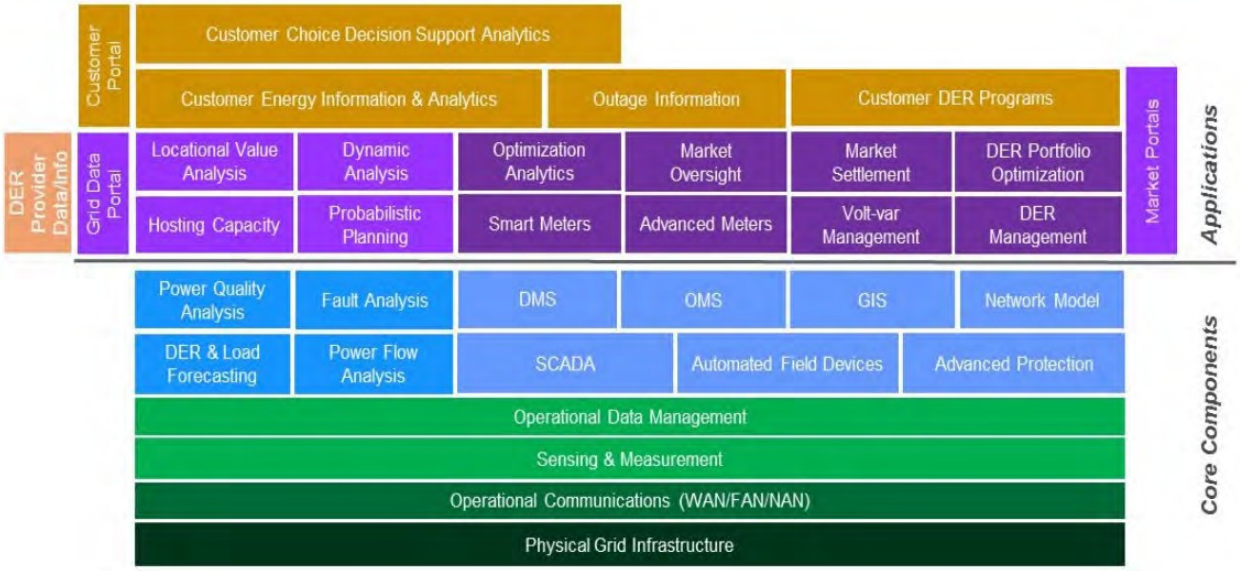


Figure 4-4. DOE Technology Stack showing core components and applications [20]

Require utility stakeholder engagement

Stakeholder engagement is an important part of transparent distribution system planning activities. By engaging with stakeholders, valuable data and information gathering can be used to guide effective regulatory policies. This can include issuing surveys or questionnaires to targeted stakeholders to understand current practices and needs at the start of regulatory proceedings on integrated distribution system planning [23], [24]. Once initial data and input is gathered, holding an initial stakeholder meeting to discuss needs, goals, and long-term vision to ensure transparency and collaboration can be considered. Additionally, hosting targeted presentations or trainings for regulatory staff and stakeholders, including review of integrated distribution system planning guidelines from other regions implementing such frameworks, can also be useful.

Require utility integrated distribution plan filings

As part of regulatory proceedings, regulators can develop guidelines and require utilities to make technical filings. Guidelines spell out what must be included by utilities in integrated distribution plan filings. These technical filings can be the mechanism for a full engagement and review of needs and planned investments. These filed plans should spell out utility grid modernization plans and/or grid needs assessments and should also incorporate and outline how utilities plan to implement smart grid technologies on their systems. These plans should also include distribution deferral opportunity reports, NWAs suitability criteria, and/or a list of NWAs opportunities. Requiring these guidelines to be publicly transparent and available can also highly valuable.

Require utilities to conduct hosting capacity analysis and publish hosting capacity maps

Hosting capacity is used to establish a baseline of the maximum amount of DERs an existing distribution grid (feeder through substation) can accommodate safely and reliably without requiring infrastructure upgrades. These hosting capacity analyses should be made available and visualized by an online map, so customers and third-party developers can understand the best places to interconnect distributed generation. By doing so, interconnection costs can be reduced for both the utility and interconnecting customers.

Harmonize assumptions and projections between distribution, generation, and transmission planning

A good place to start with distribution system planning is simply to ensure that assumptions and projections are consistent or harmonized between generation, distribution, and transmission planning activities. DER projections can impact net loads, which impact generation needs, distribution capacity needs, and, when levels get high enough, transmission system needs.

Address data privacy and data sharing

Addressing data sharing and privacy is an important part of distribution system planning with DERs. Addressing cybersecurity is also important. As advanced technology is deployed, such as smart meters, there are two types of data sharing concerns that need to be addressed. These include customer usage data and system data. Questions around whether individual and/or aggregated customer data can and should be made available to third-party service providers, with or without permission, should be addressed. In terms of system level data, identifying what level of detail can be made public or available to third-party service providers, such as hosting capacity maps utility capital investment plans, reliability statistics, load forecasts, historic loads, and/or queued distribution generation interconnection requests, should also be addressed. If data contains significant security concerns and constraints, this data should be withheld.

4.1.3 TECHNOLOGY & APPLICATION READINESS

Integrated distribution planning encompasses many different types of technology deployment planning and applications. The concept of integrated distribution planning is evolving and still not a widely practiced or recognized approach to distribution system planning among APEC regions. This section highlights applications related to new distribution system planning approaches for APEC economies to consider, as well as some emerging ideas, such as DSO, peer-to-peer trading, and transactive energy systems, that could be applied as a mechanism to integrate distribution and transmission operations with increased DER.

4.1.3.1 NEW DISTRIBUTION PLANNING APPROACHES

Integrated distribution planning introduces many new and different distribution planning approaches. To capture all these different types of approaches, Table 4-1 is a good example that illustrates the types of activities that state regulators in the United States are taking as they transition to integrated distribution system planning. These planning approaches include requiring formal distribution system plans, grid modernization plans, hosting capacity analysis/mapping, NWAs and locational value analyses, storage mandates or targets, benefit-cost methodologies, storm hardening considerations, and reporting of poor-performing circuits and associated improvement plans.

Table 4-1. Different distribution planning approaches in the United States, categorized by state [2]

Planning Approaches	States With Distribution Planning Requirements																								
	California	Colorado	Delaware	District of Columbia	Florida	Hawaii	Illinois	Indiana	Maine	Maryland	Massachusetts	Michigan	Minnesota	Nevada	New Hampshire	New Jersey	New York	Ohio	Oregon	Pennsylvania	Rhode Island	Texas	Utah	Vermont	Virginia	Washington
Distribution system plan requirement	●	●	●	●		●	●	●	●	●	●	●	●	●	●		●				●				●	
Grid modernization plan requirement	●					●					●		●		●		●									
Hosting capacity analysis/mapping requirement	●			●		●					●	●	●	●	●		●									
Non-wires alternatives / locational value requirements	●	●	●	●		●			●			●	●	●	●		●				●					
Storage Mandates or Targets	●										●			●		●	●		●						●	
Benefit-Cost Methodology / Guidance	●								●					●	●		●				●					
Storm hardening requirements					●					●															●	
Required reporting on poor-performing circuits and improvement plans		●	●		●		●			●	●		●			●	●	●	●	●	●	●	●	●		●

4.1.3.2 MODERN GRID ARCHITECTURE & THE DSO

Grid architecture combines the concepts of system architecture, network theory, and control theory with respect to the electric power grid. It is a high-level mapping of all functions and aspects related to grid operations. It covers all functions and involves entities that include everything from customers, distribution network, transmission network, generation, to regulating entities. Developing detailed grid architecture diagrams is a key tool to help understand and define the many complex interactions that exist in present and future grids.

Detailed documentation on what grid architecture is, the importance of these models, and how they can be developed can be found in PNNL's Grid Architecture report published in 2015 [25]. An example of what grid architecture looks like for a generic, vertically integrated utility in the United States can be found in Appendix B.

As distribution grids evolve with the increasing penetration of DER, deployment of new technologies, and new models of consumer engagement, changes to grid architecture will likely result. Distribution grid architectures may move toward a DSO model to more effectively manage and coordinate DERs and flexible loads with the bulk grid operation and marketplace, though the definition of this operating framework is still evolving. DSOs have the potential to untangle issues related to distributed reliability responsibility, as well as manage market interactions. A detailed example of a DSO structure can be found in Appendix C.

A DSO will become more important as DER adoption increases, as better described in Figure 4-5. A DSO would optimize the operation of the distribution system, like how the wholesale market operators optimize the operation of the transmission system to solicit bids from generating resources [26]. The

DSO model will achieve coordination between the distribution operator and the transmission/bulk power system operators, a key component to achieving integrated distribution system planning and operation [27]. This is a model that is not commonly in place today, as the business framework is still in development. However, varying levels of DSO functionality and models ("Minimal DSO" vs. "Maximal DSO") have been defined in the past several years [28].

Ultimately, a DSO model can improve integrated distribution system planning by supporting coordination between the distribution, transmission, generation, and operational aspects of the power grid. It will enable a transactive network for realizing that coordination. The concept of transactive energy and how it can be utilized for DER coordination is discussed more in the following section. The DSO model is an emerging technology, but it is important for all APEC economies to begin considering and preparing for it in advance.

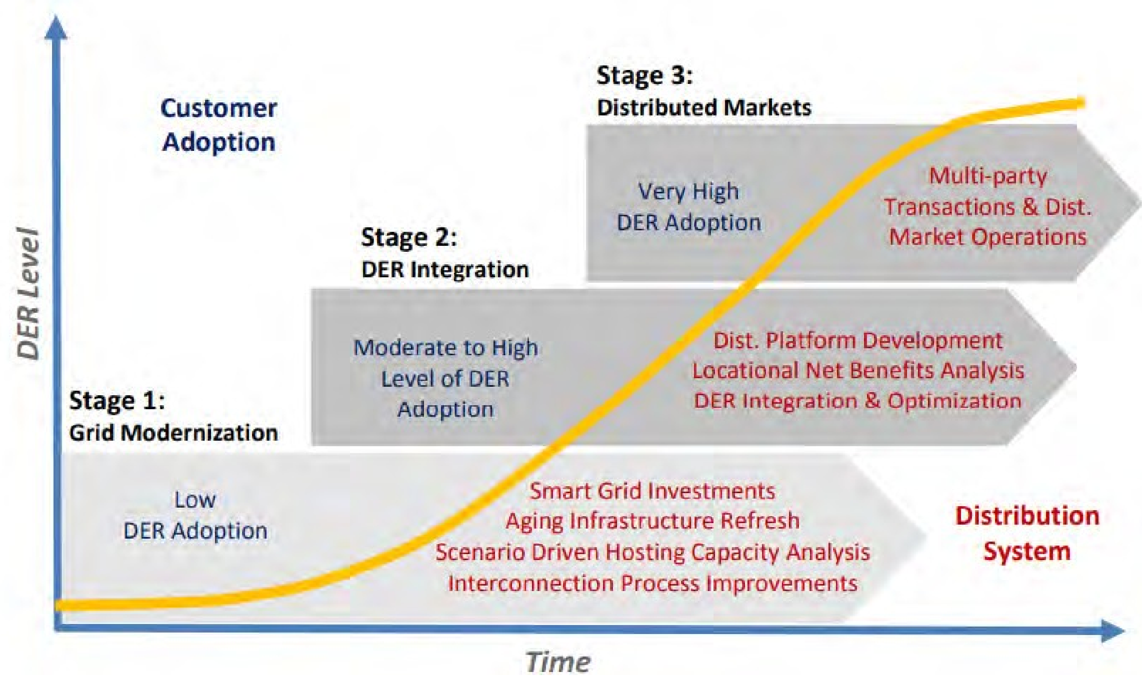


Figure 4-5. Stages of distribution system evolution toward establishing distributed markets that would leverage DSO models [28]

4.1.3.3 PEER-TO-PEER TRADING & TRANSACTIVE ENERGY

Peer-to-peer (P2P) trading has emerged as a next-generation energy management technique for smart grid that can enable prosumers to actively participate in the energy market, either by selling their excess energy or by reducing the demand of energy [29]. In Figure 4-6, an illustration of the P2P framework is shown.

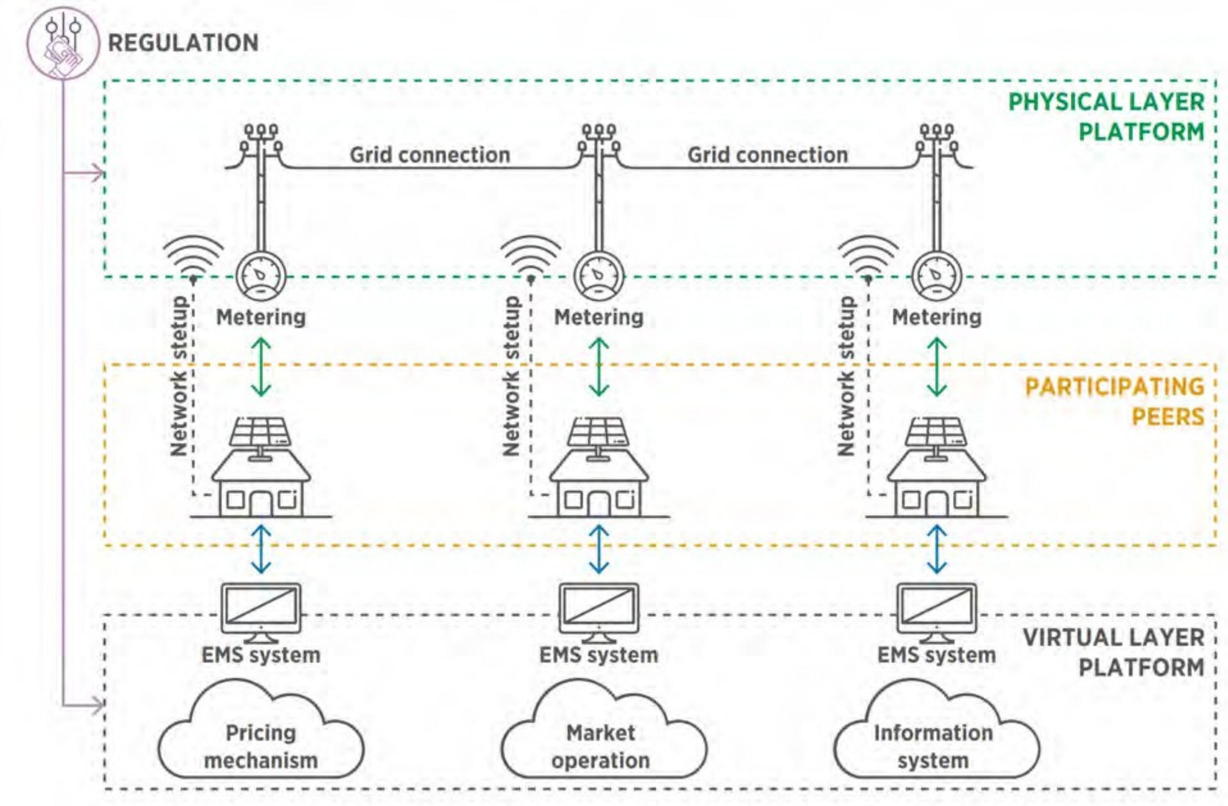


Figure 4-6. Illustration of P2P framework and communication between different elements [30]

Transactive energy systems are a class of systems in which economics and controls converge to address problems requiring control or coordination of a variety of assets in an electric power system [31]. The GridWise® Architecture Council (GWAC 2018) formally defines transactive energy systems as follows:

> **A system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter.**

Practically speaking, one can consider transactive energy systems as a means of engaging flexibility to offset variability. They are particularly useful in considering how to monetize the value propositions associated with DER integration. The challenge is to identify the specific basis for each value stream, the relationships between value streams, and the spatial and temporal dimensions of the problem. These considerations lead to both the basis for monetization—for example, avoided cost—and the identification of a specific transactive mechanism suited to the specific control and coordination problem being addressed. In many cases, a double-auction market as a transactive mechanism is well suited to the problem of creating incentive signals. A double auction refers to a market clearing process in which the buyers and sellers simultaneously submit their bids to buy and sell a commodity. The market clearing transaction occurs at the intersection of the demand and supply curves, revealing the market clearing price and the amount of commodity to be transacted. Double-auction transactive energy systems have been used in both distribution and bulk power systems to engage resources to help achieve various operational requirements of the power system, particularly for managing numerous variable DER assets.

Transitioning into an integrated distribution system planning process can better accommodate P2P and transactive energy capabilities.

4.1.4 APEC MEMBER DEVELOPMENTS

This section highlights APEC member experiences with integrated distribution planning. The economies highlighted include the United States, Thailand, and Australia.

4.1.4.1 UNITED STATES

Many states are exploring and implementing regulatory dockets that are requiring utilities to perform integrated distribution planning in its various forms.

In New York, the New York Public Service Commission required utilities to develop and file an initial integrated distribution system plan outlining current planning, operations, and administration and near-term actions utilities can take to meet jurisdictional energy or policy goals. Guidelines required that more detailed plans be developed and filed addressing future needs and investments [32]. They are also requiring utilities to develop and file stakeholder engagement plans prior to submitting technical distribution system plans.

In distribution system planning dockets in the United States, many states are requiring utilities to consider alternatives to traditional poles and wires investments. These are often referred to as non-wires alternatives, or NWAs. Some regulators require utilities to establish NWA suitability criteria that can be applied to traditional distribution system investments during the capital planning process to determine whether those investments are good candidates for NWAs. Regulators can consider requiring utilities to file reports outlining planned investments and NWAs (or distribution deferral opportunities, as they're referred to in California). In New York, utilities are also required to publish lists of potential NWAs online, as determined from applying the suitability criteria, and issue requests for proposals for third parties to propose NWAs to those traditional distribution system investments that meet suitability criteria.

Additionally, states such as California, Hawaii, Michigan, Minnesota, Nevada, and New York are requiring utilities to conduct hosting capacity analysis of their distribution system feeders and publish hosting capacity maps online, so customers and third-party developers can understand the best places to interconnect distributed generation. An of example of a hosting capacity map can be found for in New York, made publicly available by National Grid [33].

To address privacy and security concerns around data, the U.S. Commissions are addressing data accessibility in distribution planning proceedings because they recognize that limited data visibility can lead to inefficient customer and grid investments. In some cases, customer data, with permission, is being shared with third-party service providers or aggregated customer data is being shared if it meets what is being called a 15/15 rule. This is that an aggregate sample of customer data that is shared must have more than 15 customers, and no single customer's data may comprise more than 15 percent of the total aggregated data. System level data is also being shared, in some cases, to support customer and third-party solutions. An example of this is sharing hosting capacity maps online and/or locations or potential NWAs. In some cases, utility capital investment plans are being shared, reliability statistics, load forecasts and historic loads, and queued distributed generation. Each state is addressing data sharing and privacy in a different way. In some cases, data is not being shared due to security constraints.

4.1.4.2 THAILAND

In 2018, P2P energy trading was trailed in an urban precinct of Bangkok, Thailand [30], [34]. The system relied on roof-top solar with co-located energy storage, covering approximately 20 percent of the distribution system overall electricity needs [34]. In this configuration, the Thai distribution system utility, Metropolitan Electricity Authority, allowed access to their network for the physical energy transactions and for gathering metering data for customer billing.

The successful demonstration of P2P encouraged Thailand's Energy Regulatory Commission to consider "suitable regulation of peer-to-peer trading (depending on market regime)" from 2020 onwards. Some of the key success factors identified included early engagements and collaboration with the Electricity Generating Authority of Thailand, who operate and manage the transmission system, and the Metropolitan Electricity Authority, who manage the distribution system [35].

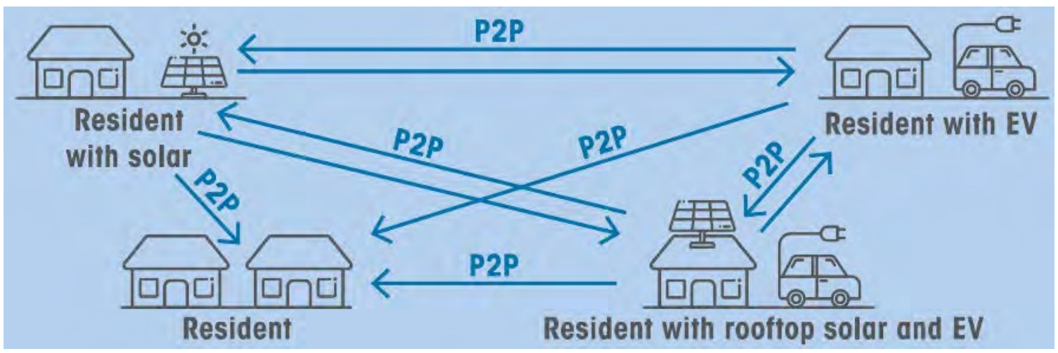


Figure 4-7. Concept of P2P trading implemented in Thailand [30]

4.1.4.3 AUSTRALIA

Australia leads the world in DER penetration, specifically photovoltaic (PV), for small, mostly residential, rooftop solar [36]. This magnitude of impact is illustrated in Figure 4-8. Electric utilities in Australia have been exploring methods to allow customers to realize the value of household storage and solar PV by trading these resources with other customers, electricity networks, and the wholesale market. A significant amount of DER interconnections is expected in Australia, as exemplified in Figure 4-9. Record low demand during times of high solar output is already being experienced in many parts of the economy. Enabling DER participation in the market can help manage the challenges they introduce and improve overall system flexibility.

In the Electricity Network Transformation Roadmap for Australia, the critical role of an integrated grid by enabling a connected future of multi-directional exchanges of energy, information, and value was identified [37]. In this roadmap, one of the milestones to accomplish an integrated grid is to establish the technical and procedural requirements of a DSO model for increased visibility, communication, and coordination between the independent market operator and the DSO.

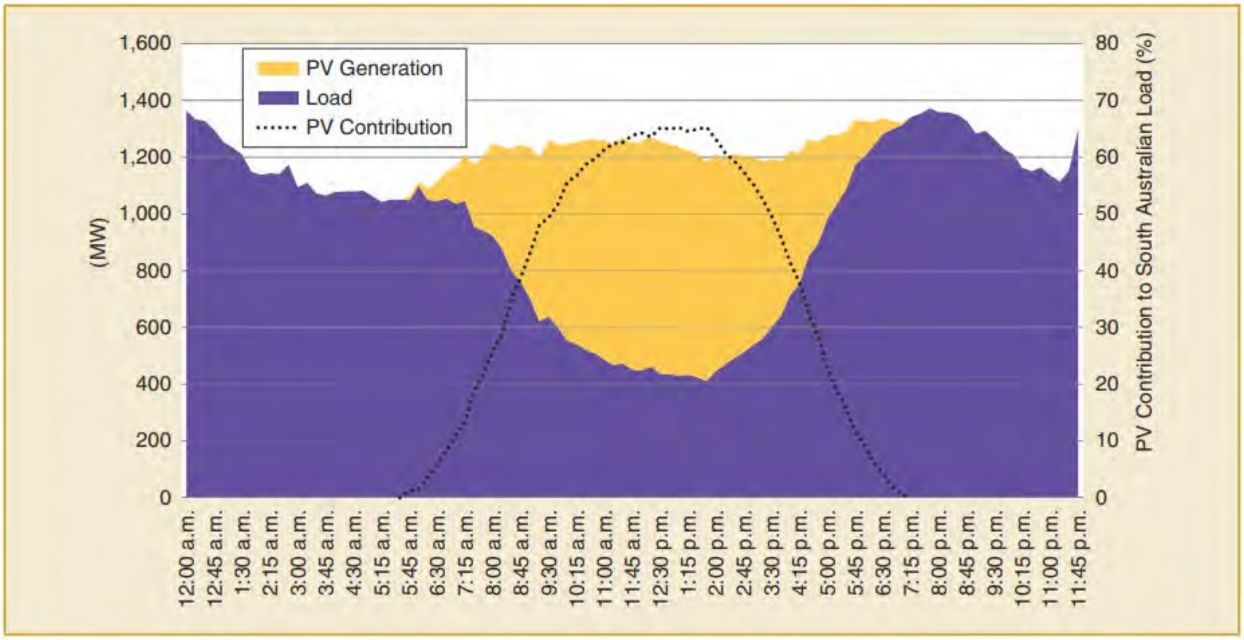


Figure 4-8. Rooftop PV generation in Australia compared to electric load demand on a minimal load day [36]

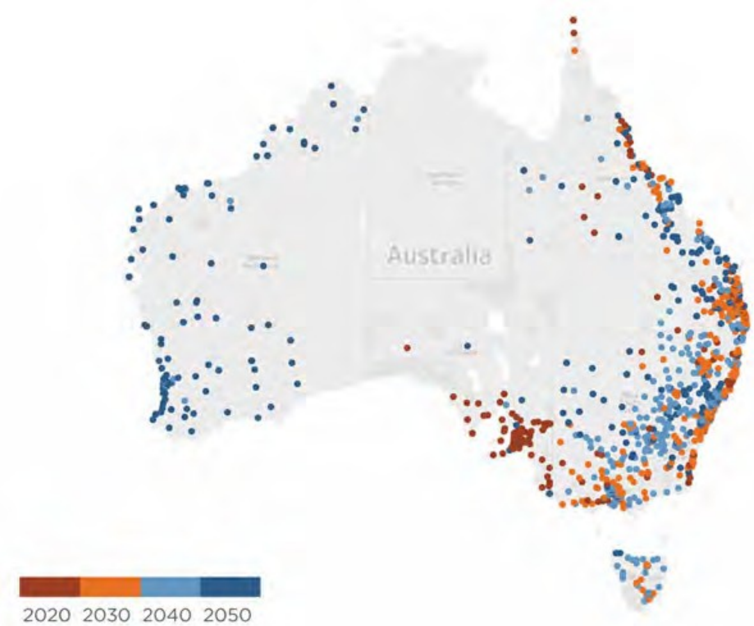


Figure 4-9. Distribution substations in Australia projected to experience reverse power flow from rooftop solar [37]

4.1.5 KEY TAKEAWAYS & RECOMMENDATIONS

Capital expenditures for distribution system upgrades and modernization are rising and, therefore, the importance of distribution systems is being recognized by the fact that it is the highest investment of capital expenditures in many APEC economies. As the distribution system evolves and begins accommodating a larger penetration of DER, newer technologies, and increased access to communication infrastructure, integrated distribution planning will become an essential strategy for ensuring reliability and resiliency is intact and improves. Regulatory bodies in APEC economies should begin supporting the development of integrated distribution system processes that consider data acquisition from utilities and stakeholders, utility guidelines and directional support, utility submittals of grid modernization plans and needs assessments, as well as requiring increased transparency by having utilities make grid modernization plans publicly available and open to stakeholder feedback. In addition, an important part of integrated distribution planning practices will be a harmonization of assumptions and projections between distribution, transmission, and generation resource planning. APEC members should be aware of emerging technologies and market mechanisms, such as a DSO model, that can support integrated distribution system planning.

> Distributed energy resources can be physical or virtual assets connected to the distribution power grid, including roof-top solar, energy storage, demand response, energy efficiency, and electric vehicles.

Therefore, recommendations for policy and regulating entities, as well as distribution planning entities, are the following:

Recommendations for Integrated Distribution System Planning	
Policy and Regulating Entities:	Develop rulings to require development of **integrated distribution system planning processes** that are also publicly available, transparent, and provide a balanced/fair opportunity for technology deployment/adoption.
Distribution Planning Entities:	Establish and document integrated system planning processes and needs assessments required for grid modernization and **allow these plans to be publicly transparent** and eligible for stakeholder feedback.

4.2 LEVERAGING DISTRIBUTED ENERGY RESOURCES FOR RELIABILITY & RESILIENCE

DERs are physical or virtual assets that are connected in some way to the distribution power grid. They include co-generation resources, rooftop solar, energy storage, demand response, energy efficiency, and EVs. They can be used individually or in a coordinated manner to provide value to the grid and nearby customers. It is essential for distribution planners to understand the expected growth and potential for DERs in advance of significant levels of penetration. DERs can serve multiple benefits that increase power quality to customers, as well as achieving resiliency goals if planned for and managed appropriately. Additionally, many APEC economies are already experiencing and have incorporated practices to plan, integrate, and manage DER penetration to meet their unique challenges. This section will elaborate on how DERs and their promising capabilities, especially when coordinated, can be leveraged to enhance distribution planning practices and, in the long run, improve overall system flexibility and resilience. Even though EVs are considered DERs, they will be discussed in more detail in section 4.3.

Reasons to take note of ***Distributed Energy Resources:***

1. Consumer behavior is a driving force in growing penetration
2. Two-way power flow is introduced
3. Distribution services can be enhanced if leveraged appropriately
4. Increased reliability and resilience can be achieved

4.2.1 VALUE & IMPORTANCE

DERs are of great value and importance for several reasons, and some of these are highlighted below.

Consumer behavior is a driving force in growing penetration

Consumer behavior is a significant driving force behind increasing interconnections of DERs in the APEC member regions. Therefore, distribution planners should be continuously monitoring the level of DERs interconnection activity, as well as its projected growth, to identify where system improvements are needed. A distribution utility may need to perform system upgrades in advance of DER interconnection to mitigate delayed processing time and increased costs.

Two-way power flow is introduced

The concept of two-way power flow, also described as multi-way power flow, on traditionally radial distribution networks introduces a new operating paradigm that will require a variety of new analytics, communications, and situational awareness. A distribution planning entity cannot let interconnection of DERs go unmanaged, as historical distribution infrastructure was not built to handle power injection from resources other than the main grid connection. DERs introduce new operational and safety challenges that need to be addressed. Two-way power flow may require a reevaluation of the organizational and engineering challenges associated with managing the electric grid [38].

Distribution services can be enhanced if leveraged appropriately

Flexible DERs can be used to optimize investments for grid modernization, operations, and markets. With respect to system investments to improve power quality for consumers, if planned for in advance, DERs with inverter-based technology can be used to provide reactive and active power control on distribution networks and drastically expand hosting capacity of additional DERs. This would mitigate traditional and costly system upgrade solutions [39]. In additional, where thermal violations occur due to growing electric demand, DERs, such as energy storage and/or a DERMS, could be leveraged as an alternative to mitigate expensive reconductoring or replacement of over-dutied equipment.

Increased reliability and resilience can be achieved

By investing in the infrastructure needed to safely interconnect, monitor, and control DER, distribution planners can improve the reliability and resiliency of electricity to their customers. This is because DERs provide energy services to consumers locally, and dependency on energy from the transmission network is relied on less. DERs are especially useful resources to leverage during extreme events (natural disaster or man-made threats), particularly when DERs are coordinated all together, to ensure electricity continuity.

Recommendations for accommodating ***Distributed Energy Resources:***

1. Build distribution system to manage two-way power flow
2. Utilize energy storage for improving reliability and resiliency
3. Implement advanced load forecasting tools
4. Utilize demand response and energy efficiency programs
5. Manage the "Duck Curve"

4.2.2 IMPLEMENTATION

Physical DER asset interconnections throughout APEC economies are occurring at a significant rate, as it is primarily driven by consumer behavior, as well as energy and environmental goals. To facilitate safe and reliable interconnection of roof-top solar and other distributed generation resources, most distribution system owners and planners have procedures in place for generator owners to apply and gain approval by the utility prior to energization. Despite this, in many regions, distribution planners are finding it a challenge keeping up with the number of applications they are receiving, straining engineering resources to ensure each one is studied sufficiently. Hence, to implement a successful facilitation of DER interconnection, distribution planners should have tools in place to forecast when and where higher levels of DER penetration are expected to ensure the appropriate resources are in place to review and approve these interconnections.

Build distribution system to manage two-way power flow

Increased number of small-scale generating resources on the distribution network, such as behind-the-meter roof-top solar, is changing how the distribution system has historically operated. Two-way power flow on the radially built distribution systems challenges aging infrastructure that was designed to handle one-way power flow (from the bulk power grid to the electric load). Despite these challenges, generating DERs provides localized energy sources, reducing energy transmission needs on the bulk power grid, as well as serving as backup sources of electricity when power from the bulk power grid is lost. Therefore, encouraging consumer and distribution utility deployment of DERs can provide additional reliability and resiliency benefits, if managed appropriately.

Utilize energy storage for improving reliability and resiliency

DER's that are inverter-based resources can provide additional reliability and power quality benefits to the local distribution network and bulk grid. Distributed energy storage infrastructure is particularly useful, as they can provide essential reliability services, such as frequency response, ramping support when solar ramps down in the evening, voltage support, and evening peak load shaving [40]. Energy storage has a unique capability to complement other DERs by addressing concerns with the uncertainly of variable energy resources. Additionally, energy storage is a key enabling technology in resilience applications [41].

Implement advanced load forecasting tools

Physical DER assets could also include EVs. Not yet widely implemented, due to lack of foundational technology, is V2G charging, which can improve system reliability, flexibility, and resiliency. This concept is discussed more in section 4.3. A major challenge here is that EVs usually do not need to go through a utility interconnection application process to connect to the distribution system and charge. Therefore, distribution planners may not receive an early notice of when and where EVs are to be charging until after the fact. This again points to the need for advanced load forecasting tools to predict when and where EV loads are to occur on the distribution grid and what their charging behavior might be.

Utilize demand response and energy efficiency programs

Virtual DER assets, such as demand response and energy efficiency programs, can be leveraged to manage load growth and changes in load demand characteristics, or profile, throughout the day. Load profiles that a distribution planner sees today may be significantly altered within the 10-year horizon, when more roof-top solar, EVs, and usage of electric appliances in urbanizing areas increase. Distribution planning should be working to identify how load growth is going to change and how demand response and energy efficiency programs can be used to manage these and reshape load profiles, if needed, to ensure system reliability and resiliency.

Manage the “Duck Curve”

An example of how high penetration of roof-top solar in California is significantly changing the shape of electric demand throughout the day is shown in Figure 4-10. This phenomenon has been named the “Duck Curve.” When the sun goes down in the evening, the high penetration of daytime solar begins to ramp down, which in turn requires a significant amount of generator ramping to serve the evening peak demand. This type of operation strains the distribution and transmission systems and puts the system at higher reliability risks.

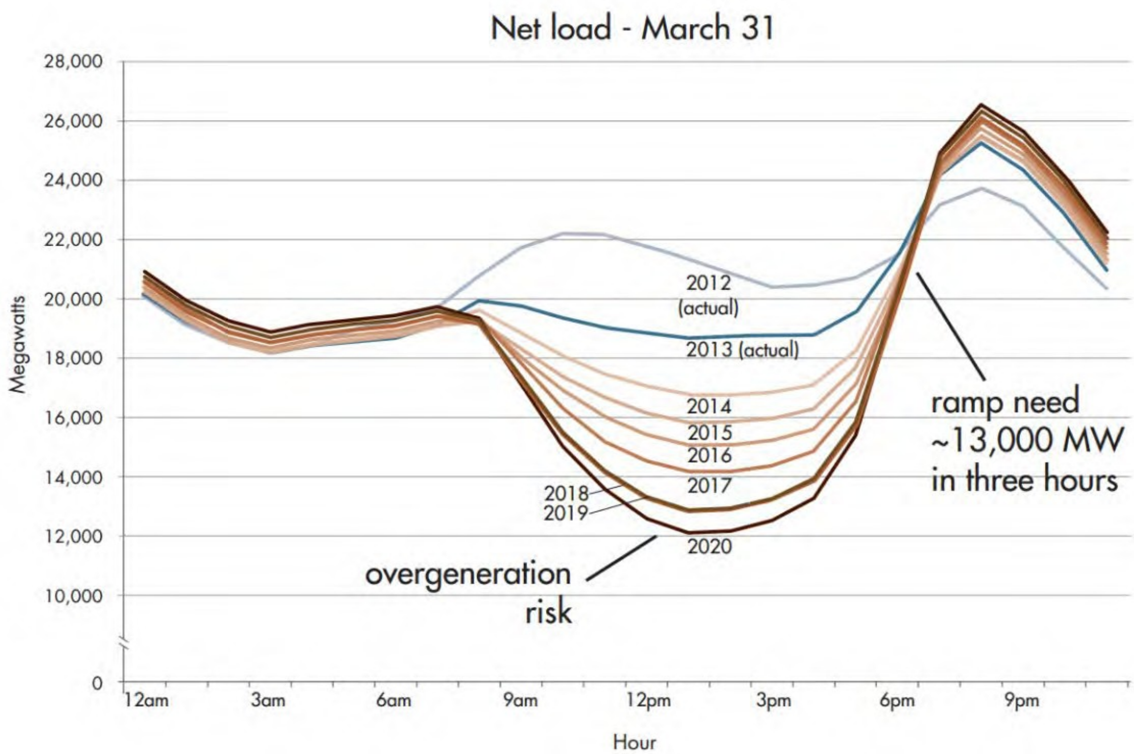


Figure 4-10. California "Duck Curve" illustrating how high penetration of solar, including DER rooftop solar, during the daytime reshapes the daily electric net load or load profile [42]

For these reasons, forecasting and managing physical and virtual DER, in a sophisticated and coordinated way, will be an important consideration for distribution planning entities to implement. These technologies are discussed in the next section.

4.2.3 TECHNOLOGY & APPLICATION READINESS

As DER penetration continues to increase, it becomes more and more important to monitor system hosting capacity and ensure that DERs can be interconnected without adversely impacting power quality or reliability under existing infrastructure. Several tools and technologies have been developed, and are being developed, to address this need.

4.2.3.1 DER LOAD FORECASTING TOOLS

DER forecasting tools encompass prediction of when and where DERs will interconnect, as well as tools that can provide hourly load forecasting for DERs. DER forecasting is a recognized need for modern distribution planning practices. However, there is not yet an established best practice forecasting tool. A comprehensive load forecasting tool requires complicated data requirements, reliable software packages, and advanced statistical methods to predict load growth and DER penetration, much of which is driven by consumer behavior in the region of interest [38]. There are many data sets that distribution planners can use to develop forecasting models. Forecasters can use data sets from multiple sources, including utility and non-utility data sources (such as census data, county data, etc.), as well as data sets used to understand how policy and rate changes may influence customer adoption [39]. Advanced DER forecasting tools require detailed granular, location-based, circuit-level models; however, given the limited availability of data among different distribution systems, technology vendors have encountered challenges in a developing a standardized approach to DER forecasting [38]. As of right now, DER forecasting models have largely been custom developed by distribution planning entities to meet their near-term and unique local needs.

An adoption maturity analysis for forecasting tools was conducted by DOE's Office of Electricity. Figure 4-11 is from this analysis and shows that DER forecasting tools are in the "Early Commercial Deployment" of technology readiness.

It is important for APEC economies to understand the importance of forecasting DERs and to begin or continue to invest and encourage distribution system planning entities to incorporate advanced load forecasting tools.

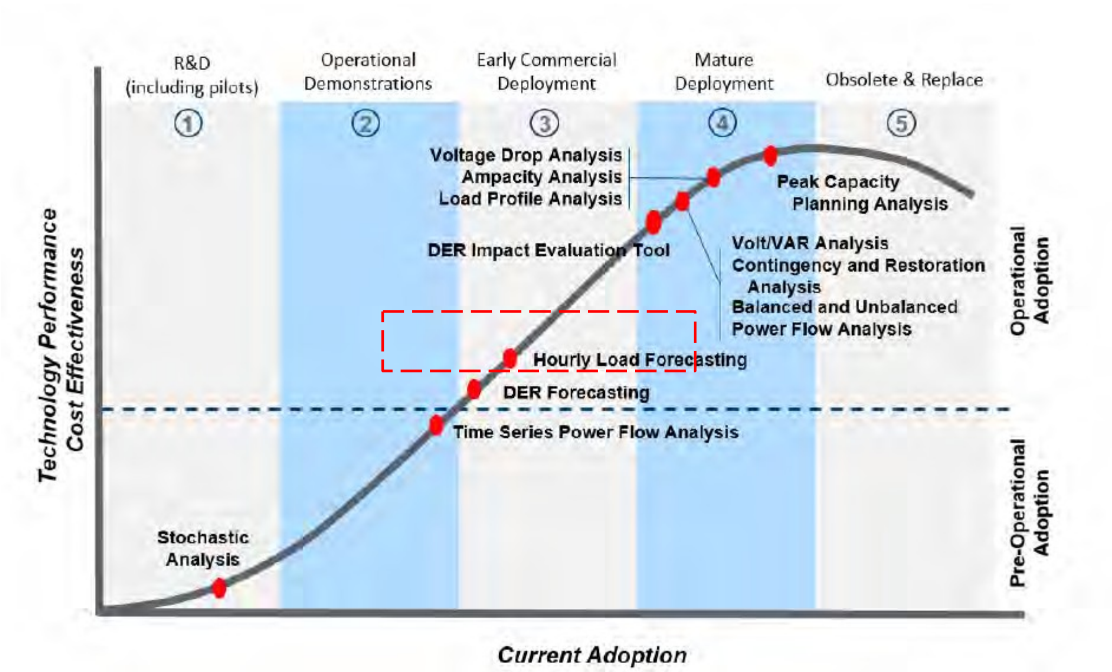


Figure 4-11. Adoption maturity analysis for DER forecasting tools [38]

4.2.3.2 ENERGY STORAGE

Although a DERs itself, energy storage, such as batteries, is a technology that can play multiple roles and be deployed to effectively integrate high levels of renewable DER penetration to increase overall reliability and resiliency of distribution systems [43]. They can be a key enabling technology that increases system resilience, as well as an alternative to traditional distribution network reinforcement. They can help offset the variability renewables introduced and can provide various other grid services that can improve performance and power quality. They can also be effective in microgrid conditions, increasing resilience during extreme events [41]. With respect to interconnections at the distribution system level, energy storage is usually seen deployed as behind-the-meter batteries with rooftop PV or as utility-scale batteries.

There are various types of energy storage technologies, as identified in a 2020 DOE energy storage market report [44]. Li-ion batteries are the fastest-growing rechargeable battery segment, with global sales doubling between 2013 and 2018.

An example of energy storage dispatch, with coordination of solar generation to ensure electric load is served in grid-connected and microgrid modes, is demonstrated in Figure 4-12.

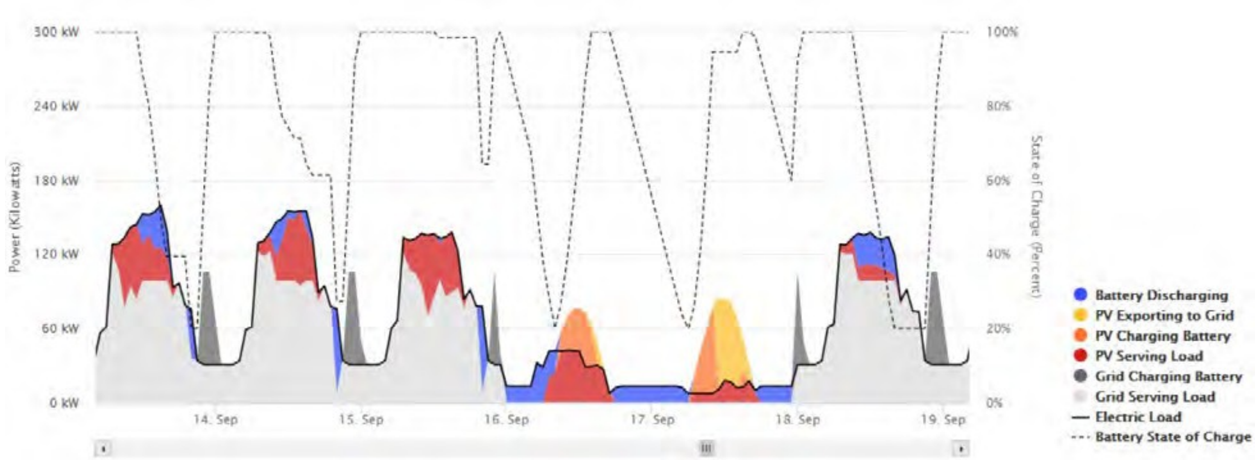


Figure 4-12. Example of critical electric load met by combination of solar PV generation and energy storage under grid-connected mode (September 14 and 15) and microgrid mode (September 16 and 17) [45]

4.2.3.3 DERMS

Distributed Energy Resource Management System (DERMS) is a powerful software-based solution that can be used to monitor, optimize, and dispatch DERs with coordinated management. It is a software solution that incorporates a range of operations to adjust the production and/or consumption levels of disparate DERs [17]. DERMS can communicate directly to different DER devices located on the distribution system, as well as monitor system conditions. DERMS functionality can enable flexible interconnection and active network management, such that DER interconnection customers can avoid paying for upgrades and the utility can, in turn, benefit by system upgrade deferrals. However, in addition to utilizing DERMS to operate DERs with a focus on mitigating distribution interconnection constraints, this system can also be enabled to communicate different operating modes to DERs to provide energy and/or reserve resources, energy regulation, customer islanding, or market participation [39]. A basic DERMS framework is show in Figure 4-13.

DERMS systems deployed to date, along with their functionality, are still being defined, and they are highly dependent on existing communication protocols and customer interfaces that make each implemented application unique [38]. DERMS configuration and design may differ drastically from one region to another, due to different consumer behaviors, operational requirements, and system constraints. DERMS can also be utilized to create virtual power plants that aggregate the output and control of many DERs connected to the system to behave similarly to a power plant [46]. The lack of uniformity of such an application is a significant gap. However, that makes this technology a powerful tool that can be leveraged to meet the unique local reliability and resiliency needs. Industry is moving toward a single unified system to manage all DER services, including demand response. Figure 4-14 illustrates the key DERMS capabilities that DERs can support.

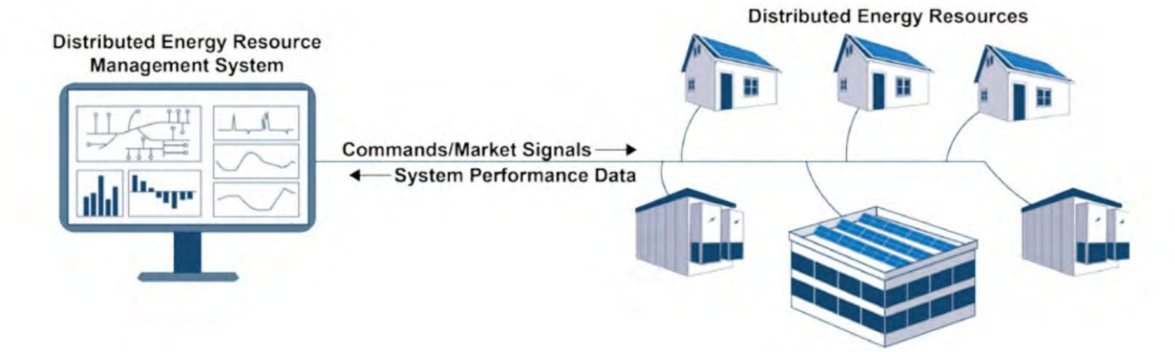


Figure 4-13. Basic DERMS framework [47]

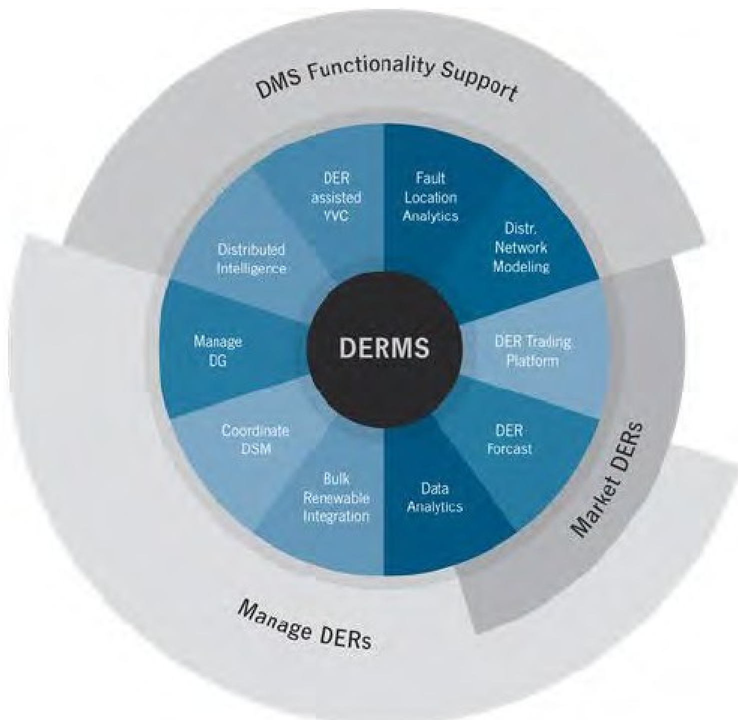


Figure 4-14. DERMS capabilities [38]

An adoption maturity analysis for DERMS was conducted by the DOE Office of Electricity. Figure 4-15 is from this analysis and shows that DERMS is in the “Early Commercial Deployment” of technology readiness.

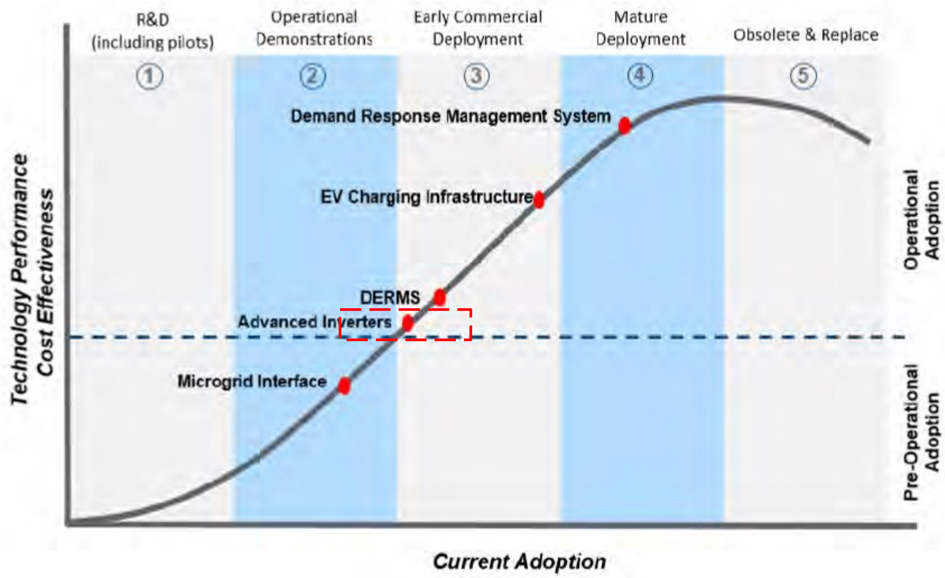


Figure 4-15. Adoption maturity analysis for DERMS [38]

It is important for APEC economies to begin investing in foundational elements to enable DERMS technology, as the potential for such to minimize costs and increase reliability and resiliency is significant.

4.2.4 APEC MEMBER DEVELOPMENTS

This section highlights APEC member experiences with managing DER. The economies highlighted include the United States, Australia, Viet Nam, and Japan.

4.2.4.1 NEW YORK, UNITED STATES

An emerging model in New York attempts to address the locational value of distributed investments, through a Value Stack tariff (called VDER) that compensates DERs based on location, in addition to compensating distributed generation based on energy, capacity, environmental benefits, and demand reduction. In this model, utilities identify locational system relief value (LSRV) zones where the system would benefit from more distributed generation. Projects developed in those LSRV zones are subject to additional compensation because they help to serve a grid need. Figure 4-16 below shows LSRV zones for ConEdison in New York.

Figure 4-16. ConEdison in New York's locational system relief value zones, indicating where system would benefit from more distributed generation [48]

4.2.4.2 CALIFORNIA, UNITED STATES

California exhibits numerous examples of state government dockets and proceedings to bolster the integration and management of DERs. These include incentive proposals for electric vehicles, energy storage, and Distributed Energy Resource Management Systems [49]. California utilities are working to increase DER deployment through pilot programs that allow utilities to collect 4% of their expenses annually if they can demonstrate that investments can serve the purposes of electric reliability and defer traditional infrastructure investments [49].

Due to the significant penetration of DERs in California, Pacific Gas & Electric (PG&E) deployed a DERMS demonstration program in 2016. In this use-case, DERMS was configured to enable utilities to use DER operational data and capabilities to issue commands, based on market signals and grid conditions, to the DERs to mitigate distribution system impacts and provide grid services [50]. An example of PG&E's DERMS demonstration software interface is shown in **Error! Reference source not found.**.

Between 2016 and 2018, PG&E demonstrated technical feasibility of their DERMS system to coordinate DERS to provide distribution grid services. However, in 2019, after extensive collaboration with DER providers, vendors, and industry leaders, PG&E concluded that a comprehensive DERMS software is not yet readily available [51]. From this report, some other key takeaways, and recommendations for implementing DERMS included

- Additional investment in foundational technology, including improved data quality, modeling, forecasting, communication, cybersecurity, and DER-aware advanced distribution management system to address near-term impacts of DERs is needed to successfully enable DERMS
- Methods to ensure sufficient DER volume, availability, and dispatch assurance are needed to offer effective grid services
- To preserve distribution safety and reliability, distribution dispatch must have priority over wholesale market operations
- Unified standards, protocols, testing, and exchanges are needed as DERMS requirements and market structures become more defined.

Figure 4-17. PG&E DERMS demonstration software interface [47]

4.2.4.3 AUSTRALIA

The Western Australia government released a "DER Roadmap" report to guide and optimize DER integration into the future [52]. With increased DER penetration already experienced at unprecedented rates in Western Australia, serious risks to the power system are being experienced and threatening the safe and reliable operation of the grid, especially distribution networks. Growing issues on the distribution system include eroding security and reliability, two-way power flow causing operational problems, system stability issues, and hosting capacity limitations. Equity challenges are also being identified, as there is an emerging divide in Western Australia between those that can afford to install DERs and those that cannot.

Therefore, the "DER Roadmap" identified the following three parts to a future vision of DER integration in the region:

1. A safe and reliable electricity system where customers can continue to connect DERs and where DERs support the system in an effective way.
2. DER capability can offer value throughout the electricity supply chain.
3. DER benefits are flowing to all customers, both with and without DERs.

In this roadmap, Western Australia recognizes the need for storage as an essential component to ensure power system stability and security under high penetrations of DERs. They can provide a cost-effective way to manage network and system issues caused by DERs and offer customers opportunities to access storage during regular operations and extreme events. Tariff pilots will be guiding and attempting to remove barriers to integrate higher levels of distributed solar and energy storage, in such a way that has the potential to lower customer energy bills.

The customer journey, whether customers install DERs themselves or not, plays a key role in this roadmap. Figure 4-18 illustrates how customers can engage with the power grid and share the benefits of DERs at a local and regional level.

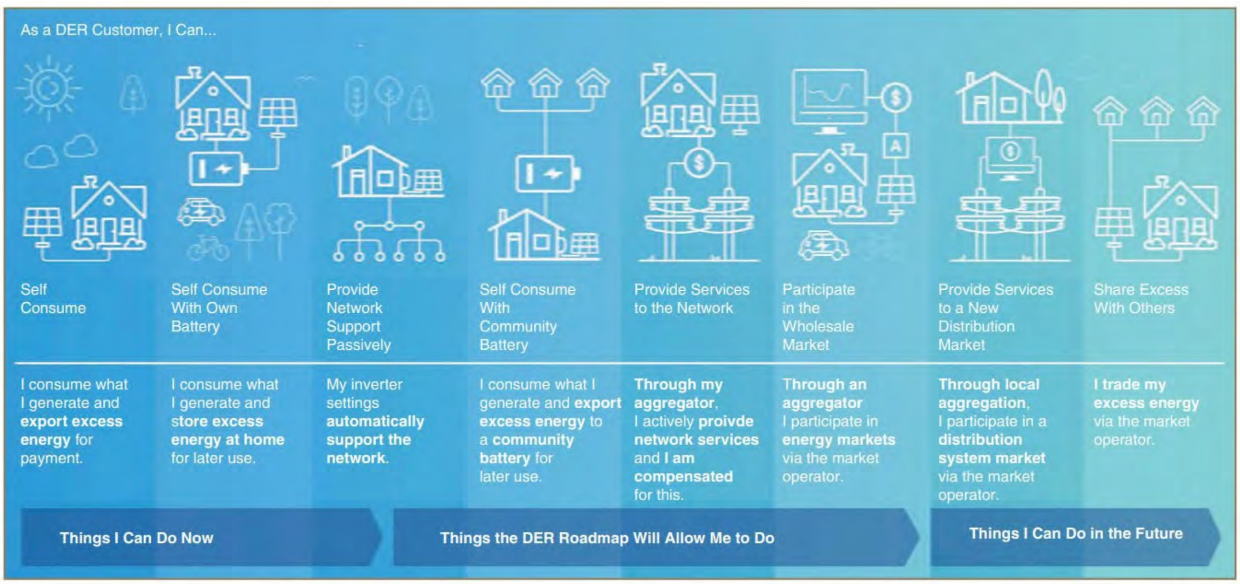


Figure 4-18. Western Australia customer DER journey [52]

4.2.4.4 VIET NAM

Viet Nam is experiencing a significant increase in electricity demand. There are some economy-specific drivers that are influencing this change, which include [53]

- High economic growth rates, poverty reduction, and demographic factors triggering a rapid increase in electricity demand and peak loads
- Plans to double electricity generation by 2030
- Overreliance on hydropower and fossil fuels due to increased drought years
- Climate risks and greenhouse gas emissions in electricity sector are high
- Air pollution hazards.

Increasing the penetration of DERs can be a strategy in managing this increase in demand. In 2017, the government of Viet Nam introduced a feed-in-tariff for new renewable capacity; however, this effort was ineffective at increasing DERs because of low electricity rates that made DERs, especially rooftop PV, unprofitable [53]. To address this, a second iteration of the feed-in-tariff, that included the target of installing 100,000 rooftop PV systems by 2025 [53], was successful. In 2020, rooftop solar installations in Viet Nam grew over 2,400 percent, with an additional 9.6 gigawatts (GW) of DERs [54].

This influx of DERs, most of which is solar, has led to concerns over grid stability during the evening peak load, when the demand peaks and solar generation diminishes [54]. Managing this new DER and additional types of DERs to be added in the future would benefit from a DERMS system.

4.2.4.5 JAPAN

In 2019, a Japanese energy services and trading company, Eneres Co., announced that they would attempt to build the world's largest virtual power plant using DERMS technology from AutoGrid software [55], [56]. The DERMs technology they plan to utilize will aggregate and dispatch energy from demand response and DERs of more than 10,000 assets.

This is system is being launched in 2020 and 2021 with only energy storage aggregated into the system but will later include other DERs. This initial trial with energy storage is partly due to the Japanese government promotion of installing lithium-ion batteries for residential and industrial use by subsidizing the capital costs of battery systems [57].

4.2.5 KEY TAKEAWAYS & RECOMMENDATIONS

New benefits of the distribution system are being defined as APEC economies experience greater implementation of DER. Despite the challenges DERs introduce, including two-way power flow and "duck-curve" operational challenges, DERs can be leveraged to improve distribution services and increase overall reliability and resilience if leveraged properly. Distribution planners should take a proactive approach to integrating, forecasting, and managing DERs. Incorporating advanced technologies and tools to manage and optimize DERs will be important. Investments in technologies, system improvements, and skill development can all be made now to ensure smooth integration and management of DERs into the future.

Therefore, recommendations for policy and regulating entities, as well as distribution planning entities, are the following:

Recommendations for Leveraging Distributed Energy Resources	
Policy and Regulating Entities:	Develop rulings to require **planning for DERs in advance**, as well as explore and field test technologies that can manage DER operation to improve reliability and resilience.
Distribution Planning Entities:	Identify and field test technologies and resources needed to **improve the management, coordination, and optimization of DERs** to improve reliability and resilience.

4.3 PLANNING FOR ELECTRIC VEHICLES & THEIR POTENTIAL

As the heart of transportation electrification, EVs have been increasing rapidly, with supportive policies from governments and go-all-electrified plans of more and more auto manufacturers. Out of the world's top 20 vehicle manufacturers, which represented around 90 percent of new car registrations in 2020, 18 have stated plans to widen their portfolio of models and to rapidly scale up the production of light-duty electric vehicles [58]. All APEC economies have announced policies and programs to promote electric vehicles. With existing policies around the world, the EV stock across all modes (except two-/three-wheels) reaches 145 million in 2030, accounting for 7 percent of the road vehicle fleet [58]. This fast-changing market represents the beginning of a demand-side challenge like no other: intelligent, interactive electricity demand that is movable in time and space. At the same time, the growing number of EVs, considered as a pooled resource, could provide a wide range of valuable grid services, from demand response and voltage regulation to distribution-level services, without compromising driving experience. This section will elaborate on the value and importance of EVs to distribution system planning, the challenges, and opportunities for distribution planners to integrate EVs successfully without adversely impacting the grid.

> Adoption of electric vehicles is increasing rapidly with supportive policies from governments and go-all-electrified plans of auto manufacturers.

4.3.1 VALUE & IMPORTANCE

EVs are of great value for distribution system planning. If the number of EVs needed to meet greenhouse gas reduction targets reach the road, GW of load will be created to charge those EVs. Forecast of this load is much more difficult. At the same time, EVs represent a large potential source of flexible load in the future and can be an important source for grid services, which can be utilized for enhanced grid reliability and resilience. This subsection presents why transportation electrification, particularly EVs, are important for distribution system planning.

Rapid increase of EV penetration

Rapid increase of EVs represent a large potential of flexible load. Distribution planners should be continuously monitoring the level of EV adoption, as well as its projected growth, to proactively take actions to manage the charging of EVs and plan for possible distribution system upgrades and investments. The EV sales in the APEC region have increased rapidly over the past decade, as consumers become more familiar with EVs, more impressed with the performance of EVs, and more aware of EVs' low total cost of ownership (instead of just their high sticker prices). EV sales will remain strong for various reasons. EV's continuing price declines and range increase, combined with

> Reasons to take note of ***Electric Vehicles:***
>
> 1. Rapid increase in penetration
> 2. Challenges in forecasting and managing EV charging load
> 3. Additional grid services from V1G
> 4. Potential for EV as grid supply

ongoing policy support, should drive EV adoption to higher rates. What's more, an intensifying focus on decarbonizing transportation to help each economy meet their climate change abatement target will naturally lead to greater vehicle electrification.

Challenges in forecasting and managing EV charging load

Forecasting EV load is much more difficult, both spatially and temporally, than other loads, such as commercial, residential, and industrial. EVs could be the single biggest end uses in homes, posing new pressures on the local distribution infrastructures if left unmanaged. The mobility nature of EVs makes the forecasting of where the charging would happen more challenging. What's more, charging power and energy needed can vary greatly between different kinds of EVs. As EV technologies advance, increasing light-duty vehicle (LDV) battery sizes and increasing numbers of medium-duty vehicles and heavy-duty vehicles will lead to different patterns. Autonomous vehicles will provide new challenges and opportunities too.

Additional grid services from V1G (vehicle as load)

Managing the charging of EVs can deliver various services at different levels of the electricity system, from bulk power markets to local distribution systems. In bulk power markets, well-managed EV charging loads can deliver system services, such as demand response, voltage support, frequency regulation, and ramp rate reduction [59]. At the distribution system level, services will be more local, delivering operational savings and helping to avoid investments in capacity. The distribution system level is where EV charging is likely to need close monitoring and management first, long before it becomes an issue at the substation or system levels. However, the need for distribution system upgrades can vary substantially within systems, so distribution system operators will need to carefully evaluate the needs of their systems down to the neighborhood level.

Potential for EV as grid supply

With appropriate V2G technology, EVs can function as grid supply—serving the same functions as power generators—as well as being grid loads. EVs could pump electricity back onto the grid at times of high demand and participate in the ancillary services markets, providing services like frequency and voltage regulation, reactive power for power factor correction, and reserve capacity.

4.3.2 IMPLEMENTATION

Transportation electrification is occurring with rapidly evolving growth rate in each of the APEC economies. In the earliest days of EVs, charging was simple, and the impact of EV charging on distribution systems was limited. However, in the emerging era of broad EV adoption and managing EV charging as a DER, distribution planners face unprecedent challenges of forecasting the load demand from EVs, evaluating the importance of EVs as DERs for maintaining a reliable and resilient grid, and coordinating all stakeholders, including regulators, utilities, manufacturers, operators, and policy makers, to maximizing the benefits of using EV charging as a DER.

Identify distribution system hosting capabilities, needs, and constraints

To realize the potential of EVs, a significantly expanded network of charging systems will be required simultaneously with more EVs on the road. While residential EV charging is the major portion, charging station deployment at workplaces and retail shopping locations could accelerate along with EV adoption. With the development of autonomous EVs, the location of the charging infrastructures will be more flexible and manageable. The owners of EV charging infrastructures could be third-party companies, consumers, or others. Utilities should identify and communicate the hosting capacity on different parts on the system, identify where adding EV charging infrastructure would be most beneficial, and increase access to certain types of non-sensitive system information to enable non-utility stakeholders, including customers and third-party charging providers, to help meet grid needs.

Forecast and manage EV charging impact in advance

Compared to the electricity usage of an average home per day, EVs (such as Tesla Model X) can store approximately four times the average household demand [60]. Clustered EV charging is likely to cause problems at the local level, as local distribution grids are not built to accommodate the huge spikes in demand. Moreover, unlike other DERs, the connection of EVs to the distribution system usually does not go through a utility interconnection application process, which makes it more difficult to forecast when and where the EVs are to be charging for the utilities. It is essential to have policies, programs, and appropriate tariffs in place to support EVs and shape their charging before EV adoption ramps up to significant levels.

Besides shaping the EV load, advanced load forecasting tools are developed or being developed and should be leveraged to forecast the load from EVs. Load forecasting should include robust scenario analysis and probabilistic planning of EV penetration to ensure a thorough understanding of future risks and opportunities.

Integrate EV charging infrastructure with the future in mind

Traditionally, to charge the batteries of an EV is the primary purpose for EV and grid integration. However, in today's or a future smart grid environment, EVs can have another purpose, which is to supply power back to the grid and provide ancillary services for enhanced grid reliability and resiliency. To fully integrate EVs and to unlock the full flexibility potential of EVs, a comprehensive EV integration framework is required, including both technical and market operation areas. From the perspective of technical operations, such a comprehensive framework should consider power infrastructure, such as types of power used, accommodation of charging circuit, charging topologies and direction of power flow, and control and communication systems for monitoring and control of EV charging and discharging, as shown in Figure 4-19. On the other hand, from the perspective of market operation area, the framework should coordinate all the stakeholders, including regulators, utilities, DSOs, transmission system operators, manufacturers, aggregators, private and public electricity prosumers, EV users, and so on.

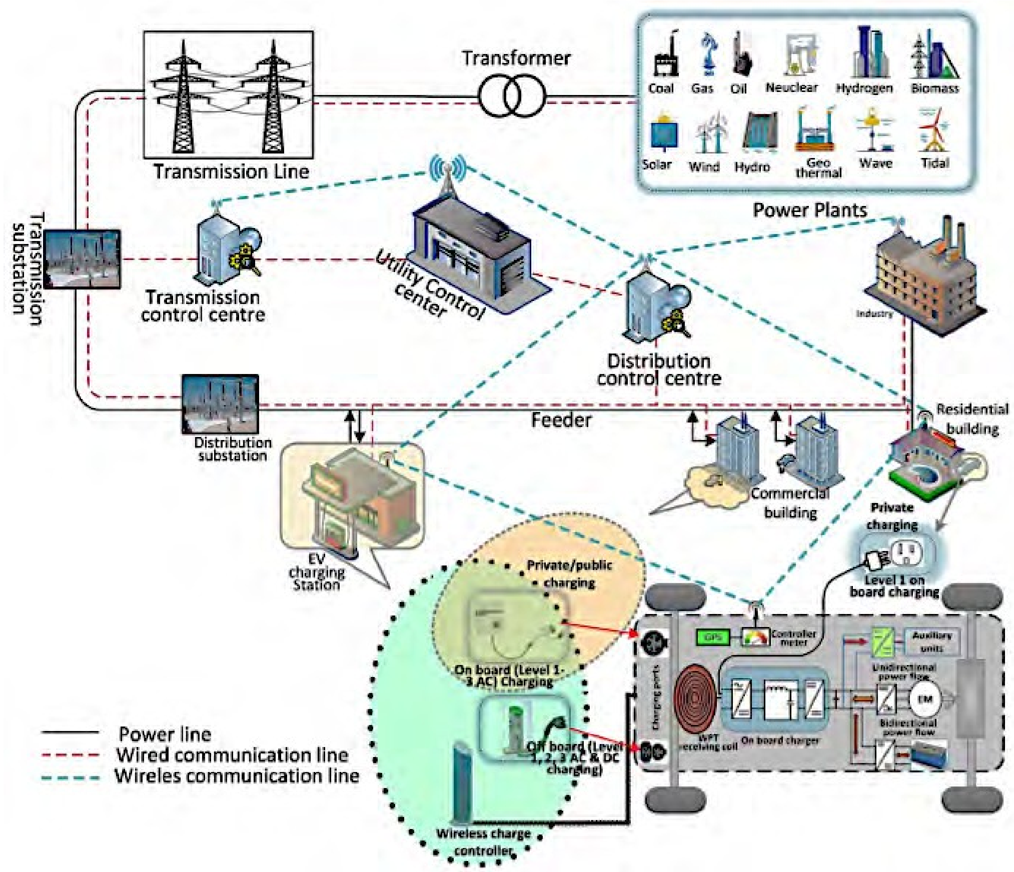


Figure 4-19. Schematic diagram of EV charging infrastructure [61]

4.3.3 TECHNOLOGY & APPLICATION READINESS

EV load forecasting technologies, EV management tools, and the related infrastructures, such as charging stations, are required to be ready and in place to embrace the coming era of electrification of vehicles. The readiness of these technologies and tools is essential to ensure the integration of EVs to grid safely, reliably, and efficiently, without adverse impact on the grid, and to maximize the potential of EVs to enhance the reliability and resilience of the grid.

4.3.3.1 EV LOAD FORECASTING TOOLS

EV charging stations generally connect to the distribution system, either at home, at a workplace, or at a public charging station, rendering its importance for distribution system planning. At a higher level, EV load forecast involves forecasting EV sales at national, state, and local levels, as well as considering the fast-changing policies and technological progress. Figure 4-20 shows the plug-in electric vehicle (PEV) new-vehicle market share forecast under different scenarios by Electric Power Research Institute. The International Energy Agency (IEA) also has developed similar tools to forecast the EV market sales [58].

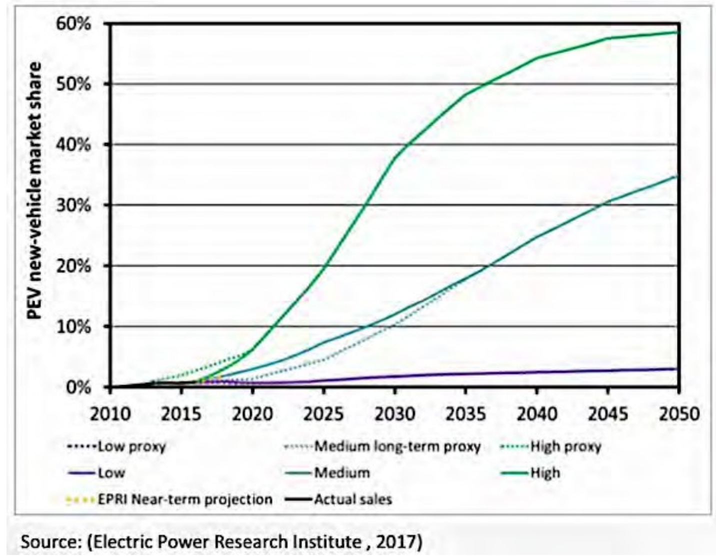


Figure 4-20. Projections of PEV market shares under different scenarios

Additionally, at a more granular level, typical EV load profiles (managed and unmanaged) should be developed to consider all possible scenarios. The National Renewable Energy Laboratory (NREL) developed a user-friendly interface tool, [EVI-Pro](EVI-Pro)to estimate the need of EV charging and its impact on load profile, given the number of EVs and other factors (such as the weather and drivers' daily miles). Figure 4-21 shows examples of the LDV load profile for each hour generated using EVI-Pro, by PNNL under different charging scenarios [62].

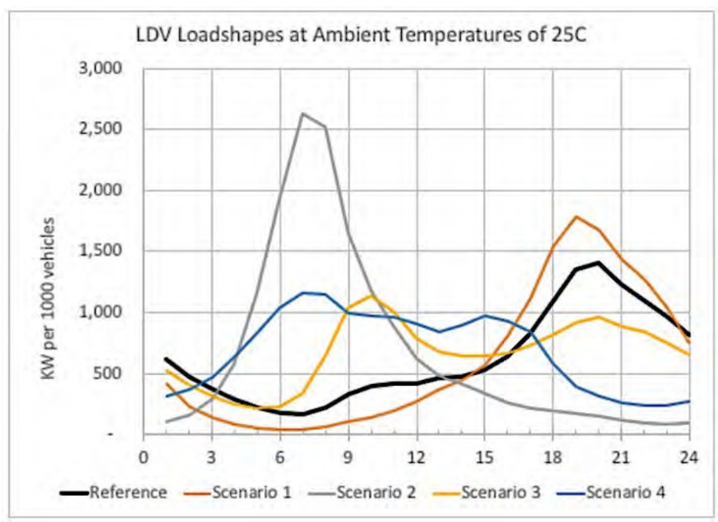


Figure 4-21. Aggregate EV charging profiles for LDVs at the base temperature (25°C) [62]

After forecasting the EV load, it is crucial to forecast (understand and quantify) the impact of the new EV charging requirements on the power system. It requires efforts to downscale the EV penetration projections to distribution system level, as shown in Figure 4-22 [62], developing tools to assess the EV charging on the distribution feeder circuits to ensure the integration of EV charging, taking into account the diversity of distribution systems that arises from variations in topologies, voltage levels, load compositions, and other factors, such as climate conditions.

For each APEC economy, the EV charging patterns could be very different. For example, 85 percent of EV charging happens in the home for the United States, while for other economies, such as China, a large share of EV charging is public charging [63]. As of January 2019, 40.7 percent of the EV chargers in China are public chargers [63]. The developed tools or tools being developed could be leveraged by each economy for EV load forecasting, tailored to each economy's specific forecasting needs.

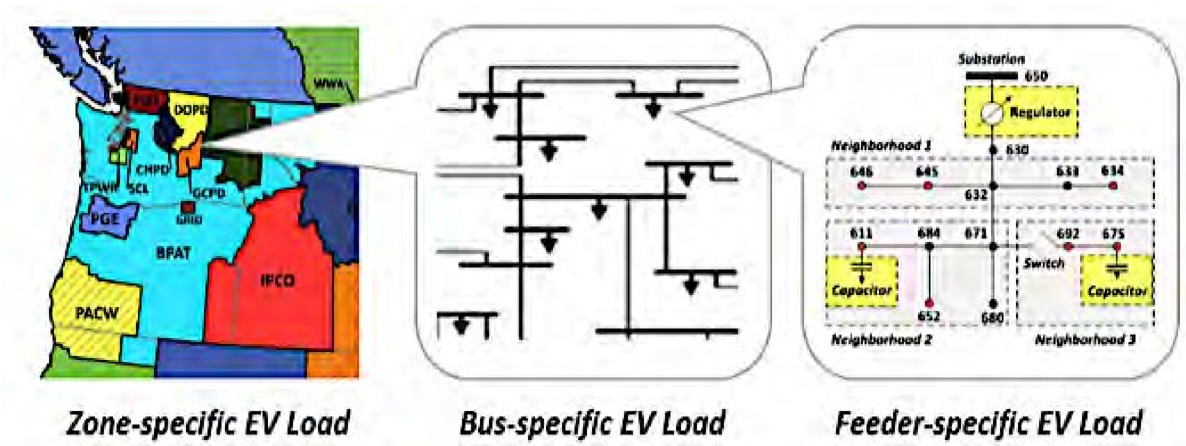


Figure 4-22. Methodology to align bulk grid and distribution feeder EV adoption [62]

4.3.3.2 EV LOAD MANAGEMENT TOOLS

Without incentives, EV charging usually occurs during the system peak (4 to 5 p.m.), and over 85 percent of EV charging occurs in the home. The impact of EV charging on the grid depends on how the EV charging demand is managed. As shown in Figure 4-23, EV charging, if left uncontrolled, will impose large pressure on the grid. It also shows the largest opportunity of EV charging loads to flatten loads and maximize renewables in the system.

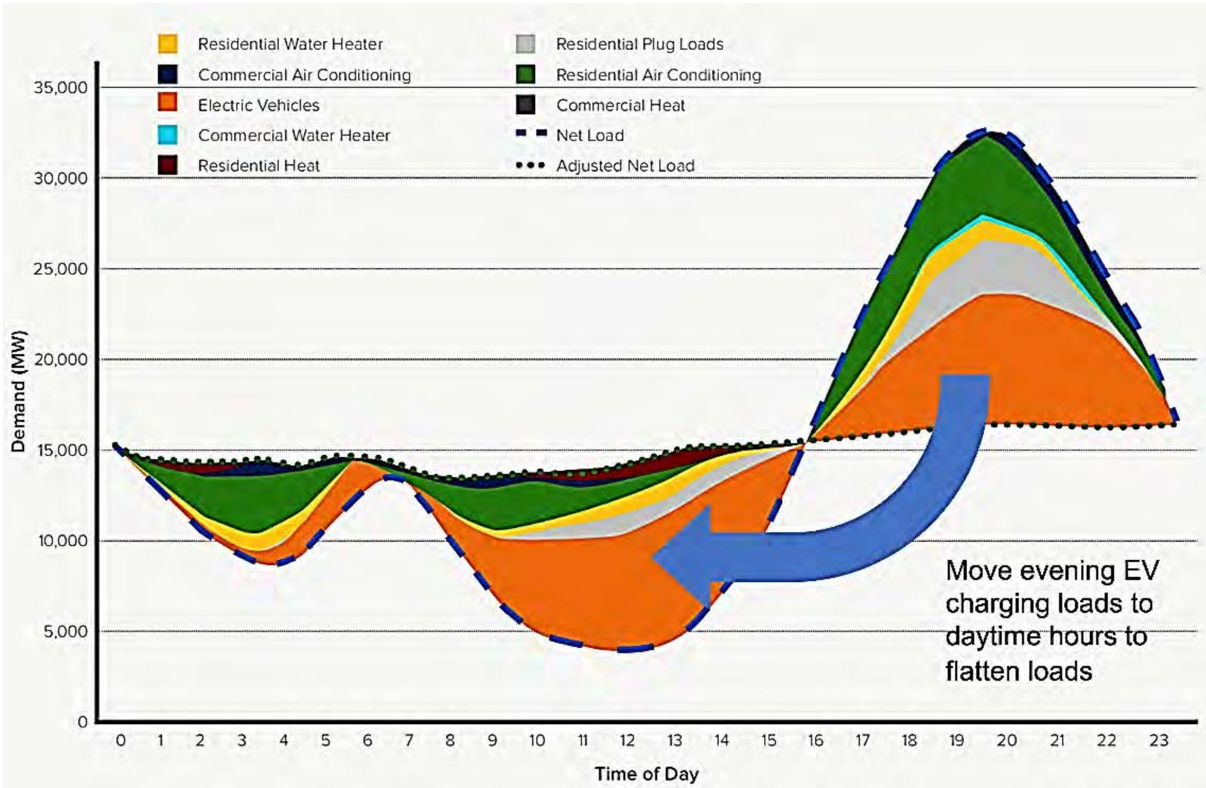


Figure 4-23. EV load management to flatten loads [64], [65]

The future trend for EV load managing is via smart charging system, where EVs, charging stations, and charging operators share data connections. The inherent flexibility of domestic EV charging, particularly when vehicles are plugged in during the evening peak time, has been demonstrated in [65]. EV demand management via smart charging was shown to be technically feasible and could be used while maintaining high levels of customer satisfaction [66]. Through this software-based and hardware-agnostic system, the charging stations may monitor, manage, and restrict the use of charging devices to optimize energy consumption. Smart charging can be divided into user-managed charging and supplier-managed charging. User-managed charging is where the customer decides the timing to charge based on the price and needs (by using tools such as Time-of-Use tariffs [67]), and supplier-managed charging is where the suppliers, such as utilities, decide the charging and discharging timing (by using tools such as Direct Load Control devices) based on real-time energy production and local energy consumption, as well as the state of charge information from nearby EVs and other electric devices.

4.3.3.3 CHARGING INFRASTRUCTURE

With the fast-growing EV market, EV charging stations have been growing rapidly. The adoption maturity of EV charging infrastructure is shown in Figure 4-24. Slow charging (level 1 and level 2) and fast charging (level 3 and DC) can be facilitated in both residential and non-residential charging stations, with a significant portion of residential EV charging with charging ports in the United States. However, the future charging stations are planned to be built up at commercial places to facilitate them as EV refueling stations, which will have all types of charging ports and brings new challenges to the grid, especially the distribution systems. Planning of EV charging infrastructure installation is essential to optimize the charging stations in the distribution systems without affecting the power system and economy negatively.

The fast evolution of EVs has created challenges to operating it uniformly all over the globe. It is essential to standardize every aspect of it, including the charging equipment. This standardization also includes integration of EV to grid. There are several standards available worldwide that deal with EV charging infrastructure, including those from the Society of Automotive Engineers (SAE) and IEEE in the United States.

Installing EV charging infrastructure without planning can cause complications that affect the power system negatively. The number of charging stations can be less or more than the required charging facilities, or the locations of charging stations can result in clustering of charging stations in specific areas and increase the risk of local overloads. The planning of charging infrastructures installment involves comprehensive consideration of growth of EVs, transportation networks, and the capability and structure of the distribution systems. EV load forecasting tools could be utilized for planning of charging infrastructures. More tools and handbooks specific for EV charging infrastructure planning have been developed or are being developed. For example, NREL has published a handbook for installation of public EV charging station hosts [68]. A Regional EV Charging Infrastructure Location Identification Toolkit was developed by M.J. Bradley & Associates and by Georgetown Climate Center to support the northeast, Mid-Atlantic, and Southeast states in the United States [69].

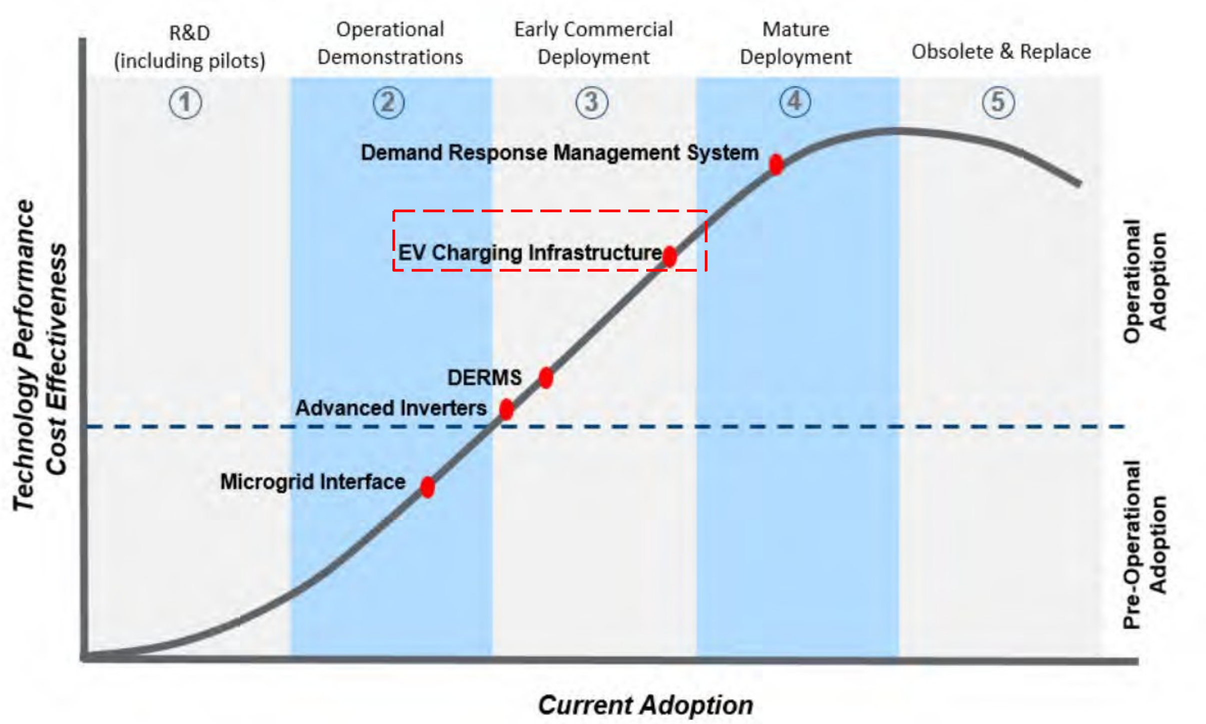


Figure 4-24. Adoption maturity analysis for EV charging infrastructure [38]

4.3.3.4 VGI

Vehicle Grid Integration (VGI) is one of the smart technologies with the ability for bi-directional communication between EVs and electrical grid to deliver and receive the electricity when EVs are connected to the grid. Besides managed charging, as detailed above, another important aspect of VGI is exporting electric power to the grid (Vehicle-to-Grid, V2G). V2G technology field testing is booming.

Across the world, pioneering V2G projects are delivering cutting-edge insights through learning by doing [70]. For industry, maturing the hardware, identifying services where V2G adds value, and considering the segmentation of user behavior are essential to realize the benefits of V2G [70]. For network operators, adapting interconnection standards and processes for the EV community along with other distributed energy providers is important, as the EV community does not expect special treatment. Network operators should also clarify the value of DSO services and design service specifications with V2G in mind. Factors such as response time required, duration the service needs to be provided for, and availability and performance levels provided by fundamentally less controllable assets should be taken into consideration when designing services provided by V2G [70].

4.3.4 APEC MEMBER DEVELOPMENTS

This section highlights APEC member experiences with planning for EVs. The economies highlighted include the United States, New Zealand, and China.

4.3.4.1 CALIFORNIA, UNITED STATES

California is, by far, the most EV-oriented state in the United States, with over 250,000 EVs on the road and an official target of 1.5 million EVs by 2025 [71]. California has the most solar energy production and the third largest wind energy production [72]. The rapid growth of EVs provides a potential manageable load to help maximize the utilization of solar and wind energy, avoiding curtailment of wind and solar production. The experiences from California in managing EV load will offer valuable insights for other economies. The California Vehicle-Grid Integration (VGI) Roadmap, led by CAISO in coordination with the Governor's Office, the California Energy Commission, the California Public Utilities Commission, and the California Air Resources Board, has provided high-level plan to enable the potential of EVs [73].

In California, the EV industry has been a driver of job creation and manufacturing exports. California has the largest EV market share because of the strong government policy support and incentive programs by the utilities, manufacturers, and dealers. At the same time, an expanding clean energy ecosystem in California is being powered by the fast-evolving EV industry. EVs have grown from zero to second most valuable commodity export for California in 2019 [74], creating new jobs and generating tax revenue for government. As of March 2020, more than 275,600 jobs related to EVs have been created, and it is expected to increase to over 300,000 by 2023 [75]. California's advantages in the competition for clean energy manufacturing, with EVs becoming a top export, vividly showcases the potential payoff of a clean energy manufacturing strategy.

The California Electric Vehicle Infrastructure Project addresses regional needs for EV charging infrastructure throughout California. It provides incentives for EV charger installations and works with local partners on projects that support regional EV needs for Level 2 and direct current fast charging. These statewide efforts provide a streamlined process for cost-effective charger installations that can reduce significant gaps in charging availability [76]. A statewide assessment of the charging infrastructure is reported in [77]. This report projects that light-duty plug-in EVs will need nearly 1.2 million shared chargers by 2030. It considers the alignment of EV charging with renewable energy generation and acceleration of electrification of medium- and heavy-duty vehicles and emphasizes the priority of charging standards and innovations. Such research and reports provide the state clear vision for future planning of EV charging infrastructure.

California has also taken a range of actions to explore and support development of programs and standards that facilitate VGI. Besides the aforementioned VGI Roadmap [73], the California Public Utilities Commission has also established a VGI Working Group to assess how and whether the adoption of a communication protocol is necessary to enable VGI resources to participate in electricity markets more economically at scale and to help the Commission determine any requirements necessary for investment decisions. The state has supported pilot projects to explore opportunities. Specifically, a V2G demonstration project at Los Angeles Air Force Base uses a non-tactical fleet of 34 light- and medium-duty plug-in electric and hybrid vehicles and their bi-directional charging stations to not only charge their vehicles but also provide grid service back to the system, earning revenue for the base [78].

4.3.4.2 NEW ZEALAND

As a key to the decarbonization of the transport sector, EVs have been one of the main policy tools to achieve New Zealand's government climate goals. As part of the recently launched initiative to combat climate change, which will require the public sector to achieve carbon neutrality by 2025, New Zealand has supported the immediate purchase of EVs and hybrid vehicles to start replacing the government's petrol car fleet [79].

To achieve its ambitious plan to be carbon neutral by 2050, New Zealand has unveiled a plan to end imports of petrol-powered cars by 2032, projecting that more than half of all light vehicle travel would be EVs and 40 percent of the light vehicle fleet would be EVs by 2035 [80], changes among a raft of recommendations presented to the government by the Climate Change Commission. The acceleration of light electric vehicle uptake is urgent and requires time-critical, necessary actions to be completed, including the phasing out of internal combustion engine cars, incentives for consumers to purchase EVs, and a plan of charging infrastructure development for greater coverage of EVs.

New Zealand has exhibited great efforts to promote EVs. Governmental efforts include, but are not limit to, the in-depth study on the barriers of EV uptakes from a consumer behavior perspective and corresponding avenues to overcome these barriers [81], building a live database—EVRoam—of electric vehicle charging infrastructure, and increasing contestable fund for investing in EV infrastructure. Utilities are working to identify the key areas that need to change to allow the increasing connection of EVs, to realize the benefits of EVs, as well as ensuring the reliability, security, and quality of power supply.

4.3.4.3 CHINA

Over the past decade, China has rapidly created the world's largest EV market. It accounts for half of the world's electric cars and more than 90 percent of electric buses and trucks. China's success is built on a foundation that includes a clearly articulated vision, consistent planning, coordinated action, city-level innovation and leadership, policy implementation, and the continued adaption of policy tools to meet the changing market [82]. China has developed its own roadmap for EV adoption according to its unique mobility needs, demographic shift, and current regulatory and technical barriers.

China has unique mobility needs. The rapid urbanization in China over the past few decades has led to ballooning demand for mobility. Since inter-city and inter-province travels have been covered by China's high-speed railway network, buses and small urban cars for shorter urban trips have been the focus for electrification. Since the early 2000s, China chose new energy vehicles, primarily electric-drive vehicles, for a national strategy to jump-start its auto industry. It started from widespread use of electric bikes and scooters to establish early consumer confidence, with continuous investment and policy supports in EV-related technologies and EV adoption. As the technologies mature (such as lithium-ion battery), EVs have now evolved to be a core solution to address China's goals for future mobility, industrial development, energy security, and air quality.

Additionally, China is experiencing a demographic shift. A highly segmented Chinese EV market is rapidly developing [83]. In Chinese regions where consumers don't have reliable public transportation, people are increasingly opting for a personally owned EV at a low price point. Two discrete tiers are forming in China. A lower tier of affordably priced, youthfully styled vehicles for younger buyers and an upper tier of vehicles aimed at family-oriented, upwardly mobile professionals. The top sales of a budget, mini EV, which costs US$4,500 and is produced by SAIC-GM-Wuling Automobile Company, has typified this point. Table 4-2 shows the top five EV models' sales in China in April 2021 and 2021, respectively [84]. Wuling HongGuang Mini EV has the largest market share in China, by far.

Table 4-2. Top five EV models for April 2021 and for the year 2021 in China [84]

	China	**April 2021**		**China**	**2021**	**Market Share**
1	Wuling HongGuang Mini EV	29,251	1	Wuling HongGuang Mini EV	125,925	19%
2	Tesla Model 3	6,264	2	Tesla Model 3	59,122	9%
3	BYD Han EV	5,746	3	BYD Han EV	27,100	4%
4	Li Xiang One EREV	5,539	4	Great Wall Ora Black Cat	23,791	4%
5	Tesla Model Y	5,407	5	Tesla Model Y	21,829	3%

In China, technology innovation is being backed by strategic policy support. In the 21st century, China is emerging as a leader in many new technologies—especially those related to mobility. Today, China is not only the biggest producer of EVs, by far, but it is also a leader in lithium-ion battery technology that powers EVs, as well as smartphones and other mobile devices. Batteries are the power storage of the future as the world moves relentlessly toward the electrification of transportation, and while China controls 60 percent of the world's production of lithium-ion batteries and nearly half of the world's global lithium production, it is also hard at work trying to advance them and developing substitutes that could be cheaper and less combustible [85].

Lastly, China is implementing VGI pilot programs and plans. China's current load management mechanisms are, to a large degree, vestiges of the planned era. Chinese Grid operators typically rely on administrative rationing during electricity shortages, rather than market-based demand response [86]. With the special characteristics of the electricity market and operations, China's VGI pilots differ from global VGI pilots in many aspects. Compared to global VGI pioneers that can be traced to the early years of EV adoption, VGI pilots in China are a recent phenomenon. Unlike global VGI projects that focus on frequency regulation with high commercial values, China's VGI projects mainly focus on deploying managed charging to defer distribution upgrades where the commercial viability remains unclear. Furthermore, most of the VGI pilots in China led by the National State Grid aim at testing VGI's technical feasibility [87]. For VGI to thrive in China, research and projects have been performed to identify regulatory, economic, and technical barriers. A roadmap for adopting VGI measures on scale have been proposed in [87].

4.3.5 KEY TAKEAWAYS & RECOMMENDATIONS

EV penetration is increasing significantly in many APEC economies and will continue to grow rapidly. Realizing the benefits of EVs will be challenging if infrastructure planning is not done in advance, as it is central to supporting vehicle electrification. Planning for EVs and their potential will require policies and mechanisms that cut across conventional boundaries, such as the ones between wholesale and retail markets or between customers and generating resources. Implementing new regulations and rate structures will take time, and each APEC economy and their subregions should consider implementing EV tariffs that will better manage EV charging impact to the grid, especially to distribution systems and their ability to host EV loads. Technologies and platforms that can coordinate, manage, and enable future V2G should be explored and supported, and it will require involving all the potential stakeholders in the policy making process. All mechanisms explored to integrate EVs and leverage their potential to manage the evolving operation of the power grid will need to be designed regarding EV users and their mobility needs, as well as the optimal use of grid assets.

Therefore, recommendations for policy and regulating entities, as well as distribution planning entities, are the following:

Recommendations for Planning for EVs and Their Potential	
Policy and Regulating Entities:	Develop rulings for transportation electrification industries, distribution planning entities, and other necessary stakeholders to require development of **rate structure mechanisms and technologies to better manage electric vehicles** (EVs) and field test technologies for future vehicle-to-grid (V2G) capability.
Distribution Planning Entities:	**Identify EV hosting capacity constraints and charge management techniques** for forecasted EV and field test technologies that can be utilized to managed EV charging that can also enable future V2G capability.

4.4 INCREASING SITUATIONAL AWARENESS

Situational awareness is the ability to have visibility into the physical variables, events, and forecasting for all grid conditions [17]. These may be conditions that represent the health of the system, equipment failures, customer outages, and cybersecurity vulnerabilities. To have situational awareness, sufficient sensing and data collection is needed to assemble an accurate view of the system state. In distribution systems, the value of having situational awareness enables visibility into consumer demand, power quality, and system outages impacting service to customers. It also enables the ability to monitor and manage increasing DER penetration and their impact on the system. Many APEC economies are moving toward increasing observability by leveraging newer technologies that centralize and monitor real-time distribution

> Situational awareness enables real-time visibility into consumer demand, power quality, and system outages, as well as the ability to monitor and manage DERs more effectively

system conditions. This section will elaborate on how distribution system planners should greatly consider and continue increasing situational awareness capability to improve overall system reliability, flexibility, and resilience.

4.4.1 VALUE & IMPORTANCE

Increasing situational awareness is of great value and importance for several reasons. The first is that, with the ability to capture historical and real-time operations, distribution planners and operators can perform advanced analytics to inform and prioritize investment and operational decisions. Second, this data can also assist restoring service more quickly post disturbance. And lastly, as advances take place to implement increased situational awareness, the resulting technological foundation will provide additional opportunities to improve system reliability, system efficiency, affordability, and market interaction objectives.

> Reasons to take note of ***Increasing Situational Awareness:***
>
> 1. Increased data for operational analytics
> 2. Quicker restoration times
> 3. Improved customer transparency and control
> 4. Technological foundation for future advances

Increased data for operational analytics

Operational analytics provides distribution planners with insights into system trends, health, and reliability and resiliency metrics. The data needed to perform this type of analytics includes measurements of actual system demand at high granularity, length of outages, power quality[8] issues, system failure characteristics, and others. As the grid modernizes and accommodates larger penetrations of DERs and multi-way flows, the new distribution operating paradigm will require new analytics and simulation solutions to perform distribution planning functions and ensure reliable operation and service into the future.

Quicker restoration times

Technologies that provide situational awareness for distribution operators on customer outages will significantly support restoration efforts after major system interruptions. Automating the understanding of where outages are occurring, who they are occurring to, and how long they have been out of service will support prioritization efforts and restoration mobilization.

Improved customer transparency & control

Making the data acquired from advanced metering and associated real-time data will improve customer engagement and satisfaction [88]. Personalized billing will improve transparency and provide consumers with more options to manage their energy consumption.

[8] Power quality at the customer level is related to maintaining acceptable voltage, frequency, and waveform, as defined by industry standards.

Technological foundation for future advances

To gain insight into the real-time conditions of the distribution system, a robust and secure communications network will need to be put in place as a foundation for implementing situational awareness. This communications network will enable future advances in demand response and distribution participation in the market.

4.4.2 IMPLEMENTATION

Recommendations for ***Increasing Situational Awareness:***

1. Replace archaic data gathering approaches
2. Roll-out new technologies with consumers in mind
3. Utilize advanced data visualization tools
4. Install a robust, secure, and reliable communication infrastructure

Globally, the rapidly aging electric distribution systems and their associated upgrades and replacements are accounting for significant distribution planning expenses [89]. Incorporating situational awareness and advanced monitoring technologies, not only when building new infrastructure, but also when upgrading or retrofitting existing facilities, should be an important consideration in distribution planning. These technologies improve operational awareness and increase maintenance savings, reduce customer outages and restoration costs, and support effective cost-saving decision-making, among many other benefits.

Replace archaic data gathering approaches

Currently, the traditional approach to gathering data for situational awareness in distribution networks is labor intensive due to old technologies [90]. These older technologies include electricity meters and system protection devices throughout distribution networks that lack capabilities to communicate real-time data remotely and accurately. Historically, gathering data from this dated equipment has been a manual effort, requiring utility personnel to drive to each substation or customer to record data manually. This type of process increases the risk for human error, is costly, and slow for acquiring awareness of system conditions. Modern technology and advanced metering infrastructures can replace this archaic approach.

Roll-out new technologies with consumers in mind

Implementing and installing technologies to increase situational awareness should be cost-effective, quick to install, and with minimal disruption to grid operations and electricity consumers. Implementation requires strategic planning and policy objectives for an efficient roll-out and funding for these capabilities [88]. In addition, partnering with technology vendors early on during the planning and deployment phases can support a smooth transition and implementation [90]. Customer engagement will also be important, as situational awareness not only improves grid operations, but also improves reliability and bill transparency for customers, which in end, can further justify the cost of implementation.

Utilize advanced data visualization tools

With increased access to historical and real-time data, being able to better visualize large data sets in such ways that will improve effective grid operations, and quicker decision-making will become important.

Install a robust, secure, and reliable communication infrastructure

Increased situational awareness and effectively utilizing the significant amounts of incoming data will rely heavily on robust and secure communications and networks that can provide real-time visibility and analytics. Distribution planners may want to prioritize the types of monitoring equipment currently available on the market, where to place them, where the information from these devices will get sent to, and what the data will be used for.

The following section will discuss situational awareness technologies that are increasingly implemented throughout APEC member economy footprints.

4.4.3 TECHNOLOGY & APPLICATION READINESS

Several tools and technologies have been developed, and are being developed, to improve situational awareness in distribution systems. Each of these tools rely heavily on robust and secure communications that can provide real-time visibility.

4.4.3.1 AMI

Advanced Metering Infrastructure (AMI) is an integrated system of smart meters that incorporates communication networks and data management systems. An illustration of this system is shown in Figure 4-25. This technology offers the ability to have two-way communication between utilities and electricity customers. The functionality that AMI offers automates a historically manual effort to collect electricity usage by customer. AMIs can also incorporate advanced features that provide customers the ability to have programmable in-home displays that can communicate to home electronics and thermostats and enable new opportunities to participate in time-based rate programs that encourage consumers to reduce energy consumption.

A report by DOE [91] surveyed the benefits of AMI implementation and the major findings indicated that AMI

- Reduced costs for metering and billing
- Provided more customer control over electricity consumption, costs, and bills
- Lowered utility capital expenditures and customer bill savings
- Lowered outage costs and resulted in fewer inconveniences for customers from faster outage restoration.

Because an AMI system requires significant communication infrastructure, secondary benefits of building out such infrastructure include improved DER connectivity. Not only do AMIs measure customer electricity consumption, but they can also measure and communicate energy production when DERs are involved, as well as data on power characteristics, operational events, and notifications at time intervals with sufficient granularity to support demand response and market participation.

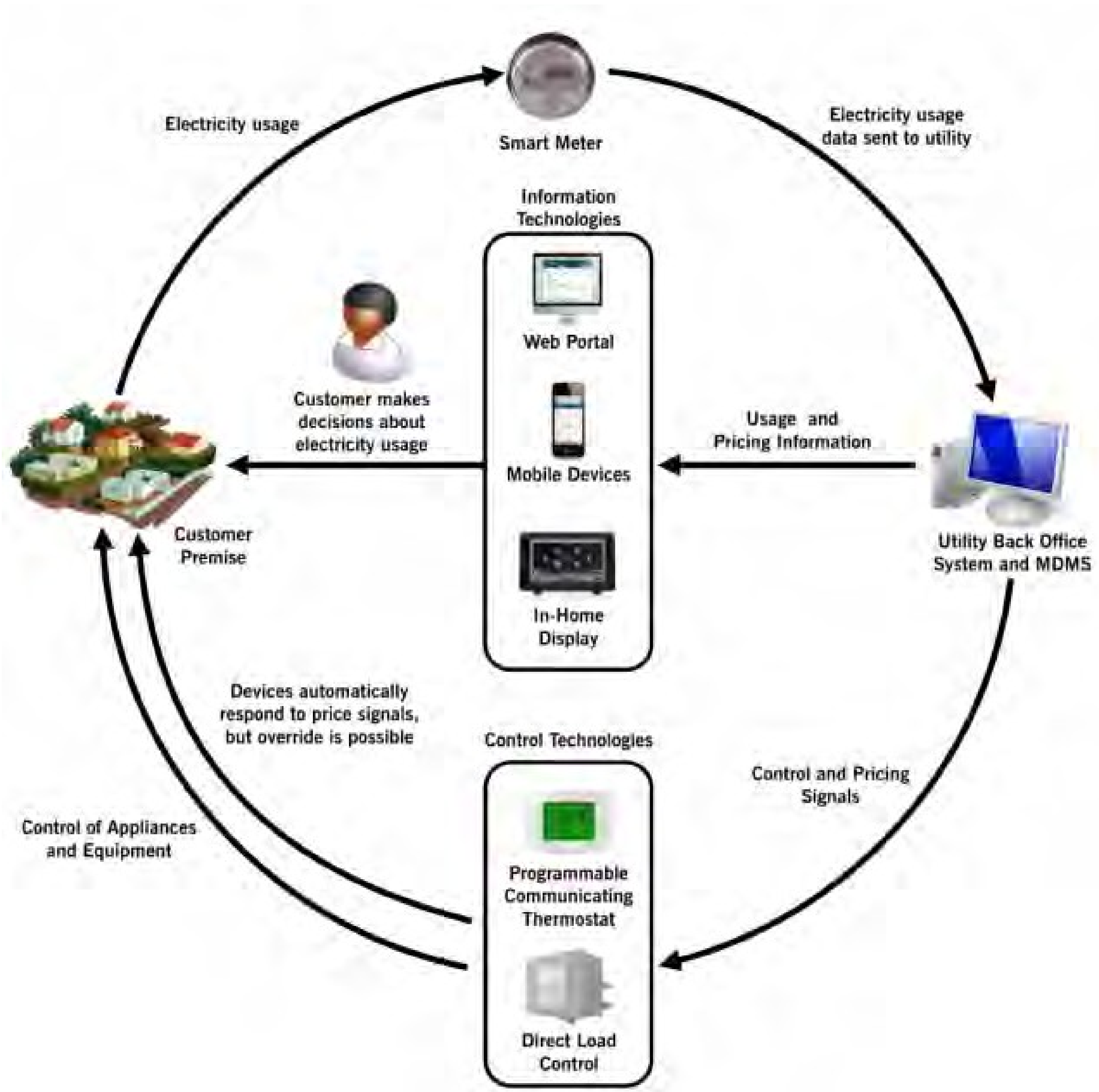


Figure 4-25. AMI system illustrating coordination and automation between utility and customer control [91]

An adoption maturity analysis for AMI was conducted by DOE's Office of Electricity. Smart meters are in the "Mature Deployment" of technology readiness.

4.4.3.2 SCADA & DMS

Distribution Supervisory Control and Data Acquisition (SCADA) is the extension of bulk grid SCADA capabilities to the distribution substations and basic distribution automation functions that can monitor and control assets (e.g., advanced switches, protective devices, etc.) on distribution feeders.

Distribution SCADA measurements and control can be used to provide information into a Distribution Management System (DMS). A DMS is like a transmission-based energy management system but, in this case, is built to provide real-time situational awareness occurring on the distribution system radial feeders and networks. This tool is one that is built to be used by distribution operators. DMS requires a seamless integration with an Outage Management System, GIS, customer information systems, and distribution SCADA.

Adoption maturity for distribution SCADA technologies, including DMS, are in the "Mature Deployment" and "Early Commercial Deployment" of technology readiness, as illustrated in Figure 4-26.

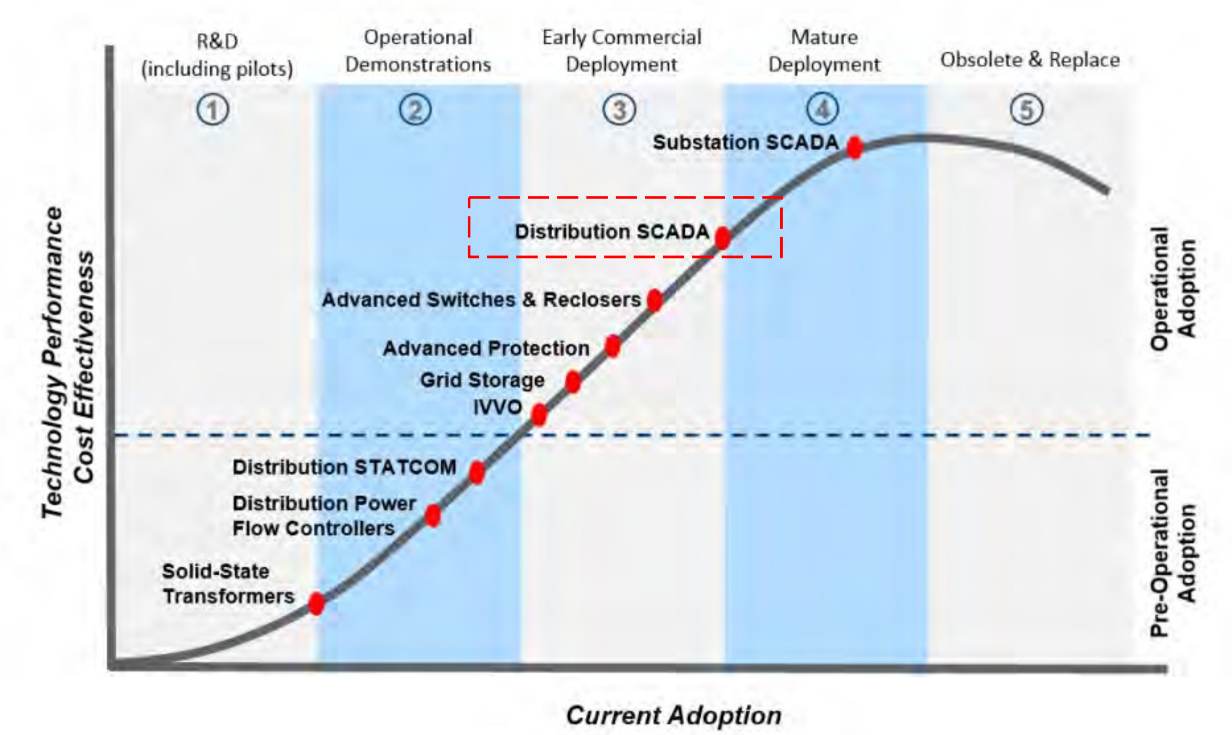


Figure 4-26. Adoption maturity for distribution SCADA technologies [38]

4.4.3.3 OMS

Outage Management Systems (OMS) is a system that integrates meter-level outage information and real-time information from incoming customer outage calls on outages. The tool will analyze this data to provide visibility into interrupted equipment and circuits [38]. Outage management systems can provide situational awareness on equipment status, outage prediction, and real-time data from customers [17]. It can also gather telemetered analog data from DSOs.

OMS also supports advanced meter data management. Meter data management consists of processes and tools for securely storing, organizing, and normalizing data from advanced meters [38].

OMS also offers the ability to manage call-handling, outage analysis and predication, crew management, and reliability reporting [92]. It can be considered a mission-critical system and can be utilized simultaneously by hundreds of users [92]. OMS can provide real-time operational decision support based on information about customers, system status, and utility resources.

Adoption maturity for OMS technologies is in the "Mature Deployment" of technology readiness, as illustrated in Figure 4-27.

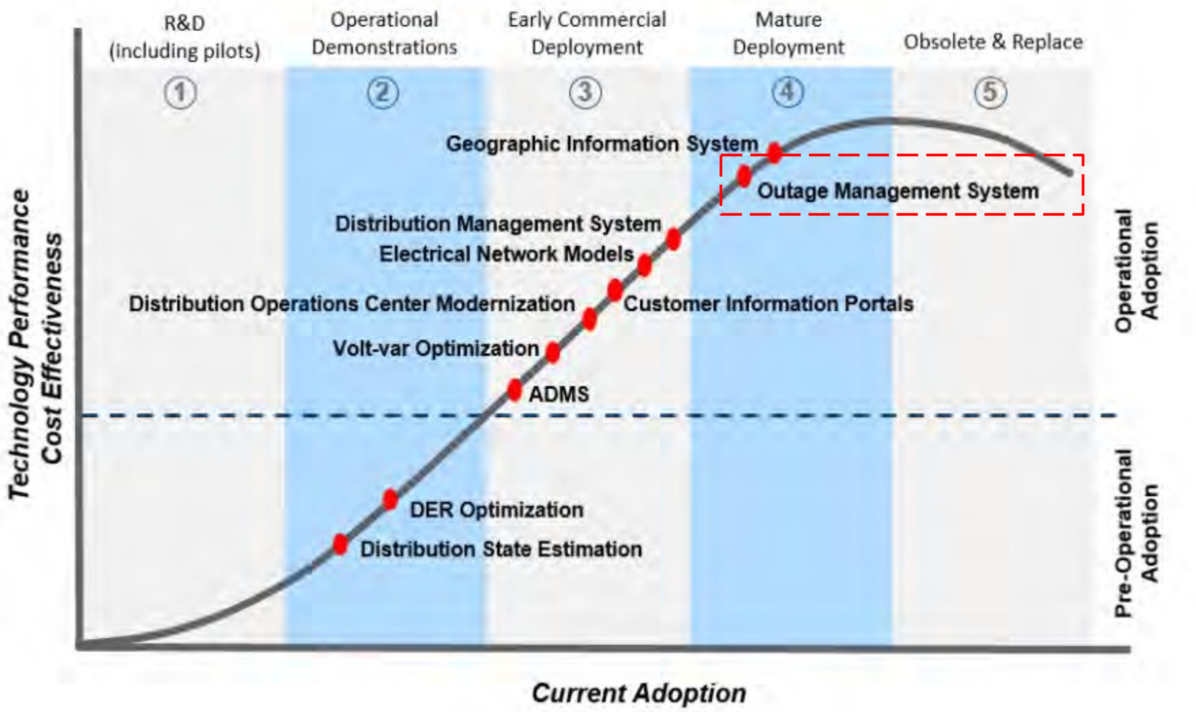


Figure 4-27. Adoption maturity for outage management systems [38]

4.4.4 APEC MEMBER DEVELOPMENTS

This section highlights APEC member experiences with increasing situational awareness capabilities. The economies highlighted include the United States, Singapore, and Mexico.

4.4.4.1 UNITED STATES

As of 2017, advanced meters are the most prevalent type of metering deployed throughout the economy, accounting for a more than 50 percent penetration rate [93]. The magnitude of this deployment is exemplified in Figure 4-28. Many electric utilities have received state approval for advanced metering deployment programs. In some states, these programs are required to include detailed program design, implementation, and customer engagement components. Some regulators and utilities agree that fully advanced meter deployment will be essential to achieving clean energy goals [93]. Advanced meters are recognized to allow customers to access retail and wholesale demand response programs, as demand response has been identified by the North American Electric Reliability Corporation (NERC) as an additional resource that can be used to meet peak energy needs for regional planning purposes [93].

Even with increased technology for situational awareness and control, the United States experience has highlighted some regulatory barriers to improved customer participation in demand response. This includes slow implementation of time-based rates. Time-based rates should ideally influence customers to reduce their electricity consumption in response to price changes, but as of 2017, only 7 percent of retail customers in the United States participate in this type of program [93]. Additional policies, technology standards, regulatory incentives, and analytical methods are needed to increase adoption and participation to fully realize the benefit and value of advanced situational awareness technologies in the Unites States.

Figure 4-28. Advanced meter growth in the United States from 2007 to 2017 [93]

With increased AMI and other distributed technologies and communication networks, OMS are becoming more prevalent in the United States. An example of a deployed OMS system is in the PG&E utility based in California. PG&E's OMS system is used for outage notification to operators and dispatchers to improve outage restoration. The deployment of the OMS system delivered the capability to create reports from AMI alarms that correlate to incoming customer calls, the capability to ping a distribution transformer to determine whether the outage is larger than just an individual customer, and the capability to ping individual meters to determine whether they have been re-energized [94].

4.4.4.2 SINGAPORE

In preparation for a full liberalization of the electricity market, Singapore's government-owned power company, SP Group, are expecting to install 280,000 AMI meters ("smart meters") to increase overall situational awareness capabilities. In addition to more smart meters, more communication equipment is being installed to expand and strengthen existing radio frequency communication networks to support retail competition and other smart grid developments [95].

In 2018, SP Group developed and published the Smart Grid Index (SGI) to rank and compare smart grid development, globally, smart grid development that incorporates components of increasing situational awareness. The SGI compares utilities globally by metrics that evaluate monitoring and control capability, data analytics, coordination of DER, etc. [96] [97]. Situational awareness among utilities can be compared globally by reviewing the results in their final report. An example of the SGI utility profile for SP Group and the components they examine are illustrated in Figure 4-29.

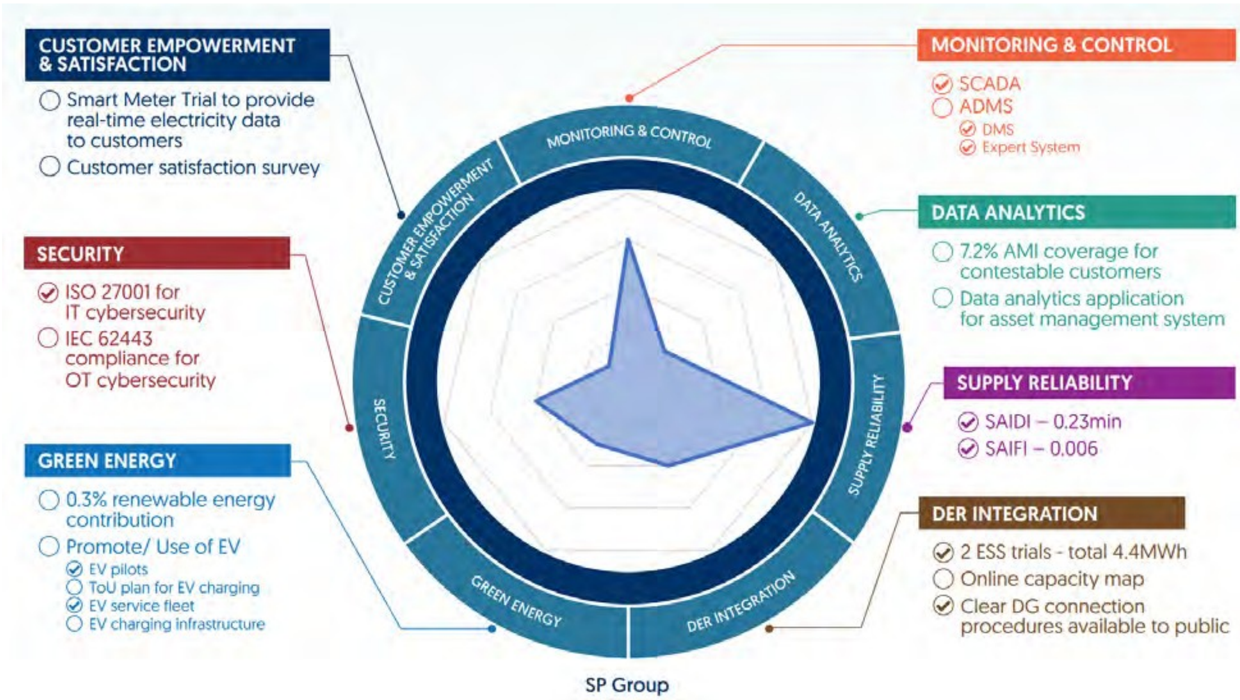


Figure 4-29. SP Group's Smart Grid Index infographic [97]

4.4.4.3 MEXICO

Mexico has set an ambitious path to meet clean energy goals and has established a Smart Grid Program [98]. In various regions of the economy, AMI has been deployed, with almost 5 million installations expected by the end of 2021. This report suggests that the single largest source of value in Mexico's smart grid initiative stems from automating the meter reading process, moving away from a manual process of reading meters [98].

In addition to Mexico's rigorous AMI deployment, the acquisition of distribution SCADA into an integrated DMS that includes visualization capabilities was developed. An example of this DMS interface is shown in Figure 4-30. This system helps DSOs stay informed about potential or real problems with feeders or substations.

Figure 4-30. Illustration of Mexico's DMS [98]

4.4.5 KEY TAKEAWAYS & RECOMMENDATIONS

With advances in technology and growing communication networks, acquiring data that provides situational awareness to distribution system operational and planning practices is becoming more accessible. A few benefits of increased situational awareness and real-time data on distribution networks include increasing data for operational analytics, facilitating quicker restoration times, and improving customer transparency and control. As grid modernization investments are made by APEC economies, archaic approaches of gathering data from the field can be replaced with more advanced automated methods, such as utilizing technologies like AMI, distribution SCADA, and DMS. The added benefit of these technologies can also be realized when their data can be collected and post-processed effectively to guide larger investment decisions into the future. However, it will be essential to keep consumers in mind when rolling out these new technologies, as they especially can be leveraged for making data accessible and transparent to customers who are continuing to increase their electricity consumption, especially in developing APEC economies.

Therefore, recommendations for policy and regulating entities, as well as distribution planning entities, are the following:

Recommendations for Increasing Situational Awareness	
Policy and Regulating Entities:	Develop rulings to require roll-out of advanced technologies (AMI, DMS, OMS, etc.) that will **increase situational awareness on distribution systems,** all while ensuring customer engagement is upheld throughout planning and deployment stages.
Distribution Planning Entities:	Build a business case, with consumers in mind, to **roll-out advanced technologies (AMI, DMS, OMS, etc.)** to increase situational awareness considering how increased maintenance savings, reduction in restoration costs, and effective cost-savings can be achieved.

4.5 ALLOWING FOR MICROGRIDS

Microgrids are power systems that can operate and supply electricity to distribution networks without supply from the bulk power grid. Microgrids are an alternative to isolated individual backup generators and are defined as a group of interconnected loads and DERs within a certain electrical boundary that can supply each other [99]. Microgrids can operate in both grid-connected and islanded (grid-disconnected) modes. Since they can operate independently disconnected from the bulk power grid, microgrids have the potential to support improved system resiliency, especially during times when the power grid cannot supply power [100].

> Determining the technical and regulator infrastructure to deploy microgrids safely and reliably still needs to be overcome.

With increase in natural and human influenced disasters, there is a growing interest globally to deploy microgrids. Utilities and regulators are rethinking how microgrids can be developed and deployed in a safe and reliable manner. However, there are many obstacles in the way of microgrid deployment. Determining the technical and regulatory infrastructure necessary to enable them still needs to be overcome [41]. This will also accommodate the increasing penetration of DERs and allow them to be leveraged in microgrid configurations.

Figure 4-31 illustrates how microgrids can be of different sizes with respect to a distribution substation. They can be designed to serve portions of customers on existing distribution feeders, a whole distribution feeder, or even all the customers off a single distribution substation. There is not a one-size fits all approach with respect to microgrid design and operation, as each implementation will have its own challenges and unique design constraints that must consider safety, operational modes, and reliability of the customers it serves.

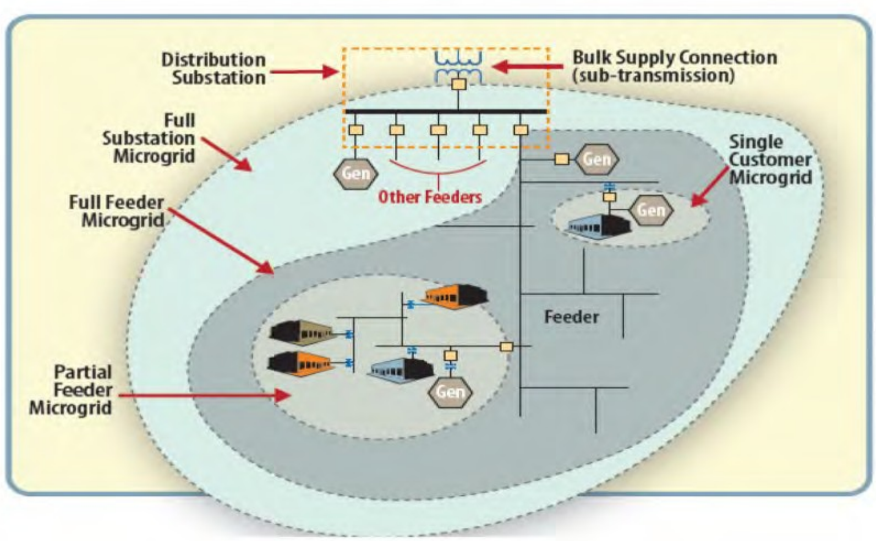


Figure 4-31. Illustration showing different sizes of microgrids that supplying energy to loads off a distribution substation [101]

4.5.1 VALUE & IMPORTANCE

Reasons to take note of ***Microgrids:***

1. Increased resilience
2. Service to essential loads
3. Increased community trust and access to resources
4. Grid modernization will more easily enable microgrids
5. Operational safety and ownership are of concern

The value and importance of microgrids is increasingly becoming realized. Their potential to increase resilience against natural disaster and other extreme events and providing backup service to essential electrical loads are a major benefit. One of these benefits is increasing community trust and more fair and equitable access to resources. As the grid modernizes, DER resources and communication networks that are deployed can be utilized for microgrids, reducing the amount of work required for implementation. However, as microgrids are still not widely and prevalently being implemented, there are challenges and some debate over who and how microgrids are to be operated, in a safe and reliable way. These concepts are explored further in the discussion below.

Increased resilience

For longer duration power outages from the main utility, microgrids can be activated to provide backup power to electric consumers. The value and importance of having backup power sources has been increasingly noticed, as APEC member states are seeing increased numbers of wildfires, storms, and other long-term disruptions that cause significant social burden. When microgrids are designed to serve electric loads under these extreme circumstances, increased resiliency to essential and critical resources can be achieved [100].

Service to essential loads

Microgrids can be costly and challenging to implement, but their value during times of need are significant and acknowledged. Therefore, selecting where and who receives microgrid benefits should be carefully considered. Microgrids have been implemented as community resources, remote off-grid locations (e.g., islands, mountainous areas, etc.), military bases, campuses, and commercial and industrial consumers. Each one of these applications may require different priorities, microgrid operational conditions, and serve different purposes. With limited resources, a formal way to develop strategic implementation and placement of microgrids that evaluate the tradeoffs of societal benefit between candidate microgrid locations may be required.

Increased community trust and access to resources

By carefully and equitably placing community microgrids in locations that will increase services to the underserved, increased community trust and independence can be achieved. In times of need, during natural disaster or other events with prolonged utility outages, microgrids can ensure essential loads in communities (such as at-home air conditioning and heating, community centers, hospitals, groceries, water supply, etc.) can be served, allowing people to withstand such events more comfortably and safely. Therefore, since there is significant benefit and value from community microgrids during times of need, strategically placing microgrids and ensuring access to these resources is done so fairly and equitably should be examined.

Grid modernization will more easily enable microgrids

As DER penetration and communication networks continue to expand to increase situational awareness and advanced distribution grid controls, theoretically, the foundational elements for deploying microgrids will be established. Microgrids will require these elements (DERs as generation and communication networks for safe control and operation) to be functional. This would reduce some of the amount of work that would be required for deployment.

Operational safety and ownership are of concern

Since microgrids position existing infrastructure to be operated in ways never done so before, with the potential for bidirectional flows and different types of power sources, the existing safety mechanisms built into distribution systems by utilities will be insufficient. There is ongoing debate, especially in the United States, over who operates and controls microgrids, and the reasoning behind this is important to understand. Division over whether microgrids should have utility control vs. third-party local control is being debated. A part of this concern also encompasses the need for a more detailed and nuanced set of technical standards [100].

4.5.2 IMPLEMENTATION

Implementing microgrids is not a straightforward effort, as there are many different microgrid applications, and each design will be unique to the electric loads that it serves, existing distribution infrastructure, and what generation resources are used to provide electricity when the utility power grid is disconnected.

Recommendations for implementing ***Microgrids:***

1. Recognize the complexity
2. Install reliable communication networks for a centralized controller
3. Safely and reliably leverage DERs
4. Plan and design for different operational modes
5. Train staff for safe operation
6. Remove regulatory obstacles

Recognize the complexity

As illustrated in Figure 4-31, microgrids can leverage existing distribution infrastructure. The scale at which microgrids can be implemented can also be uniquely configured. The larger the microgrid footprint, the more complex the system and design may become. Therefore, it is important to consider who, what, and where microgrids should be prioritized, as they can be expensive investments.

Install reliable communication networks for a centralized controller

Larger microgrids will require extensive and reliable communication networks to operate in islanded mode reliably and safely, especially if multiple sources of DERs are to be leveraged to supply power. An advanced and centralized controller will be required to manage these different components. The function of this controller may include monitoring the amount of electricity demand in the microgrid, ensuring load and generation balance, receiving renewable energy weather-based forecasts, communicating dispatch orders to connect DERs, and sending commands to automatically sectionalize the distribution network or revise protection device settings. In more advanced microgrids designs, access to the energy marketplace could also be considered; however, this concept is not well developed.

Safely and reliably leverage DERs

As DER penetration increases, without the implementation of microgrids, they can be leveraged for future microgrids. However, the more DER components attempted to leverage, the more complicated a microgrid system may become operationally. When a traditional distribution grid is designed to operate under one scenario with one power supply source, microgrids challenge existing infrastructure to now operate under many different system configurations and generation resource scenarios. Distribution networks are not traditionally designed to handle bi-directional flow. Ensuring electrical stability, reliability, and safety under all these different system configurations can be complicated but is required for successful implementation.

Plan and design for different operational modes

When microgrid communication networks go down, alternative operational modes may need to be considered. Large microgrids may not be able to fully operate safely and reliably without intact communication networks. Therefore, under some circumstances, microgrids may need to operate under loss of communications. Installing and effectively programming many smart devices, like bi-directional reclosers and switches, along distribution feeder networks to operate autonomously will be beneficial.

Train staff for safe operation

Microgrids will require well-trained operational staff, and this can be a significant challenge needing additional resources. Whether this is done by utility operational personnel or a third party, successful operational of a microgrid will likely need human interaction and monitoring. This also requires personnel who are well versed in the technical and safety implications of microgrid operations. Enhanced safety practices must be developed and enforced to prevent loss of human life and damage to infrastructure, as the complexity of safely protecting and operating microgrid systems increases from traditional radial operation of distribution feeder networks.

Remove regulatory obstacles

Regulatory guidance and microgrid tariffs may be a useful mechanism to hasten the deployment and commercialization of microgrid technologies, in a safe and reliable way. Debate over whether microgrids should be operated and maintained by distribution utilities or by third parties should be explored.

Figure 4-32 illustrates an example of an advanced community microgrid system that leverages a communication network to monitor and control electric loads and DERs. It also shows communication to the utility distribution control center, transmission control center, and the energy marketplace. In addition, it illustrates that the system as a whole will operate under cyber-secure conditions.

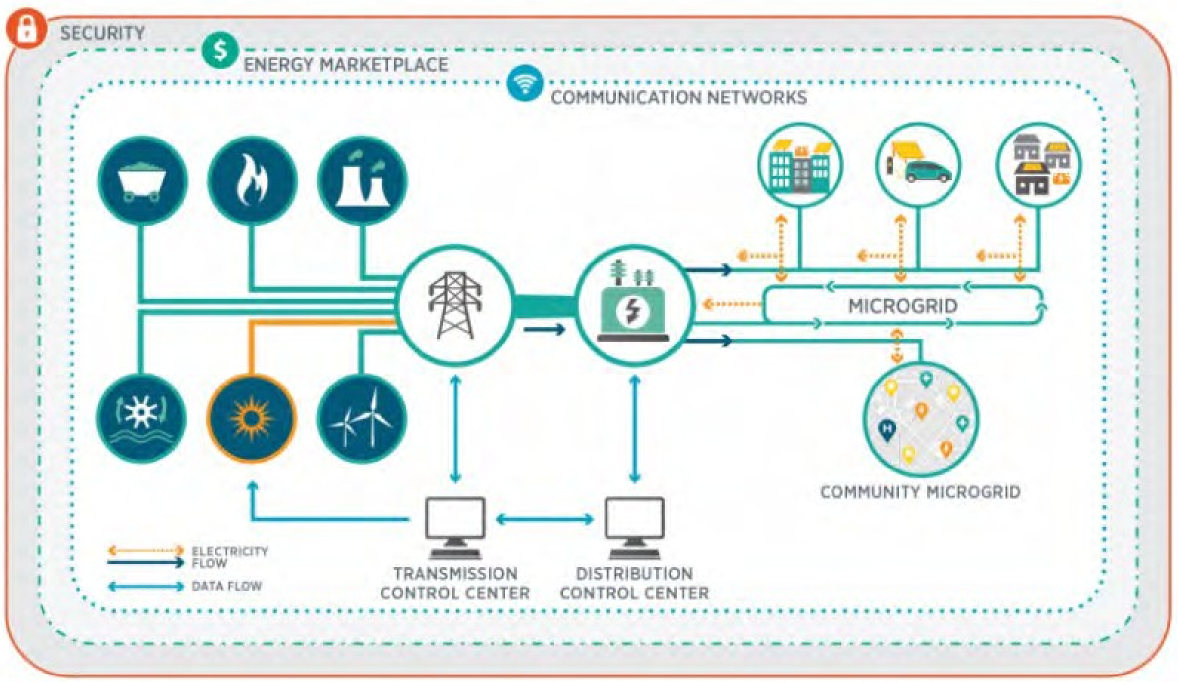


Figure 4-32. Advanced community microgrid example that leverages communication networks [102]

4.5.3 TECHNOLOGY & APPLICATION READINESS

There are two main high-level components that are highlighted in this section. These include a microgrid interface controller, and microgrid tariff and regulation mechanisms.

4.5.3.1 MICROGRID TARIFFS

Deployment of microgrids that use existing distribution infrastructure owned by a utility are not extensive in industry yet, nor do standard tariff designs exist. Microgrid tariff designs need to consider a multitude of issues, as illustrated in the top table of Figure 4-33. This includes defining microgrid terminology, understanding what the different microgrid archetypes include, establishing microgrid requirements, and grasping the different microgrid island operational structures.

In the bottom of Figure 4-33, key considerations in a microgrid services tariff is listed. These considerations will point to how to structure a microgrid tariff. They include tariff structure and eligibility, microgrid interconnection and islanding capabilities, microgrid services, compensation mechanisms, and utility-provided services. More detail on these key considerations and microgrid tariff design can be found in this report [103].

Policy makers and regulators are needed to guide the development of microgrid tariffs to ensure fair compensation of electricity and electric grid services that would be benefited by the electric utility, the person, or entity operating the microgrid.

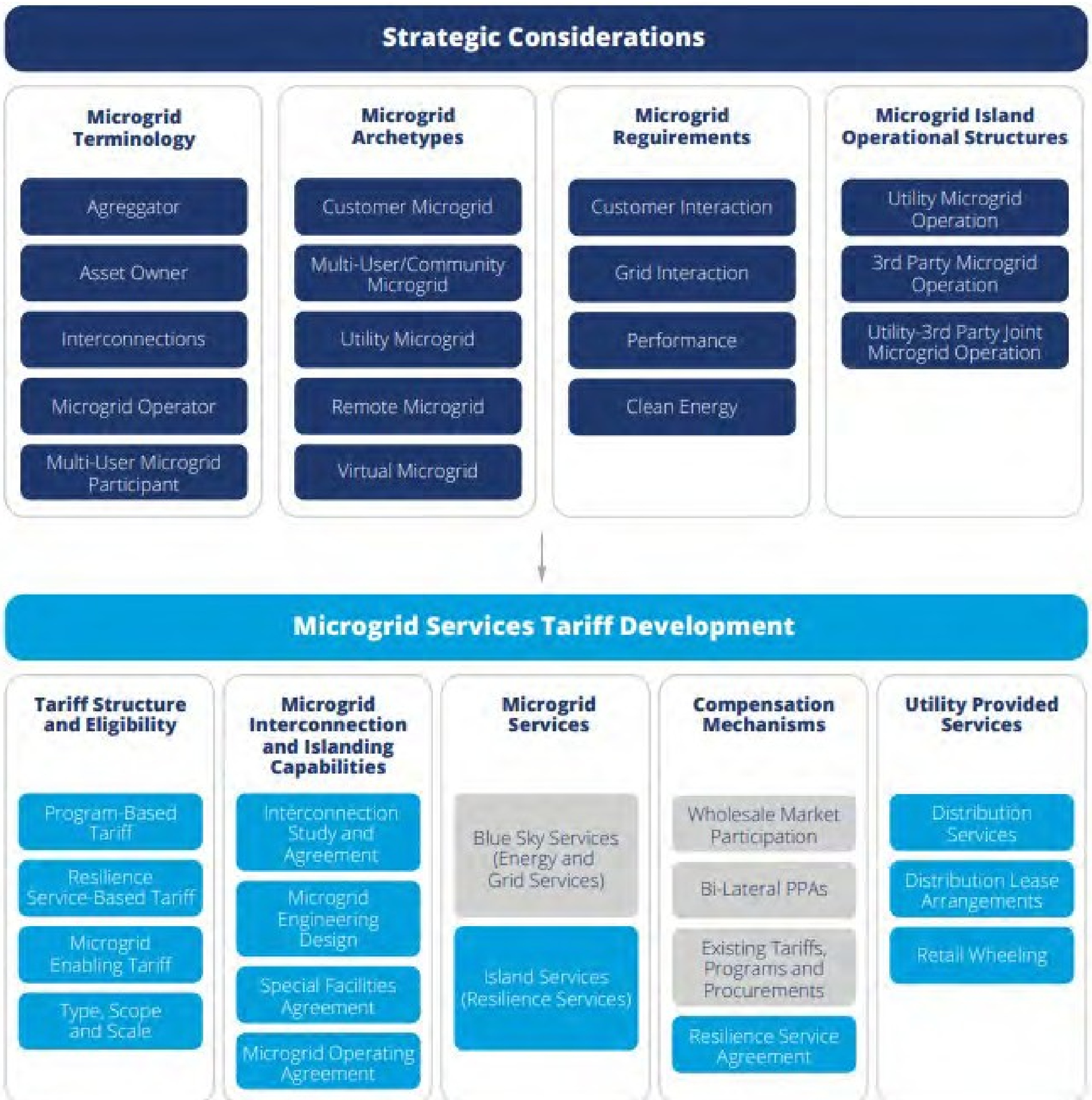


Figure 4-33. Strategic considerations that feed into microgrid services tariff development [103]

4.5.3.2 MICROGRID TECHNICAL SPECIFICATIONS

Distribution utilities should develop technical specification documentations for the interconnection of microgrids. These technical specifications should include everything necessary to ensure the microgrid will not affect the reliability and the safe operation of the distribution network. Technical specifications should encompass issues around voltage and power quality, system protection, control, and monitoring systems to detect and prevent abnormal conditions. It should also encompass requirements regarding the safe transition between grid-connected and islanded modes, as well as require documentation and diagrams of all possible microgrid system configurations when operated in islanded modes.

An example of microgrid technical specifications for a distribution planning utility is referenced in [104].

There are some tools that are available for microgrid developers to start the design process that can help ensure microgrid designs will better satisfy interconnection technical requirements. Sandia National Laboratories has developed the Microgrid Design Toolkit (MDT). This tool was built to provide decision support for microgrid designers in the early stages of the microgrid design process. This tool is publicly available for download [105].

4.5.3.3 MICROGRID INTERFACE CONTROLLER

A microgrid requires the coordination of various components to operate successfully and safely. This can be achieved by deploying a microgrid controller that interfaces with these different elements. These elements include loads; protection devices that can connect, disconnect, and sectionalize the distribution network; measurement and situational awareness devices; communication network; and operational modes. Microgrid controllers and their functions can vary drastically from one microgrid to another. Each one will need to be uniquely configured by experienced engineers and technicians.

Adoption maturity for microgrid interface technologies is in the “Operational Demonstrations” of technology readiness, as illustrated in Figure 4-34.

A microgrid interface controller may interact with other systems and technologies, including DERMs if implemented. As described in a previous section, DERMS may utilize similar monitoring and communication equipment that microgrids can interface with to operate reliably. In fact, these control systems may be centralized in similar locations. Figure 4-35 illustrates this interaction.

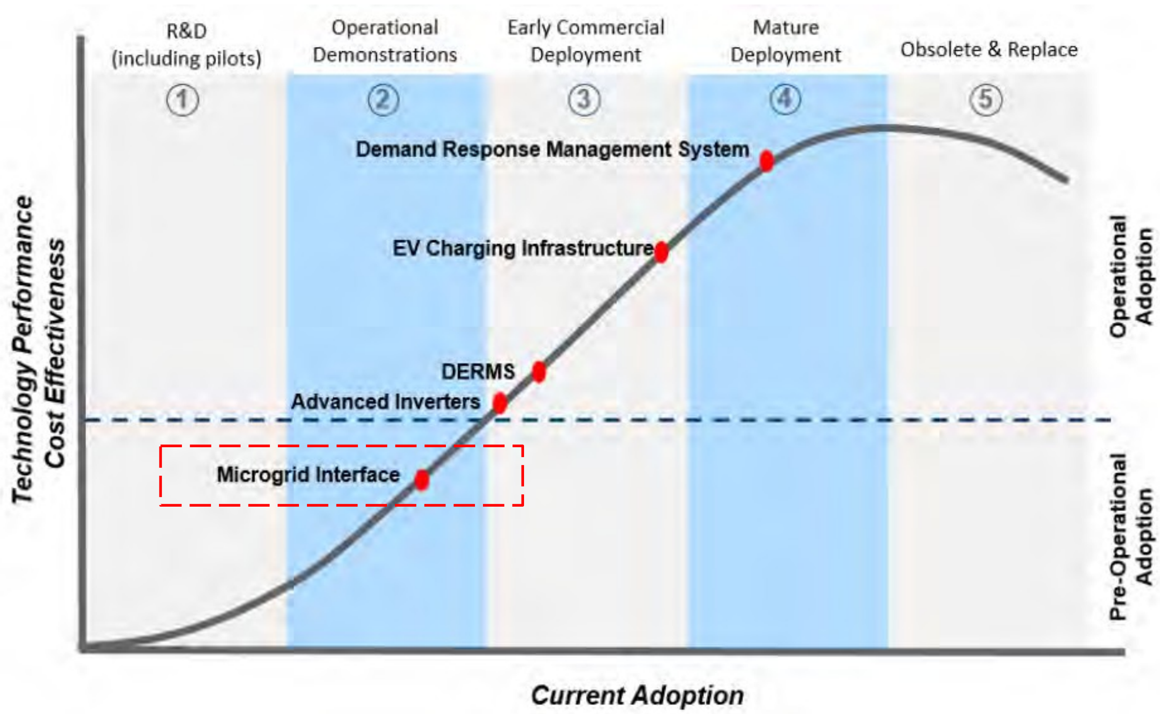


Figure 4-34. Adoption maturity for microgrid interface controller [38]

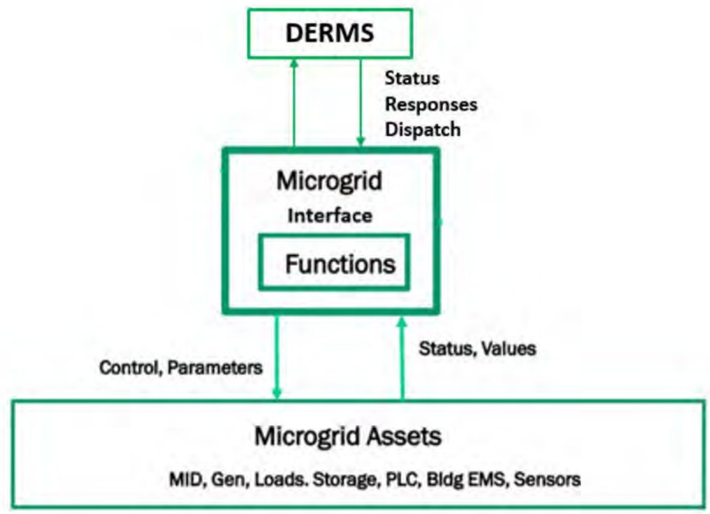


Figure 4-35. Example microgrid interface controller demonstrating interaction with DERMS technology [38]

4.5.4 APEC MEMBER DEVELOPMENTS

This section highlights APEC member experiences with allowing for microgrids. The economies highlighted include the United States, Australia, and South Korea.

4.5.4.1 CALIFORNIA, UNITED STATES

Within the backdrop of extended power outages due to California wildfires over the past several years, microgrids have been identified as a potential solution to mitigate extended outages during these extreme events. The California Public Utilities Commission (CPUC) enacted a state law (SB 1339) in 2018 to further develop policies related to microgrids [106]. As a result of this effort, in 2021 a Microgrid Incentive Program was authorized with a US$200 million budget [106]. As copied directly from the CPUC website, the Microgrid Incentive Program intends to provide the following:

- *Increased electricity reliability and resiliency in communities that may be at higher risk of electrical outages.*
- *Increased reliability for critical infrastructure facilities such as fire stations, schools, and nursing homes that keep communities safe.*
- *Reduced impacts of power outages and minimized disruptions for low-income households, individuals who rely on un-interrupted power, utilize assistive and/or medical equipment, or experience other access and functional needs.*
- *Reduced Greenhouse Gas emissions by deploying clean generation technologies and expanding the market for resiliency solutions that do not rely upon diesel generation.*

Microgrid deployment in California is being attempted to be performed in such a way that does not shift the cost to customers [107]. CPUC has also initiated microgrid rulemaking to facilitate the commercialization of microgrids for distribution customers of large electrical corporations, which would include developing standards, protocols, guidelines, methods, rates, and tariffs that eliminate barriers [108].

4.5.4.2 HAWAII, UNITED STATES

On the island of Oahu, an operational microgrid sized around 50 MW is located at the Schofield Barracks U.S. Army base [109]. It is designed to be fuel-flexible, requiring 50 percent biofuel. This microgrid is designed to be utilized during emergencies to provide power to military facilities. It also supports black start capability for outage recovery, frequency response, voltage result, and system inertial response.

Hawaii is working to promote further development of microgrids with Act 200, which was passed by legislature in 2018 [110]. This piece of legislature identified that Hawaii’s residents and businesses are vulnerable to power disruptions caused by extreme weather events. Microgrids could be a valuable resource to be deployed on the island, as it can also facilitate the achievement of Hawaii’s clean energy policies by enabling the integration of higher levels of renewable energy and advanced DERs. Hawaii’s Act 200 directed the utility commission to create a microgrid services tariff, designed to standardize microgrid interconnection and to assess the value of microgrid services.

Hawaii’s preliminary efforts in designing the components within a microgrid services tariff can be found it this referenced docket from their public utilities commission [111]. Preliminary categorization of customer versus hybrid microgrids is illustrated in Figure 4-36.

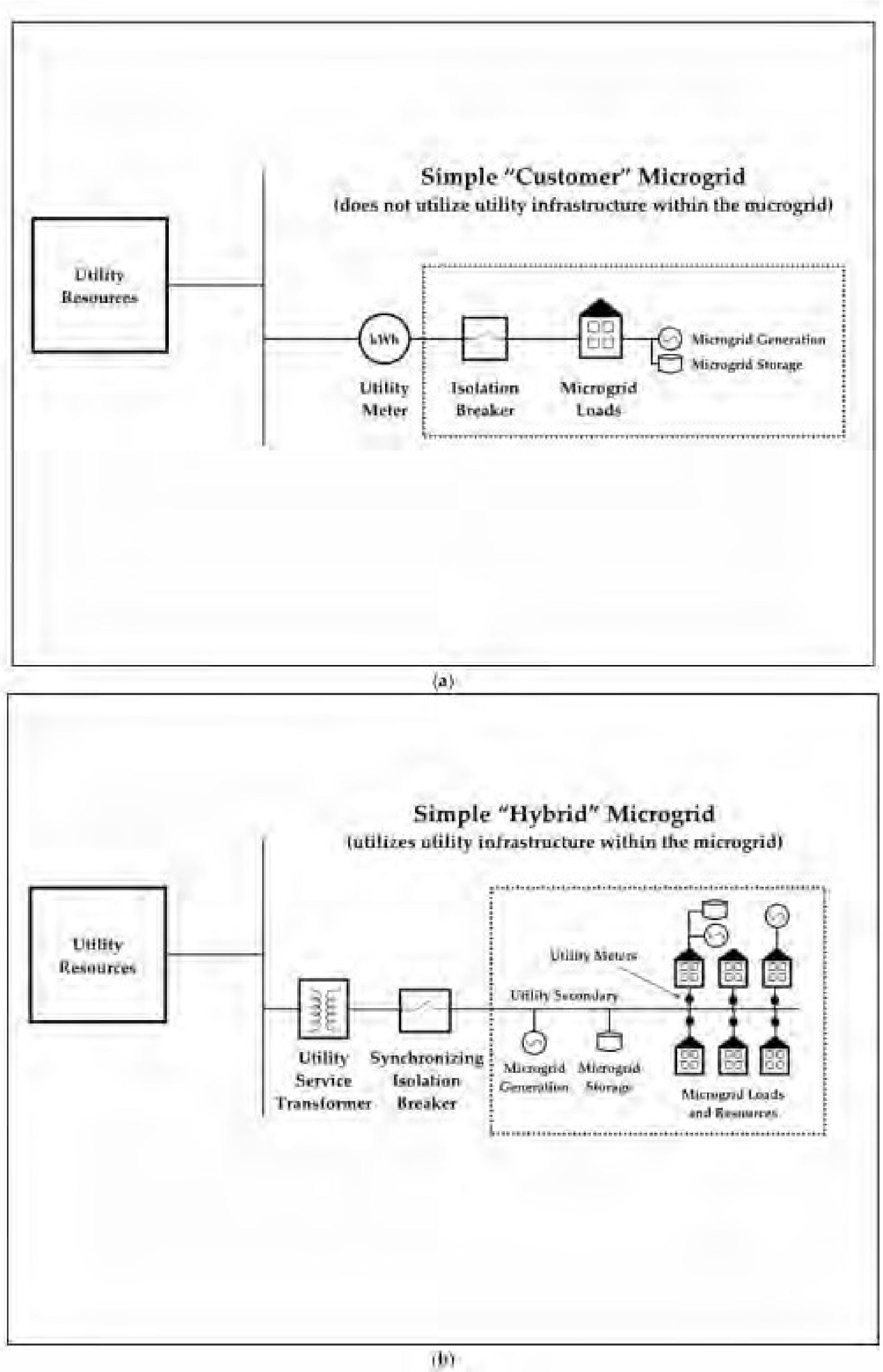


Figure 4-36. Microgrid categories proposed in Hawaii's microgrid services tariff with (a) being a customer microgrid that does not utilize any utility infrastructure and (b) being a hybrid microgrid that does utilize utility infrastructure [109]

4.5.4.3 AUSTRALIA

In Australia, microgrids are being used to manage and address challenges related to rapidly increasing electricity costs, aging infrastructure, and the need to serve very large geographically dispersed areas.

Australia is incorporating more and more microgrids of different settings, including islands, off-grid, and grid-connected configurations.

An example of an effective microgrid program is in the Australian state of Victoria [112]. The extreme wildfire conditions in 2019 and 2020 triggered a feasibility study to assess the potential of installing new resilient energy infrastructure to improve community resilience during future extreme weather events. The Microgrid Program was established in May 2021 and will deploy microgrid installations made up of solar, batteries, and other DERs to ensure essential services for high-risk rural communities receive improved resilience. Examples of microgrid projects deployed in Victoria are shown in Figure 4-37.

The microgrid projects [112] funded in the state of Victoria will include exploration of the following concepts:

- Smart microgrid controllers that can coordinate solar and battery storage in microgrid configurations
- Leveraging microgrids in rural end-of-the-grid locations across Australia to reduce lower power prices and more reliable and resilient power supplies to residents in bushfire prone areas
- The business case and regulatory barriers for the deployment of third-party microgrid electricity market operators
- Testing of commercial viability of microgrid energy market interactions, with such a framework illustrated in Figure 4-38.

Figure 4-37. Microgrid projects funded under the Microgrid Demonstration Initiative in Victoria, Australia [112]

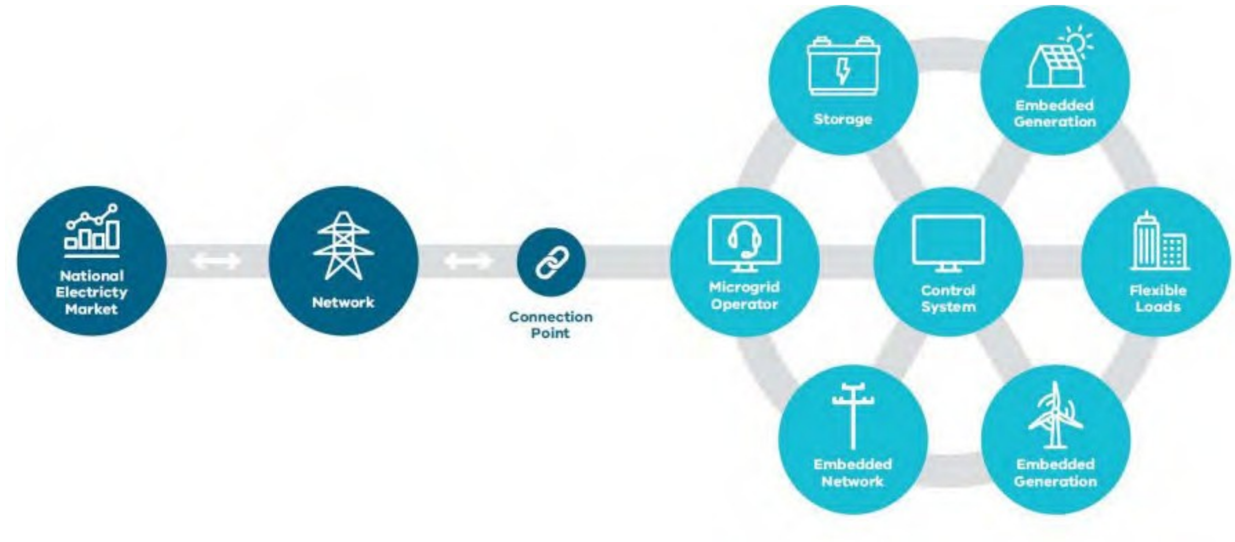


Figure 4-38. Community-based microgrid system interactions with energy market in Victoria, Australia [112]

4.5.4.4 JEJU ISLAND, REPUBLIC OF KOREA

Various Korean microgrid technologies have been commercialized since 2010, such as the Jeju Island microgrid, which was the first self-sufficient implementation in the Republic of Korea (ROK) [113]. This microgrid demonstrated a microgrid that connected solar, wind, and energy storage and is now a commercialized model of an energy-independent system [113]. Jeju Island is now seeking to fully decarbonize vehicles and electricity generation by 2030, as well as demonstrate a functioning smart grid project. If successful, the application and design would be transferred to the entire economy [114].

During the development and commercialization of microgrid technology by ROK, the government enacted several laws to establish the foundation for successful deployment, including [113]

- Low Carbon Green Growth Basic Act (Sept. 30, 2016)
- Energy Act (Sept. 23, 2016)
- Energy Use Rationalization Act (Aug. 12, 2016)
- New Energy & Renewable Energy Development, Use, and Distribution Promotion Act (Sept. 23, 2016)
- Collective Energy Business Act (Jan. 6, 2016)
- Green Building Support Act (Aug. 1, 2019)
- Act on the Construction and Promotion of Smart Grid (Sept. 22, 2017).

In ROK, the focus of microgrid deployment is now being applied to smart towns and cities. New legislation has been added, including the New Smart Grid Policy [113]. This policy includes expansion, construction, and deployment of smart grid services, as well as foundation for smart grid expansion, which includes self-sufficient microgrids in urban areas. Investment for such a deployment is US$2 billion every five years [113].

4.5.5 KEY TAKEAWAYS & RECOMMENDATIONS

Microgrids can increase resilience against natural disaster and other extreme events, among other benefits. They can be utilized to ensure service to critical loads that economies and communities depend on to function. Microgrids can result in increased community trust and access to resources for many, especially during times of need. As the grid modernizes, the ease of deploying microgrids should improve, as advanced technologies, communication networks, and increased DER penetration can all be leveraged. Operational safety and ownership mechanisms should not be overlooked by APEC economies. Microgrids introduce unique complexity in operation and maintenance, and guidelines for the deployment strategies, design, and operational training should be considered.

Therefore, recommendations for policy and regulating entities, as well as distribution planning entities, are the following:

Recommendations for Allowing for Microgrids	
Policy and Regulating Entities:	Develop technical and regulatory rulings and guidance for distribution planning entities and microgrid developers that will **enable safe and effective deployment and operation of microgrids,** including grid-connected and isolated microgrid configurations.
Distribution Planning Entities:	Allocate resources to improve planning and operational strategies for the deployment of microgrids that incorporate safety requirements and engagement with consumers to **identify essential/critical community resources** or regions needing improved reliability and resiliency.

4.6 ESTABLISHING EQUITABLE RECOVERY STRATEGIES

With climate change and the uncertainty of unforeseeable extreme events, APEC economies will continue to experience more frequent and more intense extreme events and natural disasters. These events will strain the operation, reliability, and resiliency of electric infrastructure, especially electric distribution networks. Being able to quickly recover post-disaster, and doing so equitably, is becoming more important as we continue to document the increasing social impact of such disasters. It is crucially important to begin planning for these recovery strategies and ensure they are equitable in advance.

> Being able to quickly recover the distribution grid post-disaster, and doing so equitably, is becoming more important as we continue to document the increasing social impact of extreme events

Investments to improve restoration response cuts across formal documentation of recovery strategies, information technology, operations technology, and improved business operations during both normal and abnormal grid conditions [115].

Restoration strategies for the distribution grid are especially important post natural disaster, as it usually represents the last mile required to restore power to the most in need and to essential services. This last mile effort is demonstrated Figure 4-39, where usually bulk grid power plants and transmission assets are prioritized first for restoration, then essential emergency responders, and then down to the individual customer level on the distribution system. Incorporating equity considerations throughout this process is an area that requires improvement globally.

The concept of equity confronts the problem of how to address injustices facing underserved communities. Underserved communities may be defined and understood with respect to environmental justice, minority, low-income, disadvantaged, indigenous, vulnerable, frontline, fenceline, economically distressed, or pollution impacted [116]. Equity should be incorporated in all aspects of distribution planning but should be especially considered in disaster recovery strategies.

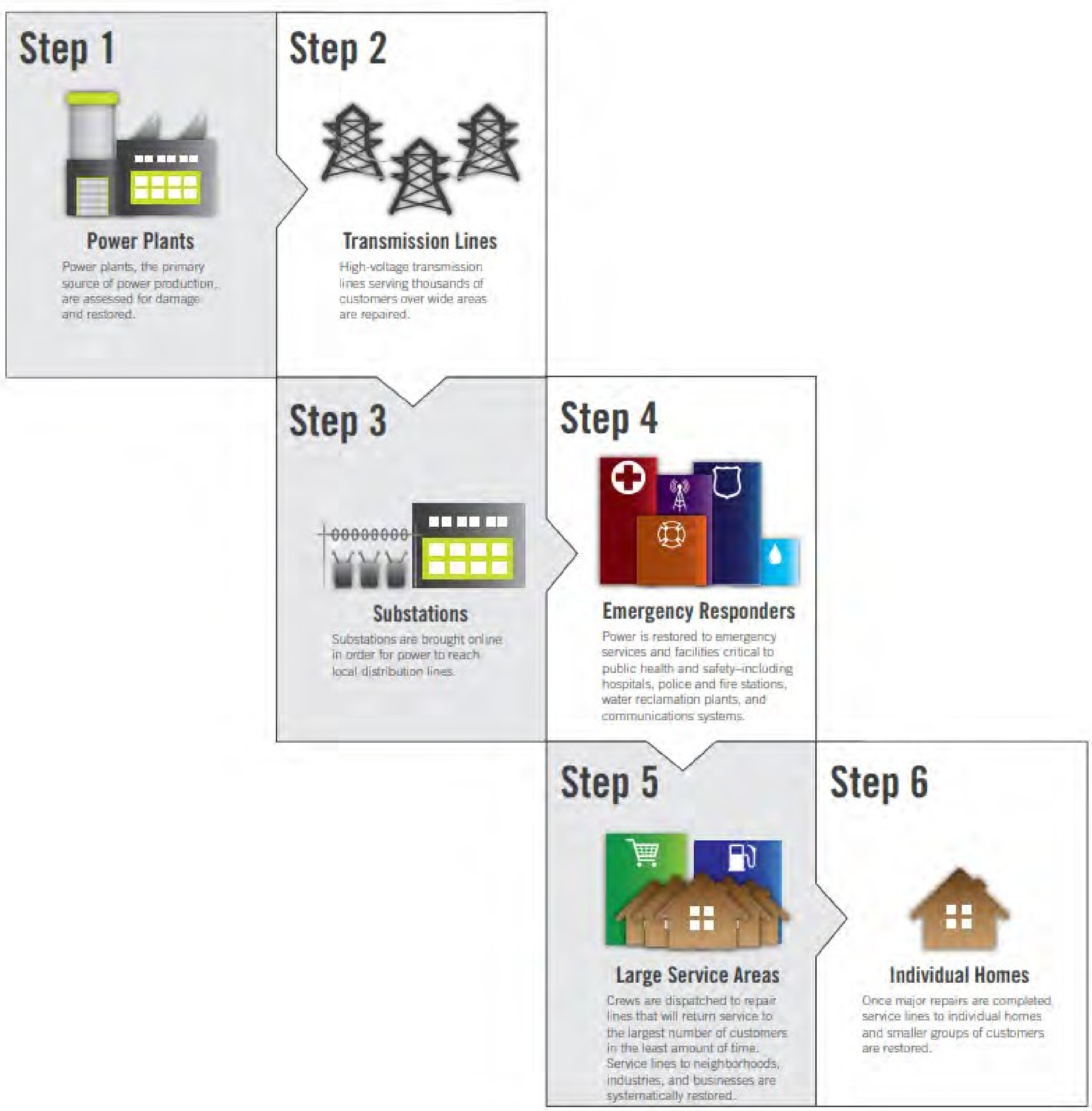


Figure 4-39. Electric utility traditional storm response process [117]

4.6.1 VALUE & IMPORTANCE

Disaster relief and recovery preparedness is of great value for APEC member economies to protect the safety and way of life for the millions of livelihoods their economies serve. Incorporating equitable recovery strategies in short-, mid-, and long-term distribution planning and operational procedures is one way to minimize social impact post-disaster. Ensuring that these practices are fair and equitable, as best as possible, will also be crucially important. Learning from previous disaster experiences will provide great value in developing the recovery strategies, as the world has seen the failures and successes of post-disaster recoveries time and time again.

Reasons to take note of ***Equitable Recovery Strategies:***

1. Minimize social burden
2. Ensure fair and equitable practices
3. Learn and improve from previous disaster experience
4. Significant room for improvement globally

Minimize social burden

Having equitable recovery strategies in advance of extreme events will minimize outage durations, expedite system recovery, and enhance overall system resilience. Being able to do so in a quick and effective way will minimize the social impacts of disaster that have historically disabled essential infrastructures that supply populations with essential heating or cooling, clean water, accessibility to hospitals, groceries, shelters, and other resources to survive and maintain safety. Reducing the time of exposure to such events by having plans in place to quickly restore, rebuild, and reenergize power distribution networks will be essential to minimizing social burden and returning to a functional economy.

Ensure fair and equitable practices

During times of disasters, prioritization of electrical infrastructure restoration becomes a natural part of the recovery process. Distribution planners and operators, along with guidance from governmental regulatory entities, must make the often-challenging decisions of what infrastructures, and whose, should be prioritized to receive recovery attention. Load classification and prioritization is becoming even more important in developing pre- and post-disaster recovery strategies. Not often done so today, load classification efforts should consider integrating socioeconomic, demographic, risk assessments, and information on vulnerable populations into the recovery planning and decision-making activities of distribution grid recovery strategies. By doing this, APEC economies can recover their distribution networks from disasters in such a way that supports sustainable and economically resilient communities.

Learn and improve from previous disaster experiences

In preparation for the effects of widespread electrical disasters, it is worthwhile to consider and review disaster experiences that various nations have suffered from, especially those that experience similar threats. Loss of life and physical damage caused by the disasters greatly impact global commerce and societal burden. Not only is disaster preparedness an issue for individual economies, but it is also a shared global issue.

Significant room for improvement globally

Substantial improvement is needed to develop post-disaster recovery strategies that are resilient and equitably sound. A large amount of work is needed, from the standardization of classification of various types of disaster, to measuring and reporting a facility's preparedness, to the preparation of detailed recovery roadmaps and guidelines. Training for disaster prevention, adopted to manage different classifications of disaster and that is unique to geography and vulnerable infrastructure make this a challenging ask. However, it highlights the importance of individual APEC economies and governments taking a closer look to identify their unique risks of natural disaster to their electrical distribution systems and develop equitable recovery strategies appropriately.

4.6.2 IMPLEMENTATION

An overall recovery strategy should be a well-documented, tested, transparent, and technology bolstered roadmap that addresses an all-hazards approach to restoring the grid. It should be re-evaluated after every disaster and made public for increased awareness and feedback. It should include measures for pre-event mitigation efforts, classification of loads, advanced asset management, training procedures, and DER utilization, to name a few.

Recommendations for implementing **Equitable Recovery Strategies:**

1. Ensure system hardening measures are in place in advance of extreme events
2. Classify criticality of loads
3. Develop annual training programs
4. Improve utilization of DERs and microgrids

Ensure system hardening measures are in place in advance of extreme events

Part of achieving a robust equitable recovery strategy will require certain aspects of the distribution planning processes to be advanced to ensure mitigation measures are in place prior to extreme events. An example of this is distribution system infrastructure hardening measures, which will not only increase system reliability in the near-term, but support resiliency in the long-term, as well. These include increased and improved procedures for vegetation management, infrastructure undergrounding, pole reinforcements, water protection, and increased physical security [16].

Classify criticality of loads

In addition, a database containing classifications of loads and their criticality can be improved upon to assist with post-disaster recovery prioritization efforts. Currently, there are no widely implemented industry standards to indicate the priority of various loads [118]. From residential dwellings to medical facilities, office spaces, and data centers, restoration strategies must include an understanding of the different types of loads the distribution load territory is serving and must identify a methodology to prioritize restoration. By understanding critical electric loads, we can work closely to minimizing social burden. Prioritization of restoration should be based on factors including the criticality of the load and the availability of resources to complete the needed repairs [16]. But what also should be considered is equitable recovery of such load, which can be an area easily overlooked.

Develop annual training programs

Developing annual training programs for storm preparation or other types of disaster events is another area for successful implementation of equitable recovery strategies. Common shortcomings of storm response include limited preparations prior to extreme events, insufficient knowledge development, and lack of role-based training and simulation [119]. Leveraging modern-day technology to provide real-world extreme event response practice should be a vital part of recovery strategy programs for distribution network planning and operations.

Improve utilization of DERs and microgrids

As discussed in section 4.2, DERs can have significant potential for providing grid solutions and increased resiliency. If planned for and demonstrated in advance, they can be used to provide temporary microgrid services when the transmission system becomes unavailable. However, as of right now, DERs generally cannot be relied upon to supply energy after major electrical disaster [118].

4.6.3 TECHNOLOGY & APPLICATION READINESS

As discussed in previous chapters, integrated resource planning, DERs, increased situational awareness, and microgrid technologies can all play a role in improving distribution system resilience and system restoration. Additional technologies that have not yet been highlighted that could greatly enhance equitable recovery strategies are discussed in this section.

4.6.3.1 ASSET MANAGEMENT SYSTEMS

An essential component of advanced asset management systems is to better evaluate risk. Risk is a combination of impact and likelihood, as shown in Figure 4-40. Utility assets and operations are considered critical and essential infrastructures, with some infrastructures posing higher risk than others with regards to failure impact [121]. Resiliency measures that are primarily taking place today include system hardening and outage management systems. But another strategy electric utilities can take are preventative maintenance strategies guided by strategic asset management systems. With increased data, the ability to collect near real-time operational data on the health and conditions of assets in the field will change asset management practices from one of scheduled maintenance to condition-based maintenance (CBM). CBM can leverage advanced analytics to identify potential or early-stage operational issues in order to prevent failure in advance [38]. It includes the application of sophisticated machine learning/artificial intelligence algorithms to assess and predict asset conditions and determine preventative maintenance in advance of catastrophic failure [38].

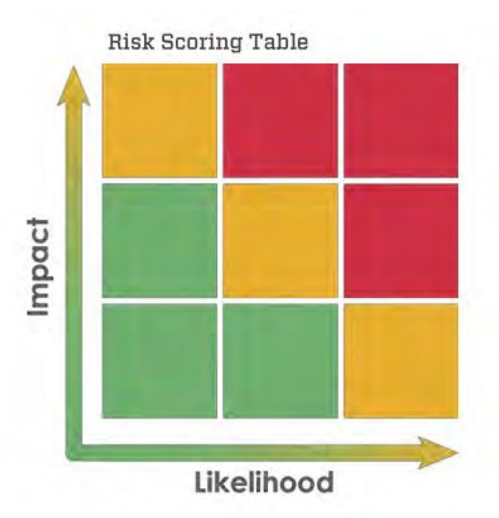


Figure 4-40. Generic risk scoring table illustrating high risk correlation to high impact and high likelihood [120]

Traditional asset management tools and databases are widely available; however, advanced asset management systems, such as CBM, are emerging. An adoption maturity analysis for asset management tools, specifically CBM, was conducted by DOE's Office of Electricity. Figure 4-41 is from this analysis and shows that DER forecasting tools are in the "Early Commercial Deployment" of technology readiness. Tools are currently available on the market for CBM-based asset management applications.

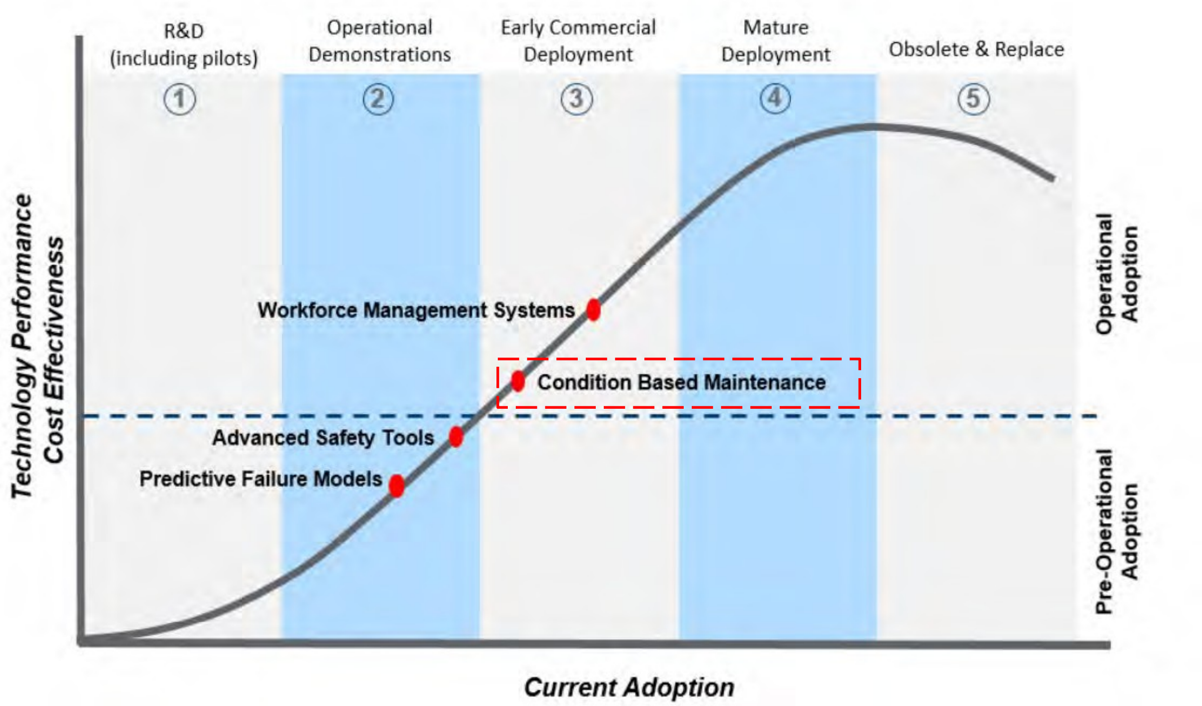


Figure 4-41. Adoption maturity analysis for CBM (asset management) [38]

4.6.3.2 GIS & HAZARD MAPS

A Geographic Information System (GIS) can be a very useful tool to visualize, capture, store, manipulate, analyze, and manage all types of geospatial data [38]. Acquiring detailed distribution system GIS data will enable distribution planners to understand and visualize distribution systems more effectively, and they can be excellent tools in disaster recovery efforts, especially when onboarding individuals not familiar with geographics and network topology in a region.

Additional GIS mapping layers could be acquired and overlaid with grid infrastructure GIS to reflect land-based data, streets, vegetation, census data that include equity-based metrics, and much more. Hazard maps that also overlay the risk of a specific type of extreme event or natural disaster can be a useful tool in developing recovery strategies, as well. An example of a flood hazard map is shown in Figure 4-42.

Figure 4-43 shows that GIS tools are in the "Mature Deployment" of technology readiness.

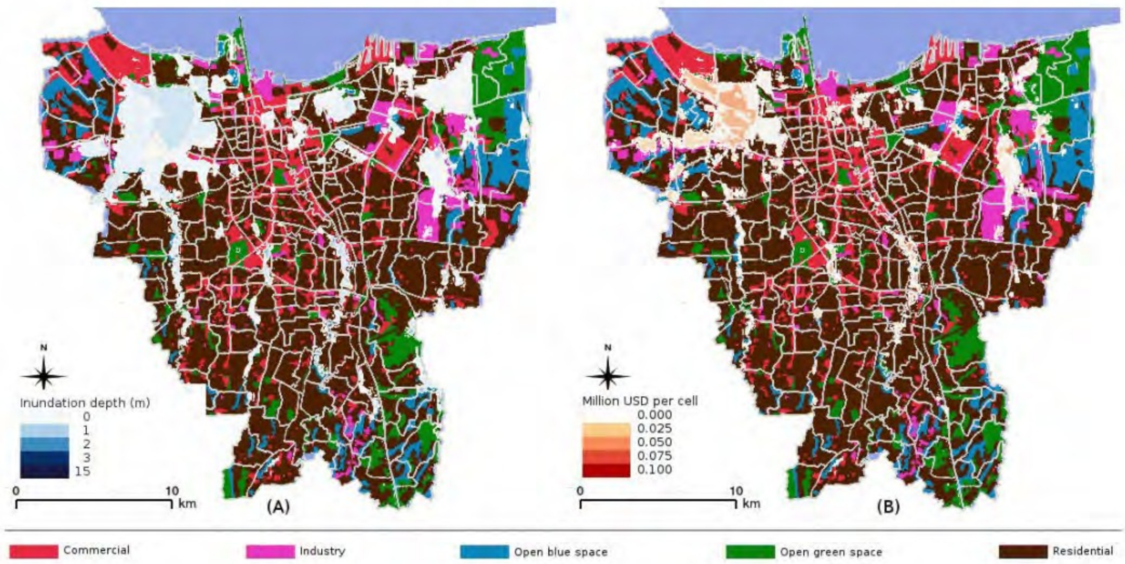


Figure 4-42. River flood hazard map for Jakarta, Indonesia [122], that could be leveraged in developing equitable distribution system recovery strategies

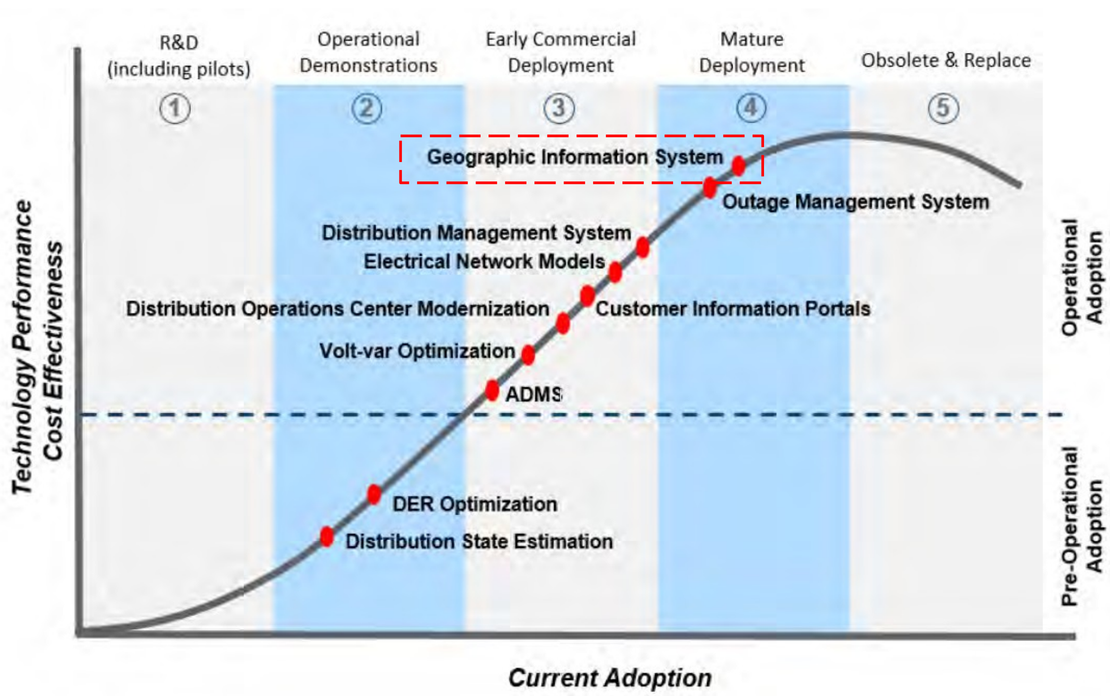


Figure 4-43. Adoption maturity analysis for GIS [38] (licensed under CC BY 4.0)

4.6.3.3 EMERGENCY RESPONSE DRILLS & TRAINING SIMULATORS

Training drills and exercises to ensure preparedness prior to extreme events are a critical component of resilience [18] and are typically conducted annually [123]. This includes performing extreme event drills to train DSOs, engineers, field personnel, and other workforce, especially those that may not routinely perform restoration duties that would be leveraged in recovery efforts post disaster. To train these individuals, there are many different types of processes and exercises that could be put into place, as discussed in an EPRI report [123]. Advanced training simulators can also be used, which are meant to replicate emergency scenarios that can make training events realistic and relevant to extreme events that pose highest risk to certain regions [124].

Additionally, emergency response training should consider how restoration efforts should be prioritized. For a distribution system, a methodology should be developed, documented, and tested in emergency response drills and simulations. An EPRI report discusses prioritization methodologies that could be considered for distribution system recovery [125]. There is a need for distribution system planning entities to identify and have knowledge of priority customers and loads that also ensure an equitable approach.

An example storm response planning checklist that might be incorporated into emergency response training and drills in some ways are listed in Figure 4-44.

Strategy	Action
Resources – changes	Assign resources to roles. Review retirement eligibility and succession planning for key roles
System changes	Review critical IT system changes, schedules and role-based impact. Adjust schedules to minimize the impact top storm season
Process changes	Evaluate planned organizational changes, system changes, and corrective actions from previous post incident critiques and the related role-based process revisions
Event Profiling	Create evaluation criteria data sheets and gather or evaluate against rolling ten-year data. Hint: Make this a component of every event debrief – create a dashboard
Event Segmenting	Segment results into low, medium, and high impact events. Incorporate even debrief comments for evaluation
Stakeholder report out	Summarize findings and recommended planning for corrective actions
Gap resolution	Budget, assign, and manage corrective actions to closure
Storm Response Level	Update level criteria based on data and debriefing observations.
Updates	Look critically at lead time and geography related decisions and actions.
Create preparation timeline	Create the off season timeline and response group definition revisions from previous year success and failures. Create call out schedule for the upcoming season. Best and most experienced leading this effort
Review foundational training	Identify revision requirements. Revise, schedule, and deliver
Review role-based training	Identify revision requirements. Revise, schedule, and deliver
Review small group simulations	Identify revision requirements. Create new simulation scripts, schedule and evaluate small group simulations
Determine Multi-site drill scenario and timeline	Establish drill objectives by role. Identify key inputs and expected responses. Identify controllers/evaluators. Schedule training for controller/evaluator roles
Stress Test systems	Ensure system can respond to high volume events when loaded with data and users
Create backup plans	Identify manual processes for critical system failures

Figure 4-44. Storm response planning checklist [119]

4.6.3.4 DMS

Also previously described in section 4.4.3, with respect to increasing situational awareness, DMS integrates a distribution utility's GIS to enable modeling, analysis, simulation, and tracking of real-time distribution system conditions. DMS can be especially valuable for recovery and outage management. It can track customers impacted by outages and the status of work crews and repairs [115]. It can also support reporting approximate outage restoration times to share with customers impacted. Pushing DMS to also consider equity, explicitly, which is often overlooked, is another valuable industry opportunity.

4.6.4 APEC MEMBER DEVELOPMENTS

This section highlights APEC member experiences with establishing equitable recovery strategies. The economies highlighted include the United States, Philippines, and Australia. It is important to note that equity is a nontraditional element not yet widely called out in recovery strategies explicitly; the examples below do highlight components of equity, but the terminology of equity may not be directly cited in the references. Being clear in documentation about what recovery strategies are addressing equity is an industry gap that requires improvement globally.

4.6.4.1 WASHINGTON STATE, UNITED STATES

States along the Pacific Coast have been experiencing increasingly catastrophic wildfire events, from California to Washington State. With respect to disaster preparedness strategies, Puget Sound Energy (PSE), a privately owned vertically integrated power company in Washington State, made available their Wildfire Mitigation and Response Plan [126]. In this public plan, PSE documents their plan objectives, wildfire risk, mitigation, and response plans, as well as their operational procedures and emergency response. PSE has a relatively large territory of T&D networks to operate and manage, with unique geographic features that make some regions more at risk to wildfire, as shown in Figure 4-45. In the effort to increase situational awareness and support operational emergency response, PSE developed a wildfire dashboard, shown in Figure 4-46, to better visualize daily wildfire risk using GIS layers that correlate to PSE's power grid assets. In terms of asset management, PSE performs pre-wildfire season inspections and attempts to mitigate imminent concerns prior to fire season.

Due to other risks in PSE's region, such as severe weather (wind, snow/ice, extreme temperatures), they also maintain an Energy System Restoration Plan that elaborates in detail their distribution system infrastructure and customer restoration priorities [127]. Within this restoration plan, PSE considers the following list of customers that would receive priority restoration during and after extreme events:

- Hospitals
- Regional airports
- Water, wastewater treatment plants and/or sewage pumping stations
- Other community-critical infrastructure, such as emergency response facilities
- Emergency shelters
- Facilities from which people cannot be easily relocated, such as nursing homes, assisted living facilities, etc.

An example of how PSE prioritizes distribution feeder recovery based on customer classification is shown in Figure 4-47.

Additionally, PSE conducts extreme event exercises at least annually, using simulated and tabletop exercises to ensure readiness prior to high-risk weather seasons [127].

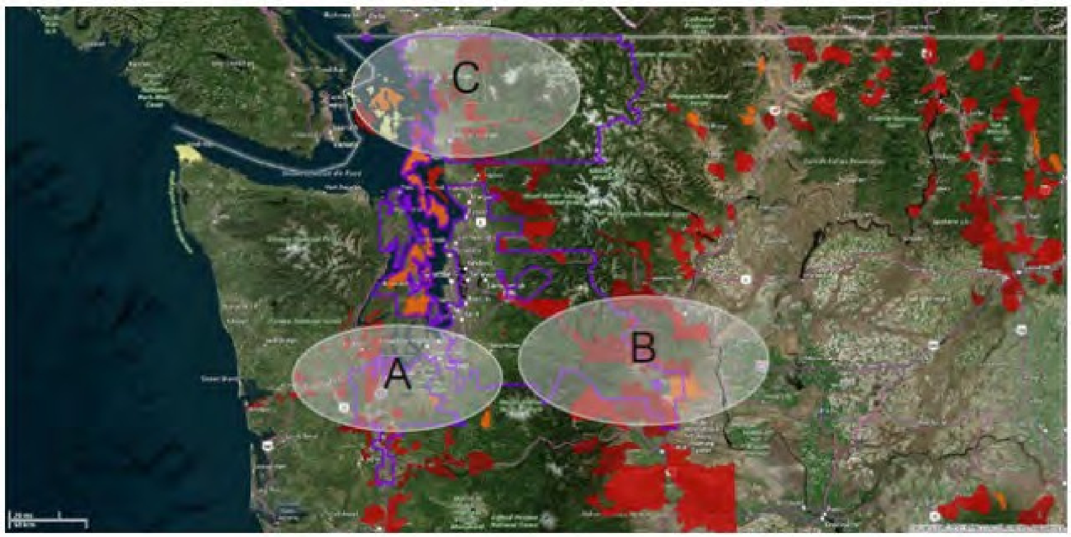


Figure 4-45. PSE's areas with highest likelihood of wildfire risk [126]

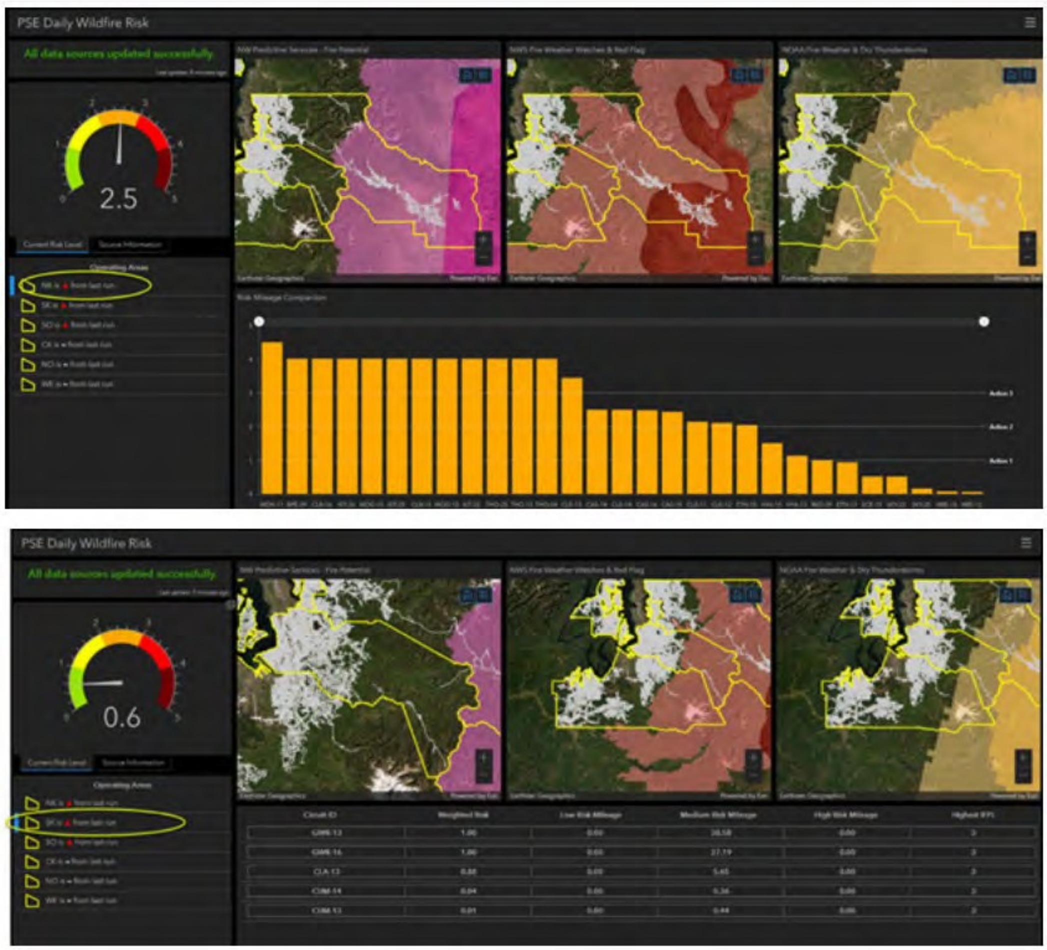


Figure 4-46. PSE's wildfire dashboard tool capturing daily wildfire risk to T&D systems [126]

High	Medium	Low
>2,500 customers affected by outage. Distribution feeders serving: • Hospitals, airports/ public transportation, police and fire facilities • High density urban/ residential areas • Key accounts, Schedule 48, and other "at risk" customers • Other industrial/ commercial load with large loss due to process disruption • Feeders that can be repaired quickly	**1,500-2,500 customers affected by outage.** Distribution feeders serving: • Medium density residential areas • Emergency shelters, blood banks, nursing homes, schools • Community wells, sewer lift pumping stations	**<1,500 customers affected by outage.** Distribution feeders serving: • Low density rural areas • Accounts with adequate backup generation • Feeders that take a significant amount of time to repair

Figure 4-47. PSE's distribution feeder restoration customer restoration priorities [127]

4.6.4.2 PHILIPPINES

The Philippines is one of the most vulnerable economies in a region that is expected to be largely affected by the changing climate [128]. They are at risk to natural disasters, such as storms, flood, landslide, volcano, and earthquakes, as shown in Figure 4-48, with almost 300 natural disasters of various forms over the past two decades [129]. They are also a region that is heavily reliant on inflexible baseload coal power, which is exposing residential and commercial consumers to resiliency issues [130]. Therefore, the Philippines has been increasing its efforts to significantly increase renewables throughout the region, as well as enable them to operate in mini- and microgrid configurations that can reach rural and remote areas without extending the main grid [129]. By increasing renewables and deployment of mini- and microgrids, increased resiliency and improved response to extreme events will be better realized.

The Philippines has extensive experience with post-disaster recovery, as well as processes and plans in place to create a resilient Philippines [131]. Malina Electric Company (Meralco), which is the largest private sector electric distribution company in the Philippines and serves the metro Manila has a distribution recovery process summarized in Figure 4-49, which describes, at a high level, customer prioritization. The Philippines' Department of Energy also developed a publicly available web-GIS tool that can be utilized to view hazard maps across the region, as demonstrated in Figure 4-50. This can be a useful tool for distribution grid operators to better prepare detailed recovery strategies in preparation for the next extreme event.

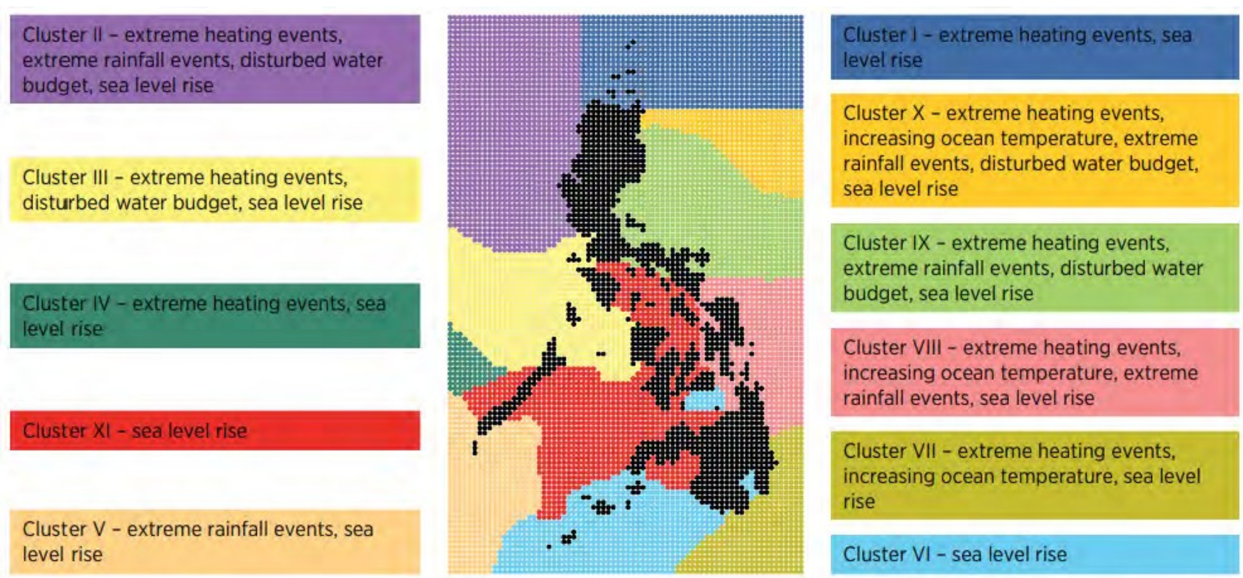


Figure 4-48. Philippine exposure to climate change [129]

Figure 4-49. Manila Electric Company (MERALCO) post-disaster recovery process for the distribution system [131]

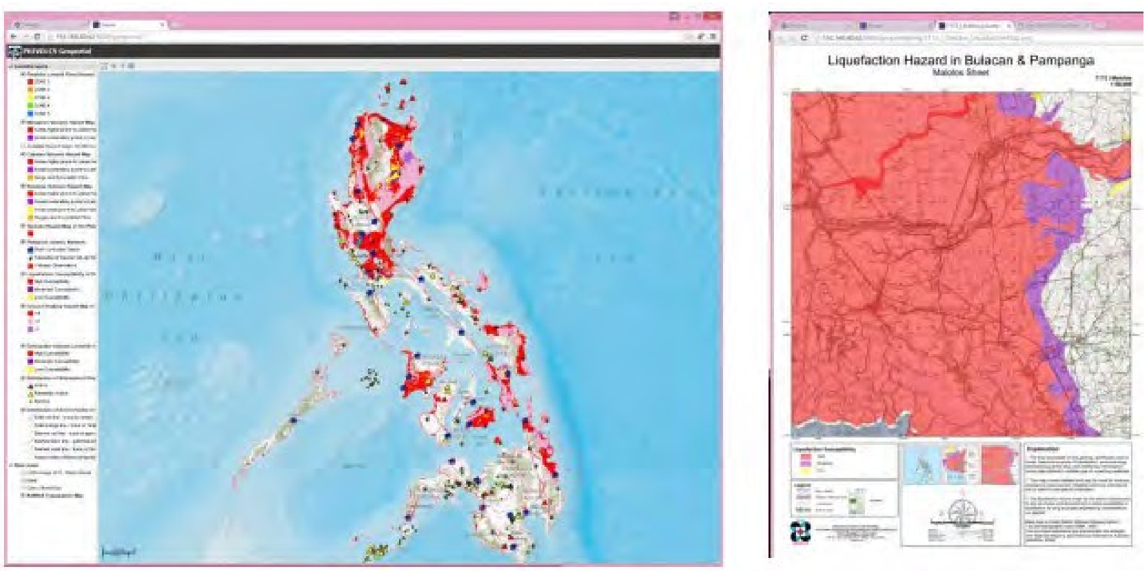


Figure 4-50. A Philippines government web-based GIS tool that enables the public to view hazard maps [132], [133]

4.6.4.3 AUSTRALIA

In Australia, Ergon Energy Network and Energex distribution service companies operate a vast area covering 1.7 million square kilometers, a network made up of over 200,000 kilometers of distribution lines, and 1.7 million poles [134]. Bushfire and storm season in this region is experienced between August to May, with an extreme event summary of electric grid impact from 2019 to 2020 depicted in Figure 4-51.

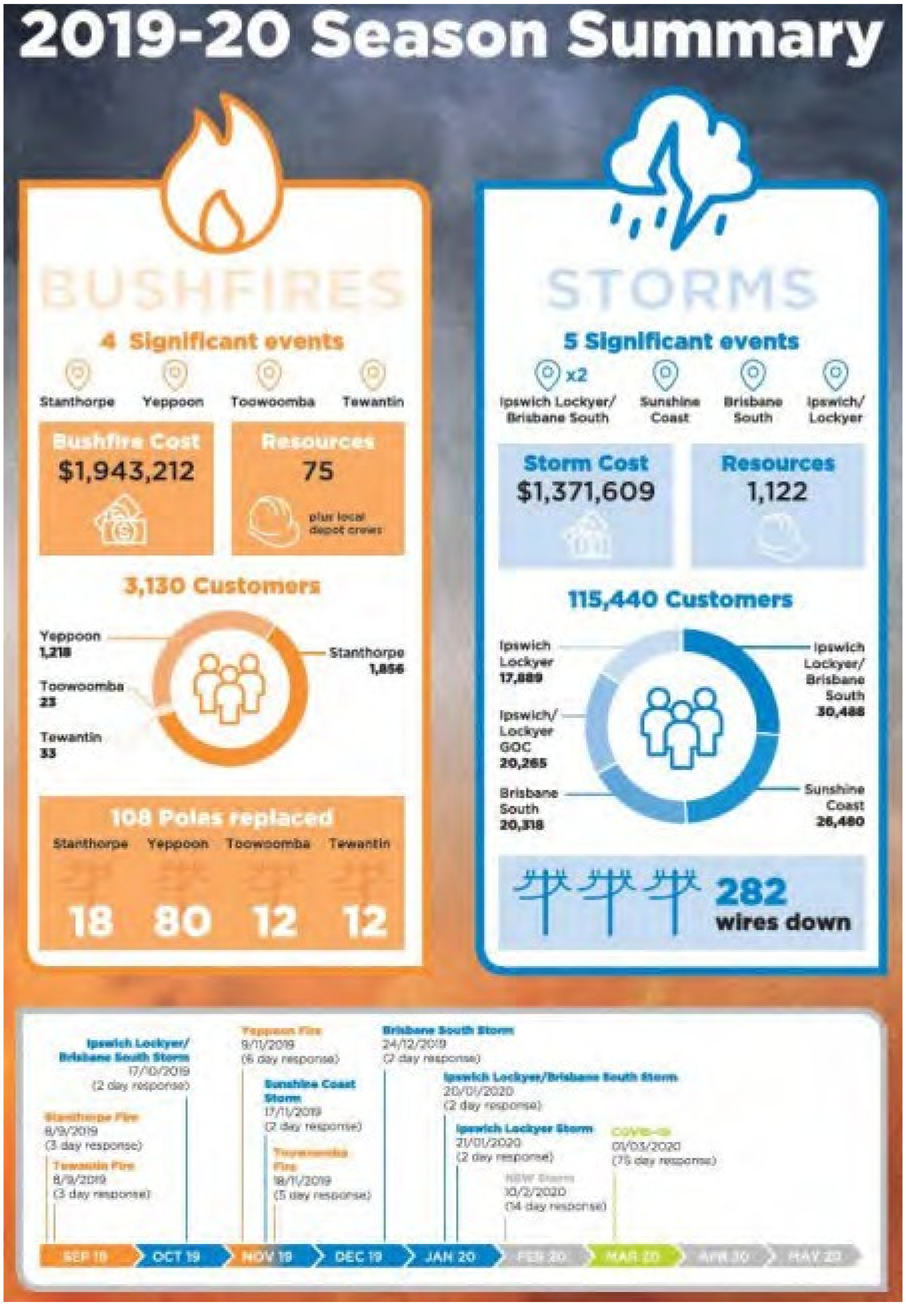


Figure 4-51. Bushfire and storm impact to customer service and distribution infrastructure in Ergon Energy Network, an Energex utility service footprint [134]

Due to these high-impact, high-risk events, Ergon Energy Network and Energex have developed a joint Summer Preparedness Plan that documents procedures related to network contingency planning, mitigation and resilience activities, emergency planning and response, communications, and their safety commitment [134]. Their emergency planning and response activities documented in this report include

- Embedding the implementation of a best practice emergency response framework
- Preparing comprehensive contingency plans for improving how we prioritize and schedule work during major or widespread outages

- Implementing emergency response procedures covering management of major network incidents
- Development of a detailed Emergency Management Plan for the Distribution Network
- Ensuring appropriate resources and skills are available to respond to an emergency or disruption event
- Development of a mobilization and resourcing strategy for maximum response efficiency
- Enhancing our use of technology to gather, analyze, and disseminate critical information
- Completion of training for all emergency managers and key emergency response roles
- Annual scenario planning and conducting desktop exercises to test the effectiveness of the response during different conditions
- Proactive monitoring of weather patterns and forecasting
- Establishing and maintaining relationships with Disaster Management Groups at local, district, and state level.

4.6.5 KEY TAKEAWAYS & RECOMMENDATIONS

Establishing equitable recovery strategies and extreme event preparedness is growing in importance, especially for APEC regions prone to natural disasters. Globally, there is room for improvement with respect to this key distribution planning element. Equitable recovery strategies and planning procedures can help to minimize social burden and better ensure fair prioritization of restoring energy to distribution customers. Ensuring system hardening measures are in place in advance of the next extreme event, classifying criticality of loads, developing annual training programs, and improving utilization of DERs and microgrids are all key components of implementing equitable recovery strategies. Additionally, continuously improving strategies will support integrating resiliency in preparation for the next disaster.

Therefore, recommendations for policy and regulating entities, as well as distribution planning entities, are the following:

Recommendations for Establishing Equitable Recovery Strategies	
Policy and Regulating Entities:	Develop requirements to **ensure fair and equitable disaster recovery strategies** are prepared by distribution system planning entities, requiring continuous improvement based on lessons learned from local and global extreme events, and opportunities to receive government funding to implement these new strategies.
Distribution Planning Entities:	Prepare publicly transparent recovery plans that incorporate classification and prioritization of critical loads, microgrid deployment, and performing annual trainings for staff to **ensure readiness for extreme events.**

5.0 SUMMARY OF RECOMMENDATIONS

This section summarizes the resulting high-level recommendations for policy and regulating entities, as well as distribution system planning entities in the APEC region. Whether an APEC economy is designated as developed or developing, these recommendations are applicable to all. Some APEC regions are already adopting many of these recommendations to some extent. All these recommendations are essential to the success of distribution grid modernization and operational reliability and resiliency; therefore, listing in terms of prioritization is challenging. Recommendations should be pursued in parallel to keep up with the quickly changing characteristics of the distribution system. Recommendations are captured in Table 5-1.

Also summarized are the technologies and applications highlighted in this report that are recommended for APEC economies to consider, if they have not yet already, in Table 5-2. Those that could be prioritized by developing economies are noted in this table. Additionally, those that are considered emerging technologies that APEC economies should be actively aware of are also noted. As these technologies and applications are considered by policy makers and distribution planners, it is important to note that there are many distribution technologies that flaunt their ability to enhance system resilience; however, the cost of deploying such technologies remains a barrier to many. Grants to field test and demonstrate these technologies should be made available to distribution planning entities to help overcome these financial barriers.

With respect to all the recommendations listed in Table 5-1 and Table 5-2, policy makers and governments should enable funding opportunities for distribution planning entities to test and deploy new technologies and frameworks described in this report.

Table 5-1. Recommendations matrix

	POLICY AND REGULATING ENTITIES	DISTRIBUTION SYSTEM PLANNING ENTITIES
Integrated Distributio n Planning	Develop rulings to require development of **integrated distribution system planning processes** that are also publicly available, transparent, and provide a balanced/fair opportunity for technology deployment/adoption.	Establish and document integrated system planning processes and needs assessments required for grid modernization and **allow these plans to be publicly transparent** and eligible for stakeholder feedback.
DERs	Develop rulings to require **planning for DERs in advance**, as well as explore and field test technologies that can manage DER operation to improve reliability and resilience.	Identify and field test technologies and resources needed to **improve the management, coordination, and optimization of DERs** to improve reliability and resilience.
EVs	Develop rulings for transportation electrification industries, distribution planning entities, and other necessary stakeholders to require development of **rate structure mechanisms and technologies to better manage** EVs and field test technologies for future V2G capability.	**Identify EV hosting capacity constraints and charge management techniques** for forecasted EV and field test technologies that can be utilized to managed EV charging that can also enable future V2G capability.
Situationa l	Develop rulings to require roll-out of advanced technologies (e.g., AMI, DMS, OMS, etc.) that will **increase situational awareness on distribution systems,** all while ensuring customer engagement is upheld throughout planning and deployment stages.	Build a business case, with consumers in mind, to **roll-out advanced technologies (e.g., AMI, DMS, OMS, etc.)** to increase situational awareness considering how increased maintenance savings, reduction in restoration costs, and effective cost-savings can be achieved.
Microgrids	Develop technical and regulatory rulings and guidance for distribution planning entities and microgrid developers that will **enable safe and effective deployment and operation of microgrids,** including grid-connected and isolated microgrid configurations.	Allocate resources to improve planning and operational strategies for the deployment of microgrids that incorporate safety requirements and engagement with consumers to **identify essential/critical community resources** or regions needing improved reliability and resiliency.
Disaster	Develop requirements to **ensure fair and equitable disaster recovery strategies** are prepared by distribution system planning entities, requiring continuous improvement based on lessons learned from local and global extreme events.	Prepare publicly transparent recovery plans that incorporate classification and prioritization of critical loads, microgrid deployment, and performing annual trainings for staff to **ensure readiness for extreme events.**

Table 5-2. Recommended technologies & applications matrix

	TECHNOLOGIES & APPLICATIONS
Integrated Distribution Planning	New Distribution Planning Approaches* Modern Grid Architecture & DSO** Peer-to-Peer Trading & Transactive Energy**
DERs	DER Load Forecasting Tools* Energy Storage* DERMS
EVs	EV Load Forecasting Tools* EV Load Management Tools Charging Infrastructure VGI**
Situational Awareness	AMI* SCADA & DMS OMS
Microgrids	Microgrid Tariffs* Microgrid Technical Specifications* Microgrid Interface Controller**
Disaster Recovery	Asset Management Systems* GIS & Hazard Maps* Emergency Response Drills & Training Simulators* DMS

***Technologies and applications developing economies should consider prioritizing**
****Considered an emerging technology and not yet widely implemented**

6.0 CONCLUSION

This report has shown the critical role the electric distribution system plays in supporting both energy resiliency and the integration of distributed renewable energy resources into the power grid and, thus, furthering APEC's clean energy goals. The report was structured to inform the reader, who may not come from a technical background, what the distribution power grid is and the value it provides, and it identified six key integrated distribution system planning elements APEC member economies need to begin considering as they modernize their grids. The six elements highlighted in the study included 1) Implementing Integrated Distribution System Planning, 2) Leveraging Distributed Energy Resources for Reliability & Resilience, 3) Planning for Electric Vehicles & Their Potential, 4) Increasing Situational Awareness, 5) Allowing for Microgrids, and 6) Establishing Equitable Recovery Strategies.

For each of these elements—their value and importance, implementation, technology and application readiness, and their varying levels of implementation in APEC member economies—were explored. Each section concluded by identifying high-level recommendations, for both policy and regulating entities and distribution system planning entities in the APEC region, that support energy resiliency and the integration of distributed renewable energy resources in their electric grids.

This report is the first step of laying out the high-level fundamentals for integrated distribution system planning and recommendations for developing and developed APEC economies. However, there is much more to explore, as this report leaves space for future APEC projects.

There are various types of future efforts APEC could consider funding. This includes projects that take a deeper dive into the various technologies and recommendations mentioned in this report. There is also opportunity to explore other infrastructures in more detail that grid modernization will be dependent on, such as communication systems. Additionally, this report primarily focused on how to manage DER penetration in the distribution planning process, but future APEC work could focus more on policies to promote DER adoption. Lastly, documenting in detail successful case studies of DER deployment technologies in such a way that achieves resiliency goals and incorporates integrated distribution planning could be of great value for developing economies. All these future areas of exploration could be facilitated through reports or APEC-hosted workshops that bring together practitioners from developing economies with subject matter experts from developed economies to share experiences and provide guidance.

References

[1] J. D. Rhodes, "The Old, Dirty, Creaky US Electric Grid Would Cost $5 Trillion to Replace. Where Should Infrastructure Spending Go?," University of Texas at Austin Energy Institute, 17 March 2017. [Online]. Available: https://energy.utexas.edu/news/old-dirty-creaky-us-electric-grid-would-cost-5-trillion-replace-where-should-infrastructure. [Accessed 31 July 2021].

[2] K. Schneider, E. Stuart, P. Dalton, R. Langner, J. Taft, P. De Martini, D. Lew, F. Kahrl, L. C. Schwartz, J. Homer, C. Miller, M. Leach, N. M. Frick, J. Twitchell, A. D. Mills and D. Black, "Integrated Distribution System Planning Training for the Midwest/MISO Region," in *Electricity Markets & Policy*, Berkeley, 2020.

[3] Asia Pacific Energy Research Centre (APERC), "APEC Energy Demand and Supply Outlook 7th Edition - Volume I," APEC Energy Working Group, Tokyo, Japan, 2019.

[4] Asia Pacific Energy Research Centre (APERC), "APEC Energy Overview 2019," APEC, Tokyo, Japan, 2020.

[5] Office of the United States Trade Representative, "Weekly Trade Spotlight: Asia-Pacific Economic Cooperation (APEC)," Executive Office of the President, [Online]. Available: https://ustr.gov/about-us/press-office/blog/2012/june/Weekly-Trade-Spotlight-Asia-Pacific-Economic-Cooperation-APEC. [Accessed 18 August 2021].

[6] USAID, "Clean Energy," U.S. Agency for International Development, 12 August 2021. [Online]. Available: https://www.usaid.gov/vietnam/clean-energy. [Accessed 17 August 2021].

[7] EIA, "U.S. Economy and Electricity Demand Growth are Linked, but Relationship is Changing," U.S. Energy Information Administration, 22 March 2013. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=10491. [Accessed 30 July 2021].

[8] EIA, "Link Between Growth in Economic Activity and Electricity Use is Changing Around the World," U.S. Energy Information Admnistration, 20 November 2017. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=33812. [Accessed 31 July 2021].

[9] P. Zummo, "The Value of the Grid," American Public Power Association, 2018.

[10] Minnesota Public Utilities Commission, "Staff Report on Grid Modernization," Minnesota Public Utilities Commission, 2016.

[11] PPPKnowledge Lab, "Distribution," PPP Knowledge Lab., [Online]. Available: https://pppknowledgelab.org/sectors/distribution#introduction. [Accessed 1 August 2021].

[12] Advanced Energy Economy, "Distribution System Planning: Proactively Planning for More Distributed Assets at the Grid Edge," Advanced Energy Economy, San Francisco, 2018.

[13] E. Polymeneas, A. Rubin and H. Tai, "Modernizing the Investment Approach for Electric Grids," McKinsey & Company, 11 November 2020. [Online]. Available:

https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/modernizing-the-investment-approach-for-electric-grids#. [Accessed 2 August 2021].

[14] Executive Office of the President, "Economic Benefits of Increasing Electric Grid Resilience to Weather Outages," The White House, Washington, D.C., 2013.

[15] P. D. Martini, "Integrated Distribution Resilience Planning," Integrated Distribution System Planning Training for Midwest-MISO Region, Grid Modernization Laboratory Consortium, 2020.

[16] National Academies of Sciences, Engineering, and Medicine, "Enhancing the Resilience of the Nation’s Electricity System," The National Academies Press, Washington, D.C., 2017.

[17] U.S. Department of Energy Office of Electricity, "Modern Distribution Grid (DSPx) - Volume I: Objective Driven Functionality, Version 2.0," November 2019. [Online]. Available: https://gridarchitecture.pnnl.gov/media/Modern-Distribution-Grid_Volume_I_v2_0.pdf. [Accessed 18 August 2021].

[18] M. Finster, J. Phillips and K. Wallace, "Front-Line Resilience Perspectives: The Electric Grid," November 2016. [Online]. Available: https://www.energy.gov/sites/prod/files/2017/01/f34/Front-Line%20Resilience%20Perspectives%20The%20Electric%20Grid.pdf. [Accessed 19 August 2021].

[19] A. R. Berkeley and M. Wallace, "A Framework for Establishing Critical Infrastructure Reslience Goals: Final Report and Recommendations by the Council," National Infrastructure Advisory Council, 19 October 2010. [Online]. Available: https://www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructure-resilience-goals-2010-10-19.pdf. [Accessed 19 August 2021].

[20] U.S. Department of Energy Office of Electricity, "Modern Distribution Grid DSPx Next-Generation Distribution System Platform: Strategy & Implementation Planning Guidebook Version 1.0," June 2020. [Online]. Available: https://gridarchitecture.pnnl.gov/media/Modern-Distribution-Grid_Volume_IV_v1_0_draft.pdf. [Accessed 18 August 2021].

[21] Edison Electric Institute, "America's Electric Companies Are #Committed2Clean: Electric Power Industry Outlook," 10 February 2021. [Online]. Available: https://www.eei.org/issuesandpolicy/finance/wsb/Documents/2021_Wall_Street_Final_Slides_Web.pdf. [Accessed 18 August 2021].

[22] W. M. Warwick, T. D. Hardy, M. G. Hoffman and J. S. Homer, "Electricity Distribution System Baseline Report," Pacific Northwest National Laboratory, Richland, WA, 2016.

[23] Minnesota Public Utilities Commission, "Notice of Comment Period on Distribution System Planning Efforts and Considerations," 21 April 2017. [Online]. Available: https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId=%7b307DE9F3-1F36-4CB1-AABA-96F0FCA6B1A8%7d&documentTitle=20174-131044-01. [Accessed 18 August 2021].

[24] State of Oregon Public Utilities Commission, "UM 2005 Investigation into Distribution System Planning: Utility Survey," March 2019. [Online]. Available: https://edocs.puc.state.or.us/efdocs/HAH/um2005hah165016.pdf. [Accessed 19 August 2021].

[25] J. D. Taft and A. Becker-Dippmann, "Grid Architecture," Pacific Northwest National Laboratory, PNNL-24044, Richland, WA, 2015.

[26] T. Lowder and K. Xu, "The Evolving U.S. Distribution System: Technologies, Architectures, and Regulations for Realizing a Transactive Energy Marketplace," National Renewable Energy Laboratory, NREL/TP-7A40-74412, Golden, CO, 2020.

[27] U.S. Department of Energy Office of Electricity Delivery & Energy Reliability, "Modern Distribution Grid: Decision Guide, Volume III," 28 June 2017. [Online]. Available: https://gridarchitecture.pnnl.gov/media/Modern-Distribution-Grid-Volume-III.pdf. [Accessed 19 August 2021].

[28] P. De Martini and L. Kristov, "Distribution Systems in a High Distributed Energy Resources Future: Planning, Market Design, Operation and Oversight," Lawrence Berkeley National Laboratory, Report No.2, LBNL-100397, 2015.

[29] W. Tushar, T. K. Saha, C. Yuen, D. Smith and H. V. Poor, "Peer-to-Peer Trading in Electricity Networks: An Vverview," *IEEE Transactions on Smart Grid,* vol. 11, no. 4, pp. 3185-3200, 2020.

[30] IRENA, "Peer-to-Peer Electricity Trading: Innovation Landscape Brief," International Renewable Energy Agency, 2020. [Online]. Available: https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Peer-to-peer_trading_2020.pd. [Accessed 18 August 2021].

[31] M. J. E. Alam, A. Somani, R. B. Melton and T. E. McDermott, "Transactive Approach for Engaging Distribution Network Assets for Voltage Management in Southern California Edison Distribution Feeders," Pacific Northwest National Laboratory, Richland, WA, 2018.

[32] New York State Smart Grid Consortium, "Distributed System Implementation Plans," [Online]. Available: http://nyssmartgrid.com/all-topics/distributed-system-implementation-plans-dsips. [Accessed August 2021].

[33] New York State, "Hosting Capacity Maps and Useful Links," [Online]. Available: https://www3.dps.ny.gov/W/PSCWeb.nsf/All/6143542BD0775DEC85257FF10056479C. [Accessed August 2021].

[34] IEEFA, "Blockchain Energy Trading Pilot Planned in Thailand," Institute for Energy Economics and Financial Analysis, 15 October 2018. [Online]. Available: https://ieefa.org/blockchain-energy-trading-pilot-planned-in-thailand. [Accessed 19 August 2021].

[35] W.-n. Chen, "Energy 4.0: Power to the People (P2P) via Innovation (Part 1)," Linkedin, 7 February 2019. [Online]. Available: https://www.linkedin.com/pulse/energy-40-power-people-p2p-via-innovation-part-1-dr-wei-nee-chen. [Accessed 19 August 2021].

[36] N. Stringer, A. Bruce, I. MacGill, N. Haghdadi, P. Kilby, J. Mills, T. Veijalainen, M. Armitage and N. Wilmot, "Consumer-Led Transition - Australia's World-leading Distriubted Energy Resource Integration Efforts," *IEEE Power and Energy Magazine,* vol. 18, no. 6, pp. 20-36, Nov.-Dec. 2020.

[37] Energy Networks Australia and CSIRO, "Electricity Network Transformation Roadmap: Final Report," April 2017. [Online]. Available: https://www.energynetworks.com.au/resources/reports/entr-final-report. [Accessed 19 August 2021].

[38] U.S. Department of Energy Office of Electricity, "Modern Distribution Grid (DSPx) Volume II: Advanced Technology Maturity Assessment, Version 2.0," November 2019. [Online]. Available: https://gridarchitecture.pnnl.gov/media/Modern-Distribution-Grid_Volume_II_v2_0.pdf. [Accessed 19 August 2021].

[39] K. Horowitz, Z. Peterson, M. Coddington, F. Ding, B. Sigrin, D. Saleem, S. E. Baldwin, B. Lydic, S. C. Stanfield, N. Enbar, S. Coley, A. Sundararajan and C. Schroeder, "An Overview of Distributed Energy Resource (DER) Interconnection: Current Practices and Emerging Solutions," National Renewable Energy Laboratory, NREL/TP-6A20-72102, 2019.

[40] NERC, "Energy Storage: Impacts of Electrochemical Utility-Scale Battery Energy Storage Systems on the Bulk Power System," North American Electtric Reliability Corporation, Atlanta, GA, 2021.

[41] J. B. Twitchell, S. F. Newman, R. S. O'Neil and M. T. McDonnell, "Planning Considerations for Energy Storage in Resilience Applications," Pacific Northwest National Laboratory, PNNL-29738, Richland, WA, 2020.

[42] California ISO, "What the Duck Curve Tells Us About Managing a Green Grid," 2016. [Online]. Available: https://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf.

[43] IRENA, "Battery Storage Paves Way for a Renewable-powered Future," International Renewable Energy Agency, 26 March 2020.

[44] U.S. Department of Energy, "Energy Storage Grand Challenge: Energy Storage Market Report," NREL/TP-5400-78461, DOE/GO-102020-5497, December 2020.

[45] U.S. Department of Energy, "How Distributed Energy Resources Can Improve Resilience in Public Buildings: Three Case Studies and a Step-by-Step Guide," September 2019.

[46] P. Asmus, "Virtual Power Plants Go Global: A Commerical Pathway for Moving from VPP to DERMS," Navigant Research, 2019.

[47] K. Ardani, E. O'Shaughnessy and P. Schwabe, "Coordinating Distributed Energy Resources for Grid Services: A Case Study of Pacific Gas and Electric," National Renewable Energy Laboratory, NREL/TP-7A40-72108, November 2018.

[48] ConEdison, "Proposed Locational System Relief Value (LSRV) Areas," ConEdison, [Online]. Available: https://www.nyserda.ny.gov/-/media/NYSun/files/vder-coned.pdf. [Accessed 19 August 2021].

[49] S. Thomas, "Evolution of the Distribution System & the Potential for Distribution-level Markets: A Primer for State Utility Regulators," National Association of Regulatory Utility Commissioners, January 2018.

[50] J. Wang, X. Lu and C. Chen, "Guidelines for Implementing Advanced Distribution Management Systems: Requirements for DMS Integration with DERMS and Microgrids," Argonne National Laboratory, Energy Systems Division, ANL/ESD-15/15, August 2015.

[51] Pacific Gas and Electric Company, "EPIC Final Report: EPIC 2.02 - Distributed Energy Resource Management System," 18 January 2019. [Online]. Available: https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/PGE-EPIC-2.02.pdf. [Accessed 27 August 2021].

[52] Energy Transformation Taskforce, "Distributed Energy Resources Roadmap," Government of Western Australia, 2019.

[53] P. Doyle, S. Enriquez, E. Hyman, L. Bauer and P. Torres, "Recommendations for Preparation of a Distributed Energy Resources Plan or Roadmap: Climate Economic Development, Investment, and Resilience (CEADIR)," United States Agency for International Development, 23 October 2020.

[54] L. Stoker, "Vietnam Proposes Heavily-cut Solar FIT Rates From Next Month," PVTech, 17 March 2021. [Online]. Available: https://www.pv-tech.org/vietnam-proposes-heavily-cut-solar-fit-rates-from-next-month. [Accessed 18 August 2021].

[55] R. Walton, "Autogrid's Japan Project Could be World's Largest Virtual Power Plant, Company Says," UtilityDive, 25 June 2019. [Online]. Available: https://www.utilitydive.com/news/autogrids-japan-project-could-be-worlds-largest-virtual-power-plant-comp/557550. [Accessed 19 August 2021].

[56] AutoGrid, "AutoGrid Announces Major Virtual Power Plant Agreement with Japan's ENERES Co., Ltd.," AutoGrid, 16 June 2019. [Online]. Available: https://www.prnewswire.com/news-releases/autogrid-announces-major-virtual-power-plant-agreement-with-japans-eneres-co-ltd-300869173.html. [Accessed 19 August 2021].

[57] AutoGrid, "Massive Transformation of Japanese Electricity Market Calls for Flexible Energy Management," AutoGrid Market Spotlight: Japan, 12 October 2018. [Online]. Available:

https://blog.auto-grid.com/massive-transformation-of-japanese-electricity-market-calls-for-flexible-energy-management. [Accessed 19 August 2021].

[58] IEA, "Global EV Outlook 2021," International Energy Agency, April 2021. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2021. [Accessed 4 August 2021].

[59] T. Markel, A. Meintz, K. Hardy, B. Chen, T. Bohn, J. Smart, D. Scoffield, R. Hovsapian, S. Saxena, J. MacDonald, S. Kiliccote, K. Kahl and R. Pratt, "Multi-Lab EV Smart Grid Integration Requirements Study: Providing Guidance on Technology Development and Demoonstration," National Renewable Energy Laboratory, NREL/TP-5400-63963, Golden, CO, May 2015.

[60] E. Schmidt, "EV Clustered Charging Can Be Problematic for Electrical Utilities," fleetcarma, 4 September 2017. [Online]. Available: https://www.fleetcarma.com/ev-clustered-charging-can-problematic-electrical-utilities. [Accessed 30 August 2021].

[61] H. S. Das, M. M. Rahman, S. Li and C. W. Tan, "Electric Vehicles Standards, Charging Infrastructure, and Impact on Grid Integration: A Technological Review," *Renewable and Sustainable Energy Reviews,* vol. 120, p. 109618, 2020.

[62] M. Kintner-Meyer, S. Davis, S. Sridhar, D. Bhatnagar, S. Mahserejian and M. Ghosal, "Electric Vehicles at Scale - Phase I Analysis: High EV Adoption Impacts on the Western U.S. Power Grid," Pacific Northwest National Laboratory, PNNL-29894, Richland, WA, July 2020.

[63] A. Hove and D. Sandalow, "Electric Vehicle Charging in China and the United States," Columbia | SIPA Center on Global Energy Policy, February 2019. [Online]. Available: https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf. [Accessed 4 August 2021].

[64] C. Goldenberg, M. Dyson and H. Masters, "Demand Flexibility: The Key to Enabling a Low-Cost, Low-Carbon Grid," Rocky Mountain Institute, 1 February 2018. [Online]. Available: http://rmi.org/wpcontent/uploads/2018/02/Insight_Brief_Demand_Flexibility_2018.pdf. [Accessed August 2021].

[65] S. Pless, A. Allen, L. Myers, D. Goldwasser, A. Meintz, B. Polly and S. Frank, "Integrating Electric Vehicle Charging Infrastructure into Commercial Buildings and Mixed-Use Communities: Design, Modeling, and Control Optimization Opportunities," National Renewable Energy Laboratory, NREL/CP-5500-77438, Golden, CO, 2020.

[66] E. Dudek, "The Flexibility of Domestic Electric Vehicle Charging: The Electric Nation Project," *IEEE Power and Energy Magazine,* vol. 19, no. 4, pp. 16-27, July/August 2021.

[67] Y. Tang, J. S. Homer, T. E. McDermott, M. H. Coddington, B. Sigrin and B. A. Mather, "Summary of Electric Distribution System Analyses with a Focus on DERs," Grid Modernization Laboratory Consortium, PNNL-26272, April 2017. [Online]. Available: https://epe.pnnl.gov/pdfs/Summary_of_electric_distribution_system_analyses_April_10_FINAL.pdf. [Accessed 26 August 2021].

[68] National Renewable Energy Laboratory, "Plug-in Electric Vehicle Handbook for Public Charging Station Hosts," U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, DOE/GO-102012-3275, April 2012.

[69] M.J. Bradley & Associates, "Electric Vehicle Infrastructure Planning Tools," Regional EV Charging Infrastructure Identification Toolkit, August 2021. [Online]. Available: https://www.mjbradley.com/mjb_form/EV-tools. [Accessed 5 August 2021].

[70] Everoze & EVConsult, "V2G Global Roadtrip: Around the World in 50 Projects," UK Power Networks and Innovate UK, October 2018. [Online]. Available: http://everoze.com/app/uploads/2019/02/UKPN001-S-01-J-V2G-global-review.pdf. [Accessed 25 August 2021].

[71] EERE, "Alternative Fuels Data Center," U.S. Department of Energy Office of Energy Efficiency & Renewable Energy, 17 June 2021. [Online]. Available: https://afdc.energy.gov/data/10962. [Accessed 17 June 2021].

[72] Inspire, "Which States Produce the Most Wind Energy," 27 10 2020. [Online]. Available: https://www.inspirecleanenergy.com/blog/clean-energy-101/which-states-produce-the-most-wind-energy. [Accessed 17 6 2021].

[73] California ISO, "California Vehicle-Grid Integration (VGI) Roadmap: Enabling Vehicle-Based Grid Services," 2014. [Online]. Available: https://www.caiso.com/Documents/Vehicle-GridIntegrationRoadmap.pdf.

[74] U.S. Census Bureau, "State Exports From California," 2020. [Online]. Available: https://www.census.gov/foreign-trade/statistics/state/data/ca.html. [Accessed 17 June 2021].

[75] M. Kane, "California's EV Industry is Booming: Creating Jobs A Plenty," INSIDEEVs, 7 March 2020. [Online]. Available: https://insideevs.com/news/402942/laedc-california-ev-industry-booming. [Accessed 17 June 2021].

[76] California Energy Commission, "California Electric Vehicle Infrastructure Project (CALeVIP) Cost Data," 14 June 2021. [Online]. Available: https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/california-electric-vehicle. [Accessed 26 August 2021].

[77] M. Alexander, N. Crisostomo, W. Krell, J. Lu and R. Ramesh, "Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment: Analyzing Charging Needs to Support Zero-Emission Vehicles in 2030," California Energy Commission, CEC-600-2021-001-CMR, July 2021. [Online]. Available: https://www.energy.ca.gov/programs-and-topics/programs/electric-vehicle-charging-infrastructure-assessment-ab-2127. [Accessed 26 August 2021].

[78] M.J. Bradley & Associates, "Case Study: Vehicle Grid Integration in California," Online Interactive Toolkit: Policy Explorer, 2021. [Online]. Available: https://www.mjbradley.com/Vehicle-Grid-Integration-in-California. [Accessed 26 August 2021].

[79] J. Ardern, S. Nash and J. Shaw, "Public Sector to be Carbon Neutral by 2025," Beehive.govt.nz The official website of the New Zealand, 2 December 2020. [Online]. Available: https://www.beehive.govt.nz/release/public-sector-be-carbon-neutral-2025#:~:text=Minister%20of%20Climate%20Change%2C%20James,to%20net%2Dzero%20carbon%20emissions.. [Accessed 26 May 2021].

[80] Climate Change Commission, "2021 Draft Advice for Consultation," Climate Change Commission, New Zealand, 2021.

[81] Ministry for the Environment, "Reducing Barriers to Electric Vehicle Uptake: Behavioural Insights: Analysis and Review," Ministry for the Environment, Wellington, 2018.

[82] L. Jin, H. He, H. Cui, N. Lutsey, C. Wu, Y. Chu, J. Zhu, Y. Xiong and X. Liu, "Driving a Green Future: A Retrospective Review of China's Electric Vehicle Development and Outlook for the Future," January 2021. [Online]. Available: https://theicct.org/publications/china-green-future-ev-jan2021. [Accessed 22 August 2021].

[83] D. Allen, "China's Global EV Revolution," East West Bank, 16 August 2021. [Online]. Available: https://www.eastwestbank.com/ReachFurther/en/News/Article/Chinas-Global-EV-Revolution. [Accessed 25 August 2021].

[84] M. Kane, "China: Plug-In Cars Grab 10% Market Share in April 2021," 24 May 2021. [Online]. Available: https://insideevs.com/news/509300/china-plugin-cars-april-2021. [Accessed 25 August 2021].

[85] H. Rauscher, "Where China is Leading the Mobility Revolution," Automotive Manager, 2019. [Online]. Available: https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2019/jun/AutomotiveManager2019/Oliver_Wyman_Automotive_Manager_Innovation_in_China_web_final.pdf. [Accessed 25 August 2021].

[86] D. Li, "China's Grid and the Electric Car," Chinese Energy Storage Alliance, 29 November 2015. [Online]. Available: http://en.cnesa.org/featured-stories/tag/V2G. [Accessed 25 August 2021].

[87] L. Xue, J. Liu, Y. Wang, X. Liu and Y. Xiong, "Action Plans and Policy Recommendations on Vehicle Grid Integration in China," WRI China, June 2020. [Online]. Available: https://www.wri.org.cn/en/report/2020/06/action_plans_and_policy_recommendations_on_vehicle_grid_integration_in_China_EN. [Accessed 25 August 2021].

[88] National Renewable Energy Laboratory, "Voices of Experience: Insights on Smart Grid Customer Engagement," U.S. Department of Energy Office of Electricity Delivery & Energy Reliability, July 2013. [Online]. Available: https://www.energy.gov/sites/prod/files/2013/07/f2/VoicesofExperience.pdf. [Accessed 18 August 2021].

[89] R. Walton, "Aging Grids Drive $51B in Annual Utility Distribution Spending," Utility Dive, 25 July 2018. [Online]. Available: https://www.utilitydive.com/news/aging-grids-drive-51b-in-annual-utility-distribution-spending/528531/. [Accessed 18 August 2021].

[90] R. Kirker, "Situational Awareness Offers Grid Benefits," T&D World, 20 December 2016. [Online]. Available: https://www.tdworld.com/grid-innovations/distribution/article/20967535/situational-awareness-offers-grid-benefits. [Accessed 18 August 2021].

[91] U.S. Department of Energy Office of Electricity Delivery and Energy Reliability, "Advanced Metering Infrastructure and Customer Systems: Results from the Smart Grid Investment Grant Program," September 2016. [Online]. Available: https://www.energy.gov/sites/prod/files/2016/12/f34/AMI%20Summary%20Report_09-26-16.pdf. [Accessed 19 August 2021].

[92] T. Taylor and H. Kazemzadeh, "Integrated SCADA/DMS/OMS: Increasing Distribution Operations Efficiency," EE Online, March 2009. [Online]. Available: https://electricenergyonline.com/energy/magazine/389/article/Integrated-SCADA-DMS-OMS-Increasing-Distribution-Operations-Efficiency.htm. [Accessed 18 August 2021].

[93] Federal Energy Regulatory Commission, "2019 Assessment of Demand Response and Advanced Metering," December 2019. [Online]. Available: https://www.ferc.gov/sites/default/files/2020-04/DR-AM-Report2019_2.pdf. [Accessed 19 August 2021].

[94] Pacific Gas and Electric Company, "Pacific Gas and Electric Company Smart Grid Annual Report 2018," 2018. [Online]. Available: https://www.pge.com/pge_global/common/pdfs/safety/how-the-system-works/electric-systems/smart-grid/AnnualReport2018.pdf. [Accessed 26 August 2021].

[95] Singapore Power, "Our Future Our Mission: Singapore Power Annual Report 2015/2016," July 2016. [Online]. Available: https://www.spgroup.com.sg/wcm/connect/spgrp/ea560383-d6d8-4a92-9925-af27cce9462b/SP+Group+Annual+Report+FY1516.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_M1IEHBK0MOUJ20ABQK7Q593U32-ea560383-d6d8-4a92-9925-af27cce9462b-neeudJV. [Accessed 19 August 2021].

[96] C. Z. Shawn and A. B. Soon, "Singapore SP Group's Smart Grid Index for 2020," T&D World, 26 March 2021. [Online]. Available: https://www.tdworld.com/grid-innovations/smart-grid/article/21159231/singapore-sp-groups-smart-grid-index-for-2020. [Accessed 19 August 2021].

[97] SPgroup, "Smart Grid Index," SPgroup, [Online]. Available: https://www.spgroup.com.sg/sp-powergrid/overview/smart-grid-index. [Accessed July 2021].

[98] R. Binz, R. Bracho, A. Anderson, M. Coddington, E. Hale, M. Ingram, M. Martin, I. Mednoza, B. Normak, M. Olofsson, B. O'Neill, P. Statwick and B. Speer, "A Report on the Implementation of Smart Grids in Mexico," National Renewable Energy Laboratory, NREL/TP-7A40-72699, 2019.

[99] K. P. Schneider, C. Miller, S. Laval, W. Du and D. Ton, "Networked Microgrid Operations: Supporting a Resilient Electric Power Infrastructure," *IEEE Electrification Magazine,* vol. 8, no. 4, pp. 70-79, Dec. 2020.

[100] M. Hightower and B. Schenkman, "APEC Workshop on Improving Electric Grid Resilience to Natural Disasters," APEC Energy Working Group, March 2020. [Online]. Available: https://www.apec.org/Publications/2020/03/APEC-Workshop-on-Improving-Electric-Grid-Resilience-to-Natural-Disasters. [Accessed 19 August 2021].

[101] U.S. Department of Energy Office of Electricity, "The Role of Microgrids in Helping to Advance the Nation's Energy System," [Online]. Available: https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/role-microgrids-helping. [Accessed 19 August 2021].

[102] U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Solar Energy Technologies Office, "Systems Integration," [Online]. Available: https://www.energy.gov/eere/solar/systems-integration. [Accessed 19 August 2021].

[103] P. De Martini, J. Leader, B. Blair and H. Cutler, "How to Design Multi-User Microgrid Tariffs," Smart Electric Power Alliance, August 2020. [Online]. Available: https://sepapower.org/resource/how-to-design-multi-user-microgrid-tariffs. [Accessed 27 August 2021].

[104] Consolidated Edison Co. of New York, Inc., "Technical Requirements for Microgrid Systems Interconnected with the Con Edison Distribution System," Consolidated Edison Co. of New York, Inc, 15 June 2017. [Online]. Available: https://www.coned.com/-/media/files/coned/documents/save-energy-money/using-private-generation/specs-and-tariffs/eo-2161.pdf?la=en. [Accessed 27 August 2021].

[105] Sandia National Laboratories, "Microgrid Design Toolkit (MDT)," U.S. Department of Energy Office of Electricity , 2016. [Online]. Available: https://energy.sandia.gov/download-sandias-microgrid-design-toolkit-mdt. [Accessed August 2021].

[106] California Public Utilities Commission, "Resiliency and Microgrids," [Online]. Available: https://www.cpuc.ca.gov/resiliencyandmicrogrids. [Accessed 19 August 2021].

[107] K. Silverstein, "California to Fight Wildfires with Microgrids and Batteries," Forbes, 16 June 2020. [Online]. Available: https://www.forbes.com/sites/kensilverstein/2020/06/16/california-energy-regulators-want-to-fight-wildfires-by-facilitating-more-microgrids-and-energy-storage/?sh=26818f33141c. [Accessed 26 August 2021].

[108] California Public Utilities Commission, "Order Instituting Rulemaking Regarding Microgrids Pursuant to Senate Bill 1339," California Public Utilities Commission, 19 September 2019. [Online]. Available: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M314/K274/314274617.PDF. [Accessed 26 August 2021].

[109] R. Wallsgrove, J. Woo, J.-H. Lee and L. Akiba, "The Emerging Potential of Microgrids in the Transition to 100% Renewable Energy Systems," *Energies,* vol. 14, no. 6, 2021.

[110] State of Hawaii, *HB2110 HD2 SD2, Relating to Resiliency,* Hawaii: Energy Resiliency; Microgrid Services Tariff, 2018.

[111] State of Hawaii Public Utilities Commission , "Instituting a Proceeding to Investigate Establishment of a Microgrid Services Tariff," November 2018. [Online]. Available: https://www.hawaiianelectric.com/documents/about_us/our_vision_and_commitment/resilience/microgrid_services_tariff/dkt_2018_0163_20181121_PUC_order_35884.pdf. [Accessed 27 August 2021].

[112] Victoria State Government, "Microgrid Program," [Online]. Available: https://www.energy.vic.gov.au/renewable-energy/microgrids. [Accessed August 2021].

[113] W. Hwang, "Microgrids for Electricity Generation in the Republic of Korea," NAPSNet Special Reports, Nautilus Institute for Security and Sustainability, 27 September 2020. [Online]. Available: http://nautilus.org/wp-content/uploads/2020/09/Hwang-ROK-Microgrids-SR-Sep27-2020.pdf. [Accessed 19 August 2021].

[114] COE, "The Path to a Carbon-free Island," Aruba Centre of Excellence for Sustainable Development of SIDS, 2019. [Online]. Available: https://www.sustainablesids.org/wp-content/uploads/2019/01/COE-Case-Study-in-Sustainable-Energy-The-Path-to-a-Carbon-free-Island-Jeju-Republic-of-Korea-2019.pdf. [Accessed 19 August 2021].

[115] ABB Power Grids, "Electric Power and Storm Restoration Roadmap Recommendations," Hitachi ABB, [Online]. Available: https://library.e.abb.com/public/e2e8a4d81b6eb5a285257c14006409cf/Storm%20Preparedness(final).pdf. [Accessed 19 August 2021].

[116] J. Richardson, "How to Ensure Energy Storage Policies are Equitable," Union of Concerned Scientists, Cambridge, MA, 19 November 2019. [Online]. Available: https://www.ucsusa.org/resources/equitable-energy-storage. [Accessed 27 August 2021].

[117] Edison Electric Institute, "Understanding the Electric Power Industry's Response and Restoration Process," October 2016. [Online]. Available: https://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/documents/ma_101final.pdf. [Accessed 27 August 2021].

[118] International Electrotechnical Commission, "Microgrids for Disaster Preparedness and Recovery-With Electricity Continuity Plans and Systems," [Online]. Available: https://www.preventionweb.net/files/42769_microgridsfordisasterpreparednessan.pdf. [Accessed 19 August 2021].

[119] B. Bjorklund and R. Cummings, "Strategies for Successful Storm Response and Management," *Electric Energy T&D Magazine,* vol. 19, no. 1, 2015.

[120] Consulting Engineers of Alberta, "Building Community Resilience Through Asset Management: A Handbook & Toolkit for Alberta Municipalities," November 2015. [Online]. Available: https://www.cea.ca/files/2015-11-17%20Handbook%20-%20FINAL%20-%20web.pdf. [Accessed July 2021].

[121] J. Villali, "Enhancing Grid Resiliency and Asset Management in the New COVID-19 Working Environment," Smart Energy International, 18 June 2020. [Online]. Available: https://www.smart-energy.com/industry-sectors/energy-grid-management/enhancing-grid-resiliency-and-asset-management-in-the-new-covid-19-working-environment. [Accessed 27 August 2021].

[122] Y. Budiyono, J. C. J. H. Aerts, D. Tollenaar and P. J. Ward, "River Flood Risk in Jakarta under Scenarios of Future Change," Natural Hazards and Earth System Sciences, Vol. 16, 757-774, 2016.

[123] B. Green and J. Tripolitis, "Distribution Grid Resiliency: Storm Response Practices," Electric Power Research Institute, December 2015. [Online]. Available: https://www.epri.com/research/products/000000003002006784. [Accessed 28 August 2021].

[124] R. Davies, "Power Simulation: Training Distribution System Operators," Power Technology, 24 June 2019. [Online]. Available: https://www.power-technology.com/features/power-simulation-training-distribution-system-operators. [Accessed 28 August 2021].

[125] J. Tripolitis, S. Martino and J. Wharton, "Distribution Grid Resiliency: Prioritization of Options," Electric Power Research Institute, December 2015. [Online]. Available: https://www.epri.com/research/products/000000003002006668. [Accessed 28 August 2021].

[126] Puget Sound Energy, "Wildfire Mitigation and Response Plan," July 2021. [Online]. Available: https://www.pse.com/-/media/PDFs/7616_Wildfire_Plan.pdf. [Accessed 28 August 2021].

[127] Puget Sound Energy, "Energy System Restoration Plan, Volume 1," 15 November 2019. [Online]. Available: https://www.pse.com/-/media/PDFs/PSE-Energy-Restoration-Plan-Vol1-Rev_20191115.pdf. [Accessed 28 August 2021].

[128] E. R. Florano, "Chapter 26 - Integrated Loss and Damage–Climate Change Adaptation–Disaster Risk Reduction Framework: The Case of the Philippines," in *Resilience*, Z. Zommers and K. Alverson, Eds., Elsevier, 2018, pp. 317-326.

[129] IRENA, "Renewables Readiness Assessment: The Philippines," International Renewable Energy Agency, Abu Dhabi, 2017.

[130] S. J. Ahmed, "Philippines Power Sector Can Reach Resilience by 2021," Institute for Energy Economics and Financial Analysis, June 2020. [Online]. Available: https://ieefa.org/wp-content/uploads/2020/06/Philippines-Power-Sector-Can-Reach-Resilience-by-2021_June-2020.pdf. [Accessed 27 August 2021].

[131] Republic of the Philippines Department of Energy, "E-POWER MO: Towards an Energy Resilient Philippines," 26 June 2018. [Online]. Available: https://www.doe.gov.ph/e-power-mo-towards-energy-resilient-philippines?ckattempt=1. [Accessed 28 August 2021].

[132] J. L. Cruz-Salcedo, "Magnitude 7.2: Effects to Lifelines (Power) 6th E-Power Mo: Developing Energy Resilient Philippines," 26 June 2018. [Online]. Available: https://www.doe.gov.ph/sites/default/files/pdf/announcements/a_plenary_02_magnitude_7_2_effects_lifelines.pdf. [Accessed 28 August 2021].

[133] PHIVOLCS, "About PHIVOLCS," Department of Science and Technology Philippine Institue of Volcanology and Seismology, [Online]. Available: https://www.phivolcs.dost.gov.ph/index.php/about-us/about-phivolcs. [Accessed 28 August 2021].

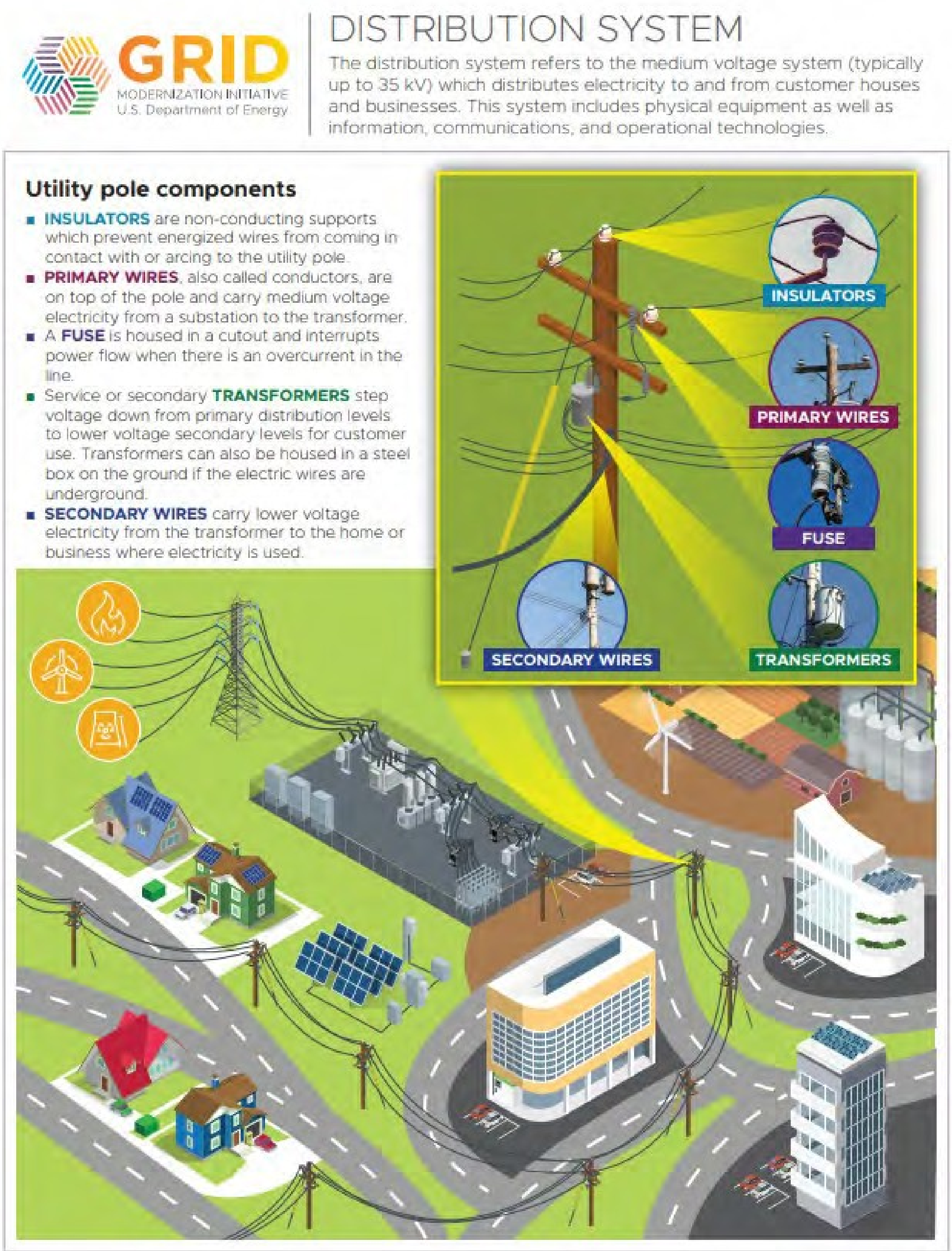
[134] Ergon Energy Network and Energex, "Summer Preparedness Plan: 2020-21," Ergon Energy Network and Energex, Australia, 2020.

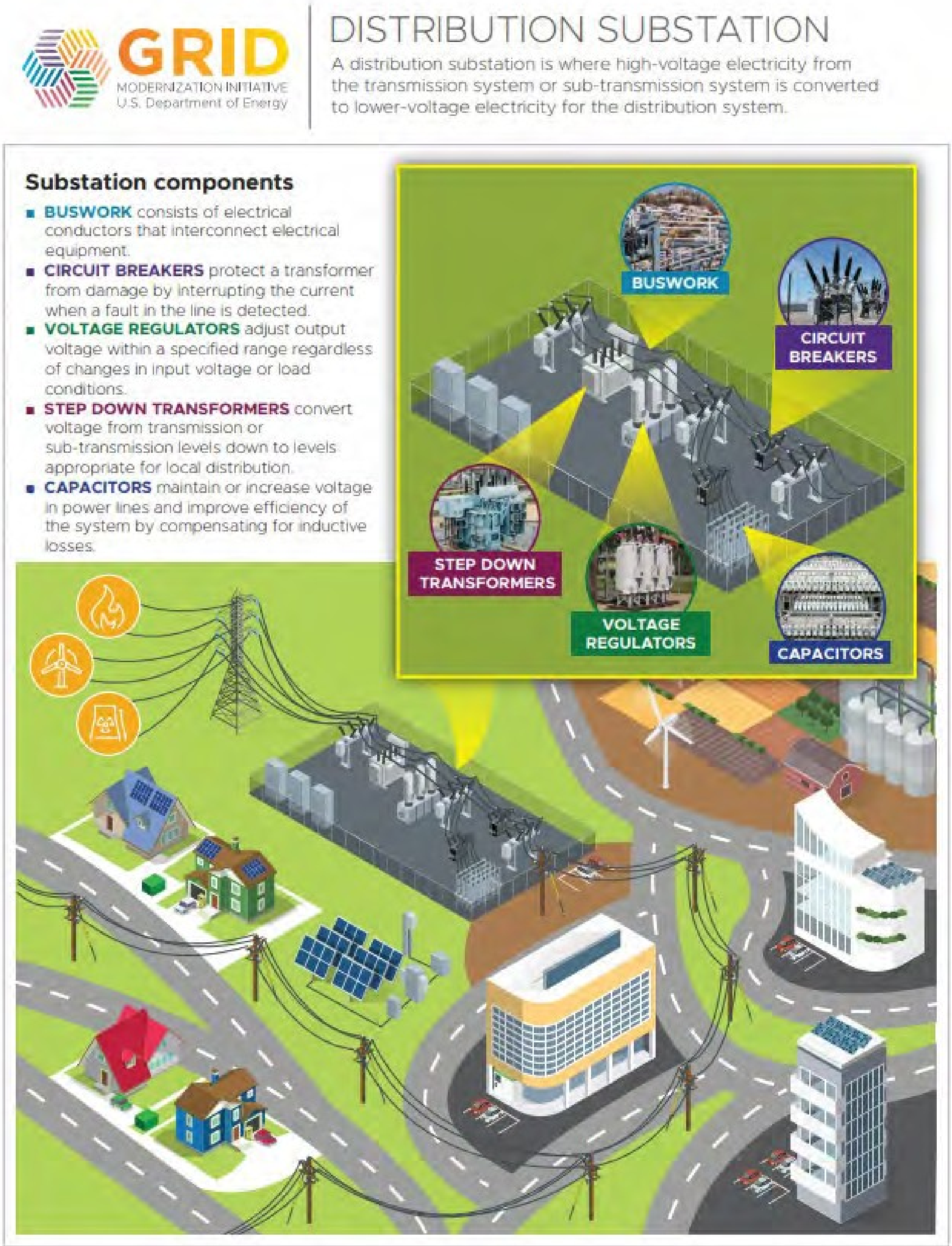
[135] AESO, "AESO Distributed Energy Resources (DER) Roadmap," Alberta Electric System Operator, June 2020. [Online]. Available: https://www.aeso.ca/assets/Uploads/DER-Roadmap-2020-FINAL.pdf. [Accessed 19 August 2021].

[136] Tokyo Electric Power Company Holdings, Inc., and Accenture, "Utility of the Future in Japan Utility 3.0," 2019.

Appendix A – Distribution System Component Descriptions

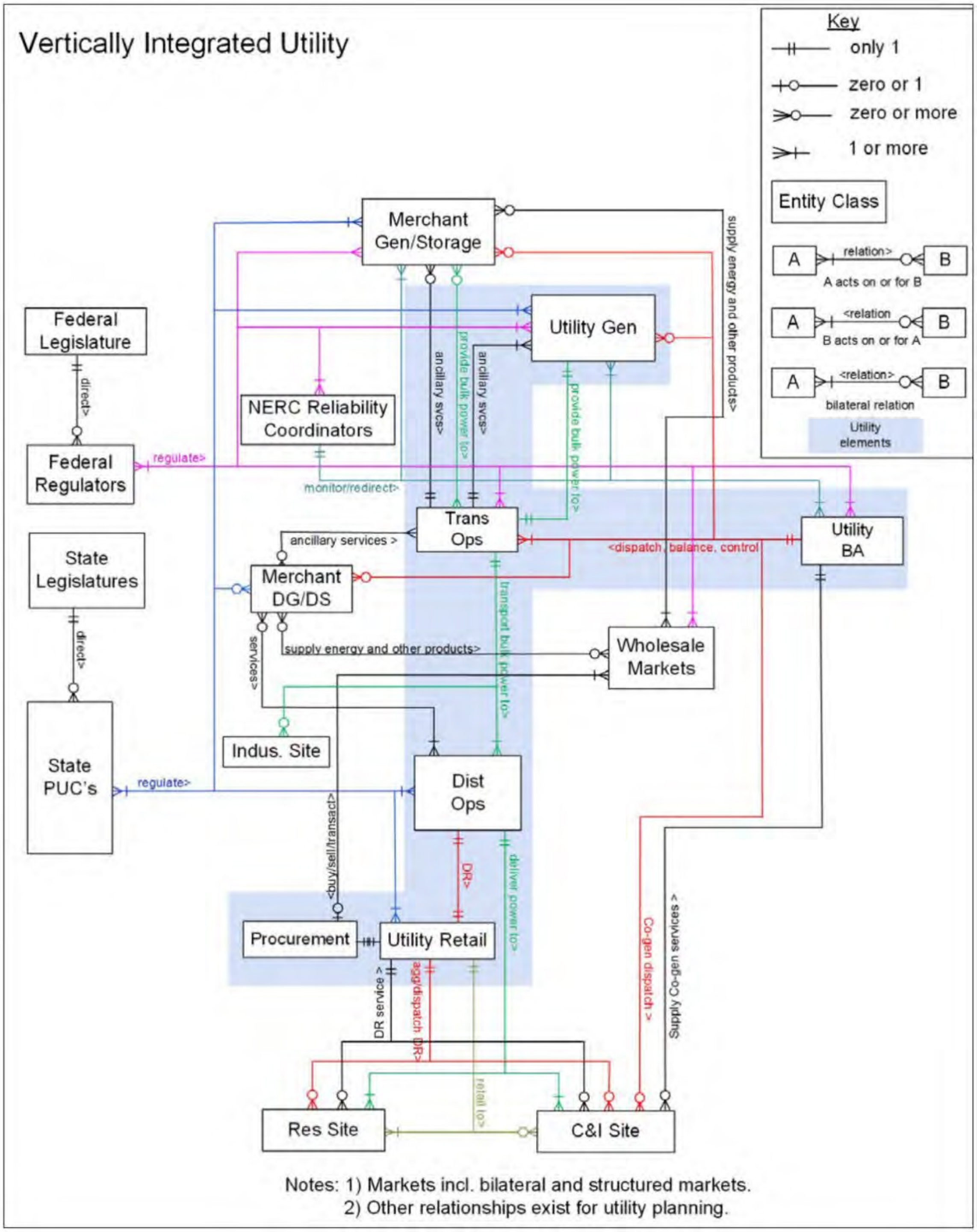
This distribution system flyer can be found at
https://eta-publications.lbl.gov/sites/default/files/distribution_system_infographic_final.pdf.




GRID
MODERNIZATION INITIATIVE
U.S. Department of Energy
DISTRIBUTION SUBSTATION
A distribution substation is where high-voltage electricity from the transmission system or sub-transmission system is converted to lower-voltage electricity for the distribution system.
Substation components
BUSWORK consists of electrical conductors that interconnect electrical equipment.
CIRCUIT BREAKERS protect a transformer from damage by interrupting the current when a fault in the line is detected.
VOLTAGE REGULATORS adjust output voltage within a specified range regardless of changes in input voltage or load conditions.
STEP DOWN TRANSFORMERS convert voltage from transmission or sub-transmission levels down to levels appropriate for local distribution.
CAPACITORS maintain or increase voltage in power lines and improve efficiency of the system by compensating for inductive losses.
BUSWORK
CIRCUIT BREAKERS
STEP DOWN TRANSFORMERS
VOLTAGE REGULATORS
CAPACITORS

Appendix B – Grid Architecture Example

The PNNL Grid Architecture report that includes this drawing can be found at https://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf.



Appendix C – DSO Structure Example

The PNNL Grid Architecture report that includes this drawing can be found at https://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf.