RECOMMENDATIONS FOR PREPARATION OF A DISTRIBUTED ENERGY RESOURCES PLAN OR ROADMAP

CLIMATE ECONOMIC ANALYSIS FOR DEVELOPMENT, INVESTMENT, AND RESILIENCE (CEADIR)

October 23 2020

This report was made possible by the support of the American people through the United States Agency for International Development (USAID). It was prepared by Crown Agents USA and Abt Associates.

Recommended Citation: Doyle, Patrick; Santiago Enriquez; Eric Hyman; Loretta Bauer; and Pablo Torres. 2020. Recommendations *for Preparation of a Distributed Energy Resources Plan or Roadmap*. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

Front photo source: Creative Commons (Pixabay).

Crown Agents USA Ltd. | 1129 20th Street NW | Suite 500 |
Washington, DC 20036 | T. (202) 822-8052 |
www.crownagentsusa.com

With:
Abt Associates

RECOMMENDATIONS FOR PREPARATION OF A DISTRIBUTED ENERGY RESOURCES PLAN OR ROADMAP

CLIMATE ECONOMIC ANALYSIS FOR DEVELOPMENT, INVESTMENT, AND RESILIENCE (CEADIR)

Contract No. AID-OAA-I-12-00038
Task Order AID-OAA-TO-14-00007

Economic Policy and Global Climate Change Offices
Bureau for Economic Growth, Education and Environment
U.S. Agency for International Development
1300 Pennsylvania Avenue NW
Washington, DC 20523

Prepared by

Patrick Doyle (Abt Associates);
Santiago Enriquez (Abt Associates);
Eric Hyman (USAID);
Loretta Bauer (Abt Associates); and
Pablo Torres (Crown Agents USA)

October 23, 2020

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AC	Alternating current
ACEEE	American Council for an Energy-Efficient Economy
AMI	Advanced metering infrastructure
BESS	Battery energy storage systems
BEV	Battery electric vehicle
CAISO	California Independent System Operator
CCTE	Consejo Consultivo para la Transición Energética (Mexico)
CEADIR	Climate Economic Analysis for Development, Investment and Resilience
CEL	Certificado de Energía Limpia (Mexico)
CENACE	Centro Nacional de Control de Energía (Mexico)
CFE	Comisión Federal de Electricidad (Mexico)
CPUC	California Public Utilities Commission
CONAMER	Comisión Nacional de Mejora Regulatoria (Mexico)
CONUEE	Comisión Nacional para el Uso Eficiente de la Energía (Mexico)
CRE	Comisión Reguladora de Energía (Mexico)
CREG	Comisión de Regulación de Energía y Gas (Colombia)
DC	Direct current
DER	Distributed energy resources
E3	Economic Growth, Education, and Environment Bureau (USAID)
EE	Energy efficiency
EP	Economic Policy Office (USAID/E3)
EPRI	Electric Power Research Institute
EV	Electric vehicle
EVI	Electric Vehicle Infrastructure
EVN	Electricity Vietnam (national, state-owned utility)
EVSE	Electric vehicle supply equipment
FCHEA	Fuel Cell and Hydrogen Energy Association
FERC	Federal Energy Regulatory Commission (United States)
FiT	Feed-in-tariff
GAMS	General Algebraic Modeling System
GCC	Global Climate Change Office (USAID/E3)
GHG	Greenhouse gas
GiZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoM	Government of Mexico

GoV	Government of Vietnam
GW	Gigawatt
GWh	Gigawatt-hours
HEV	Hybrid electric vehicle
HOMER	Hybrid Optimization of Multiple Energy Resources
ICE	Internal combustion engine
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IRENA	International Renewable Energy Agency
ISO	Independent system operator
kV	Kilovolts
LACE	Levelized avoided cost of electricity
LEAP	Long-range Energy Alternatives Planning (model)
LEAP-IBC	Long-range Energy Alternatives – Planning Integrated Benefits Calculator (model)
LCOE	Levelized cost of energy
Li-ion	Lithium-ion (battery)
MME	Ministerio de Minas y Energía (Colombia)
MOIT	Ministry of Industry and Trade (Vietnam)
MW	Megawatts
MWh	Megawatt-hours
NARUC	National Association of Regulatory Utility Commissioners (United States)
NERC	North American Electricity Reliability Corporation
NPV	Net present value (present value of net benefits)
NREL	National Renewable Energy Laboratory (United States)
NWA	Nonwire alternatives
NYISO	New York Independent System Operator
NYSERDA	New York State Energy Research and Development Authority
O&M	Operating and maintenance
PDP	Power Development Plan (Vietnam)
PDPAT	Power Development Planning Assistant Tool
PEV	Plug-in electric vehicle
PEPCO	Potomac Electric Power Company (United States)
PHEV	Plug-in hybrid vehicle
PLMA	Peak Load Management Alliance
PRODESEN	Programa de Desarrollo del Sistema Eléctrico Nacional (Mexico)
PV	Photovoltaic
RE	Renewable energy

RTO	Regional transmission organization
SCADA	Supervisory control and data acquisition system
SCE	Southern California Edison
SENER	Secretaría de Energía (Mexico)
SEPA	Smart Electric Power Alliance (United States)
SMUD	Sacramento Municipal Utility District (California)
TWh	Terawatt-hours
UL	Underwriters Laboratories
UPME	Unidad de Planeación Minero Energética (Colombia)
U.S. DOE	Department of Energy (United States)
U.S. EIA	United States Energy Information Administration
USAID	United States Agency for International Development
USG	United States Government
V-LEEP	Vietnam Low Emission Energy Program (USAID-funded activity)
V1G	Unidirectional managed charging (smart charging)
V2G	Vehicle-to-grid
VGI	Vehicle–grid integration
WEAP	Water Evaluation and Planning (model)

ACKNOWLEDGMENTS

This work was funded by the United States Agency for International Development (USAID) Economic Growth, Education, and Environment Bureau (E3) Global Climate Change Office (GCC). It was managed by GCC and the E3/Economic Policy Office (EP). CEADIR would like to thank Dr. Eric Hyman (EP Contracting Officer's Representative and Activity Manager) and Matthew Ogonowski (former GCC Alternate Contracting Officer's Representative and Activity Manager for Clean Energy). CEADIR also greatly appreciates the guidance and information provided by Thomas Black (USAID/Colombia), Riccardo Bracho (National Renewable Energy Laboratory), and Sarah Lawson (E3/Energy and Infrastructure Office).

The authors would like to thank interviewees from the following organizations who provided valuable insights: California Independent System Operator, California Public Utilities Commission, Colombia Ministry of Mines and Energy, Ha Da Song from Deloitte and the USAID Vietnam Low Emission Energy Program, ENEL (Colombia), Hawaiian Electric, PJM Interconnection LLC, Sacramento Municipal Utility District, Southern California Edison, and XM (Colombia). The authors would like to thank Alexa Smith-Rommel (Abt Associates) for editorial support.

EXECUTIVE SUMMARY

The United States Agency for International Development (USAID) requested the Climate Economic Analysis for Development, Investment, and Resilience (CEADIR) Activity to prepare this report to help governments and utilities in USAID partner countries prepare roadmaps or plans for distributed energy resources (DER). CEADIR conducted desktop research on good practices for DER roadmaps and plans in the United States (U.S.). CEADIR interviewed representatives of U.S. utilities, government regulatory agencies, and regional grid market operators that have participated in state or regional DER planning. These organizations included the California Independent System Operator, California Public Utilities Commission, Hawaiian Electric, PJM Interconnection, Sacramento Municipal Utility District, and Southern California Edison. CEADIR also conducted interviews on DER policies and planning in Colombia, Mexico, and Vietnam.

A *DER roadmap* is a planning study, guidance document, or action plan that can help government planners and regulators, utilities, and other stakeholders make better decisions on distributed energy resource investment and use. It can identify national or subnational goals and targets for electric power generation, transmission, and distribution systems and the major milestones needed to reach them. The term roadmap is often used as a synonym for a plan, but a roadmap is sometimes viewed as less prescriptive than a plan on the timetable for achieving the targets. This report focuses on planning for integration of DER on the power grid, including macrogrids and microgrids connected to the macrogrid. It does not focus on planning for off-grid DER or minigrids that are not connected to a macrogrid.

Distributed energy resources (DER) include 1) distributed generation, 2) transmission and distribution grids, 3) energy storage, 4) electric vehicles and charging infrastructure, 5) demand response, and 6) energy efficiency. Key drivers of DER growth include increasing electricity demand and expansion of utility-scale renewable energy (RE) generation, the policy and regulatory environment, and technology improvements and cost reductions.

DER can have many financial, economic, environmental, and social benefits for utilities, power markets, and end users. Distributed generation and demand response programs can help meet peak power requirements, enabling utilities to defer or reduce costly, new capital investments in centralized power generation and transmission and distribution. DER also offer the potential for better service reliability and power quality. They can increase energy security and improve the balance of trade for countries that rely on imported fuels for power generation. Decentralized power generation often relies on RE resources that produce little or no air and water pollution and greenhouse gas (GHG) emissions.

However, a high reliance on variable RE resources can lead to a mismatch between the supply and demand for electric power unless balanced by a mix of different RE resources from different locations or energy storage and smart grid and metering technologies. DER expansion can reduce short- and medium-term revenues and profits from power generation and transmission and distribution even if the long-term impacts are positive. Distributed generation can increase the complexity of grid operations, including power control and dispatchability, voltage regulation, and system responses during disruptions. However, distributed power technologies and demand response programs can also reduce these challenges.

A DER roadmap or plan can help achieve various desired outcomes for the power generation and transmission and distribution systems, including affordability, environmental and social sustainability, flexibility, reliability, resiliency, and security. DER roadmaps and plans should discuss available and emerging technologies, technology research and development priorities, gaps in human and institutional capacity that need to be addressed for successful implementation, impacts of current and new policies or regulations, the value of DER investment decisions for the public and private sectors and communities, and coordination and monitoring of DER investments and use.

A DER plan or roadmap can help utilities develop consensus on objectives, targets, technologies, and location-specific priorities, and plans for procurement, financing, and implementation of investments and programs. This can reduce regulatory delays and increase public and private sector support and investments.

CEADIR recommended a three-phase approach for the DER plan or roadmap process. The first phase includes preliminary work to secure buy-in and sponsorship, stakeholder mobilization, scoping, data collection and analysis, and communications. The second phase is formulation of the DER plan or roadmap. The third phase consists of follow-up activity, including preparation of a budget and schedule for implementation and a plan for updating the DER roadmap.

Some key themes for DER policies, adoption, and planning are listed below:

- **Most developing countries need to expand electricity generation and transmission and distribution systems and beyond the grid services to increase affordability, reliability, and access and DER can play an important role.** Many also have country-specific reasons for increasing DER adoption. For example, Colombia is heavily dependent on large-scale hydropower that is vulnerable to drought risks and faces grid constraints. Mexico continues to incur high costs for electricity rate subsidies and had relatively high generation costs from fossil fuels despite extensive solar and wind resources. Vietnam has experienced large increases in the demand for electricity due to rapid economic growth and still has limited power transmission and distribution infrastructure. It has also relied heavily on domestic and imported coal for electricity generation and faces major health impacts from severe air pollution problems.

- **Many developing countries were still at an early stage of DER adoption.** Common challenges to DER expansion in developing countries include the absence of wholesale power markets; limited ability for remuneration of ancillary services; the absence of interconnection standards; slow approval processes; the need for greater transparency on electricity distribution systems to inform the development of new markets, business models, and private investment opportunities, limited visibility on the types, capacity, and location of private DER connected to the grid; subsidized electricity rates; and the need for greater data sharing and for greater use of models for decision making.

- **When DER use is low, governments may need to consider policy, regulatory, and market reforms to create a more favorable enabling environment for scaling up DER investment rates.** In the U.S., Federal Energy Regulatory Commission (FERC) Order 745 of 2011 required wholesale markets to compensate demand response providers for load reductions at the same rates available for generated electricity.

  FERC Order 841 of 2018 increased investments in utility-scale BESS by removing barriers to the equitable participation of storage resources in capacity, energy, and ancillary services markets operated by regional transmission organizations (RTOs) and independent system operators (ISOs). In 2020, FERC Order 2222 broadened the requirements to include the full range of DER technologies.

  Decreasing costs and improving performance of DER technologies have also encouraged policy, regulatory, and market reforms in developing countries. Between 2013 and 2015, Mexico was an exemplary model of major electricity market and policy reforms. However, Mexico reversed many important reforms between 2018 and 2020. Colombia began major electricity reforms in 2014 and has continued to build on them. Vietnam began reforms more recently. For example, Vietnam replaced feed-in-tariffs with competitive RE auctions in 2017.

- **DER can help balance grid demand and supply** at multiple timescales, enabling utilities to defer or reduce new capital investments in generation, transmission, and distribution. Increased DER use can improve variable RE generation and the ability of utilities to meet peak loads at lower costs. Bidirectional flows from EV charging can also have positive impacts on the power system. DER also increase energy security for countries that rely on imported fossil or nuclear fuels for power generation.
- **DER technologies can be disruptive.** DER can require new approaches to power generation, distribution, and transmission investment and operations. DER can pressure existing utility business models by reducing capital costs as well as revenues and changing the relationship between utilities and their customers. However, DER can strain transmission and distribution systems, especially when data are insufficient on their capacity and location, power production profile, behavior during disturbances, controllability, and impact on regulating voltages.
- **Utilities need to monitor customer adoption of grid-connected distributed generation and forecast future growth to plan their investments.** Utilities will also need to assess the technological and financial feasibility of their own DER and conventional infrastructure investments. The impacts on operations and investments depend on whether utilities are involved in power generation as well as transmission and distribution and competition from independent power generation companies and customers with their own distributed generation.
- **Utilities need more data from their customers with grid-connected, distributed generation, storage, and EV charging systems to manage and plan their operations.** As DER adoption expands, utilities need real-time data from their customers and market networks to improve system reliability and efficiency. Real-time monitoring of voltages along transmission and distribution lines is important when there are bidirectional electricity flows. Many developing countries need to improve interconnection standards and adopt smart grids and automated, monitoring technologies to overcome data and capacity limitations. Utilities may also need to adopt new practices, such as establishing voltage reserves.
- **DER roadmaps and plans can smooth the transition from a centralized grid to a distributed electric power system.** The complexity of the power system increases as more DER are integrated into the grid. During the early stages with low DER integration, policy making can focus on projecting customer adoption rates and managing interconnections. As DER integration progresses, policies should focus on incentives for distribution network changes that can increase system reliability and the ability to defer conventional generation and distribution investments. With widespread DER integration, policies should focus on improving electricity markets, such as facilitating peer-to-peer transactions, wholesale markets, and regional reliability improvements and cost reductions.

  A DER roadmap can help build consensus on policy goals and the process and milestones needed to achieve them. Proactive planning can help manage the challenges associated with DER integration and take better advantage of the potential savings from avoided capital costs.
- **In the U.S., DER planning is typically done at the state, rather than federal government level.** California, Hawaii, and New York have taken a leading role in DER planning. In some states, government agencies prepare DER roadmaps. Some states require utilities to prepare DER plans instead of or in addition to public sector plans. The Potomac Electric Power Company (PEPCO), is an example of a U.S. transmission and distribution utility that has prepared a DER roadmap for its multistate service area subject to different regulatory frameworks and entities. Some states have multiple DER roadmaps that cover various market segments or political jurisdictions. Multistate power pools may also produce DER plans.

- **DER planning in most developing countries has lagged adoption rates.** Few developing countries have prepared have roadmaps or plans that focus on DER. However, some have prepared long-term or short-term, national energy plans that addressed some DER technologies.

  The Government of Colombia established an Energy Transformation Mission with national and international experts to develop the country's first roadmap for modernization of the electric power system. This roadmap will address DER and broader sectoral topics: 1) competition, participation, and market structure (including RE integration and pricing for system stability and reliability); 2) role of natural gas in the electricity transformation; 3) decentralization and digital technologies in the electric power system and pricing for efficient demand management; 4) closing gaps in coverage and service quality and formulation of efficient subsidies; and 5) review of the institutional regulatory and framework. In Colombia, diverse stakeholders contributed to DER planning through the Consejo Nacional de Operación's multidisciplinary workgroups, Colombia Inteligente, SER Colombia, and Energética 2030.

  In 2018, the Government of Mexico included a chapter on distributed generation planning in its national electricity development program, Programa de Desarrollo del Sistema Eléctrico Nacional (PRODESEN) for the first time. However, multiple policy and regulatory changes between 2018 and 2020 have reversed or undermined many of the earlier power sector reforms.

  The Government of Vietnam has an extensive history of preparing plans for the electric power system. Vietnam's Ministry of Trade and Industry (MOIT) will be developing the Eighth Power Development Plan (PDP-8), covering 2021 through 2030. The national parastatal utility, Electricity Vietnam (EVN), was also preparing its five-year plan for 2021-2025. The Seventh Power Development Plan and earlier plans were prepared without sufficient data on the demand, variable RE generation, and transmission capacity to allow *operations modeling* – production cost and reliability simulations.

  The USAID-funded Vietnam Low Emission Energy Program (V-LEEP) provided technical assistance to improve the eighth plan. It recommended using at least a full year of data on power demand and electricity generation, transmission and distribution operations over one-hour or half-hour time periods. V-LEEP also recommended restructuring the geographic regions to reflect differences in the marginal costs of power generation, rather than legislatively mandated regions or the regions used in the previous plans. This will facilitate the analysis of transmission and distribution system congestion. The MOIT also received support from the World Bank, Deutsche Gesellschaft für Internationale Zusammenarbeit (GiZ), and other development assistance organizations to improve local data on solar and onshore wind resources. Further work will be needed to screen areas suitable for solar and wind power development and identify offshore wind power potential.

- **Diverse stakeholders should be included in a DER roadmap or planning process.** Key stakeholders include national or subnational regulators, other government agencies, executive and legislative branch officials; utilities and other power generators; industrial, commercial, and residential users; community-based organizations; environmental organizations; and consumer advocacy organizations. It is important for utilities to keep these stakeholders informed about the planning process and available data and analyses. Residential, industrial, and agricultural users and consumer organizations often seek subsidies or lower electricity rates. Environmental organizations advocate for air and water quality improvements and GHG emission reductions from fossil fuel use.

Planning and policy issues. DER are rapidly evolving and technologies are improving and unit costs are declining. Although these trends are favorable, they increase uncertainty about optimal adoption rates and timing. Furthermore, many government policy and utility planning issues remain to be determined:

- How to best drive DER to particular locations of optimal deployment?

- How to align compensation, rates, and market structures to better realize the value of DER services?
- How to provide customers with timely and more granular information so that they can make informed decisions about their energy use?
- Whether utilities be allowed to own and operate DER products and services?
- How to evolve utility business models and regulatory models to properly value and take advantage of DER opportunities? (Deora *et al*. 2017).

Areas for further research.

- DER sourcing best practices;
- Ownership and control of DER;
- Utility contracting benchmarks with technology providers and third-party owners;
- Navigating multiple value streams of, and cost recovery approaches for DER;
- Benefit-to-cost analyses and new incentive models for utilities; and
- DER impacts on the bulk power system (Chew *et al*. 2018).

Energy Systems Integration Group (2019) recommended research to improve modeling of the relationships between power resource adequacy and the transmission and distribution system; distributed generation, demand response; energy efficiency innovations, storage, electric vehicle charging, and cogeneration. It also called for improvements in the quality of weather and climate data and forecasting for modeling power supply and demand and risks.

The Energy Systems Integration Group noted that modeling results will need to be better integrated into probabilistic tools for planning, outage scheduling, contingency assessments, unit commitment and dispatch, and real-time operations and control. It also recommended reconsidering the design of markets and the regulatory framework to increase incentives for an optimal mix of resources, based on cost efficiency, reliability, and other beneficial attributes as the share of renewable electric power increases toward 100 percent.

Changes will be needed in planning and management of the power transmission and distribution systems as distributed generation and demand-side participation scale up. Decentralization and digitization increase the number of participants in power generation and load response, making it difficult to maintain a command and control distribution system. The expert group observed that the planning process has begun to change for power transmission, but not so much for power distribution.

1. BACKGROUND

1.1 PURPOSE AND SCOPE

The United States Agency for International Development (USAID) requested the Climate Economic Analysis for Development, Investment, and Resilience (CEADIR) Activity to prepare this report to help governments and utilities in USAID partner countries prepare roadmaps or plans for distributed energy resources (DER). A *DER roadmap* is a planning study, guidance document, or action plan to help government energy ministries, regulatory agencies, utilities, and other stakeholders improve their decision making. A roadmap is often used as a synonym for a plan, but may be less prescriptive and less specific on the timing of targets and milestones. A DER roadmap can be prepared at multicountry, national, or subnational levels.

This report focuses on the integration of DER into the main power grid (*macrogrid* or *mains*) as well as microgrids connected to the main grid. It does **not** address DER for *off-grid use* or *minigrids* without connections to the main grid. Off-grid DER (including minigrids) can be critically important in developing countries, especially in remote areas where macrogrid extension is expensive or grid-connected areas with unreliable electricity service. However, minigrids are relatively small and serve a limited group of end users. As a result, they do not have a major impact on the power generation and transmission and distribution systems at the national or state (provincial) levels.

CEADIR conducted desktop research on good practices for DER roadmaps and plans in the United States (U.S.). CEADIR interviewed representatives of U.S. utilities, government regulatory agencies, and regional grid market operators that have participated in state or regional DER planning: the California Independent System Operator (CAISO), California Public Utilities Commission (CPUC), Hawaiian Electric, PJM Interconnection, Sacramento Municipal Utility District (SMUD), and Southern California Edison (SCE). The interviews with U.S. organizations focused on the following questions:

- What led them to move from conventional approaches for power planning to inclusion of DER?
- What state and federal policies have been important in their decisions to include DER in electricity generation, transmission, and distribution planning?
- What were the benefits and challenges of using modeling software in DER planning?
- Which stakeholder groups have been important in DER planning? How did they ensure broad participation in the planning process?
- Did the planning process try to influence the location of DER so that they would be available on the grid where and when they were needed?
- Has DER development smoothed variability in hydropower generation associated with seasonal water variability and drought risks?
- Has DER planning increased renewable energy (RE) development or grid modernization?
- Which DER technologies have been most successful and why? Which DER technologies have faced the most adoption challenges and why?
- What are the expected impacts if DER growth either exceeds or lags behind the projections?
- What technologies and management solutions have been implemented to help ensure good grid integration of DER?
- What are your recommendations on DER planning and integration for developing countries?

CEADIR also conducted interviews on DER policies and planning in Colombia, Mexico, and Vietnam. The questions varied, but generally included

- How does your organization define DERs and what technologies have been included?
- Do your organization think it is important to develop a roadmap specific to DERs or is it sufficient to conduct DER planning within electricity or energy master plans?
- What role has your organization had in planning for DER integration?
- What are the main drivers of DER adoption in the country? Do these factors vary in different parts of the country? Are there targets for the adoption of specific DERs?
- What are the most important existing regulations, policies, and incentives for DER adoption? Are new regulations, policies, and incentives for DER being developed? What is the expected timetable for their adoption?
- What have been the most important aspects of the DER planning process? What recommendations would you make for improving DER planning?
- What platforms, coordinating bodies, or procedures are in place for DER planning in your country? Which public and private sector organizations have led these efforts? Which other public and private sector organizations have participated? Has the planning process been participatory with broad stakeholder involvement?
- What tools and models has your organization used in DER planning?
- What are the most important challenges to DER expansion in your country and for your organization? What recommendations do you have for overcoming these challenges?

The rest of section 1 describes the various definitions of DER and the types of technologies, uses, and potential barriers, as well as key drivers affecting adoption. Section 2 discusses the benefits and challenges of DER roadmaps and plans. Section 3 provides examples of DER roadmaps and plansg in the U.S., Colombia, Mexico, and Vietnam. Section 4 contains recommendations for the DER roadmap or planning process. Section 5 summarizes key themes for DER roadmaps or plans. Annex A defines common terms in power generation, transmission, and distribution. Annex B lists resources and tools for DER analysis and planning. Annex C describes related CEADIR work.

1.2 DIVERSE DEFINITIONS OF DER

There are various definitions of DER that have evolved over time. Some early definitions focused on geographically dispersed, distributed generation, such as wind power, rooftop photovoltaics (PV) or combined heat and power (cogeneration). *Distributed generation* technologies produce electricity near the point of use, whether connected to a distribution grid (macrogrid, minigrid, or microgrid) or only serving off-grid users. State governments in California and New York have defined distributed generation to include technologies in all sizes and locations on-or off the grid. Owners of grid-connected distributed generation may be able to sell their surplus power to the grid. The value of this power to the grid depends on whether it is available when and where the demand exists and the regulatory environment.

More recent definitions of DER have included distributed power technologies and demand response, and energy storage. *Distributed power technologies* include gas turbines, reciprocating engines, back-up generators, and stationary energy storage. *Demand response programs* include energy efficiency technologies and financial incentives or penalties to motivate grid customers to reduce their total or peak period electricity consumption. Bidirectional vehicle charging systems can also be demand response resources.

The National Association of Regulatory Utility Commissioners (NARUC) in the U.S. defined DER to include distributed generation and demand response programs:

> A resource sited close to customers that can provide all or some of their immediate electric and power needs and can also be used by the system to either reduce demand (such as energy efficiency) or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, are small in scale, connected to the distribution system, and close to load (NARUC 2016).

The North American Electric Reliability Corporation (NERC) definition included

> Any non-bulk electric system generating unit or multiple generating units at a single location owned and/or operated by the distribution utility or a merchant entity. They included distribution generation, behind-the-meter generation, energy storage, virtual DER aggregation, microgrids, cogeneration, and emergency, standby, or back-up generation (NERC 2017).

Deora *et al.* 2017 defined DER as:

> Physical and virtual assets that are deployed across the distribution grid—typically close to load and usually behind the meter—that can be used individually or in aggregate to provide value to the grid, individual customers, or both. A particular industry interest centers on DER that can be aggregated to provide services to the electric grid, such as solar, storage, energy efficiency, electric vehicles, and demand management.

In 2020, the U.S. Federal Energy Regulatory Commission (FERC) Order 2222 defined DER broadly as "any resource located on the distribution system, any subsystem, or behind a customer meter." It supported a technology-neutral approach in selecting the mix of DER.

DER may be located in front-of-the-meter or behind-the meter. *Front-of-the-meter* refers to large power generation, transmission, distribution, or storage systems at the utility scale. *Behind-the-meter* systems place power generation, storage, or smart technologies at the locations of end users (industrial, commercial, institutional, and household users).

Dispatchability is the ability to produce usable power from centralized or DER generation that can be sold on the grid. *Curtailment* occurs when the quantity of electricity supplied exceeds the quantity demanded (*load*), leading to wasted power and is a particular problem for RE resources such as hydropower and solar and wind power. Smart grid and energy storage technologies can regulate the supply of electricity to reduce curtailment.

Nonwire alternatives (*nontransmission alternatives*) use nontraditional transmission, distribution, and demand response solutions to defer or eliminate the need to upgrade transmission or distribution infrastructure. Examples include distributed generation, energy storage, energy efficiency, demand response, and grid software and controls (Feldman 2017).

Aggregation combines the capabilities of individual DER units and is important because of the minimum size thresholds for participation and the complex rules and procedures in power markets. Aggregation also reduces transaction costs and improves the ability of the grid operator to plan, control, and dispatch, and use electricity effectively (Migden-Ostrander *et al.* 2018).

Ancillary services support the generation, transmission and distribution, or usability of electric power. Some ancillary services are required more frequently than others and the benefits to the power supply system and marketability of the various services vary across and within countries. Ancillary services include various types of contingency, regulation, and flexibility reserves, such as black start, spinning reserves, nonspinning reserves, and voltage and frequency regulation.

Black start is the process of restoring a power generating unit or part of an electric grid to operation to recover from a total or partial shutdown. It is only rarely needed. *Spinning reserves* are back-up generation units that can be quickly ramped up to meet immediate load requirements on the grid. Spinning reserves are used infrequently used in a particular hour. Tait (2017) reported that U.S. utilities generally maintain spinning reserves for 3.0-4.5 percent of their average loads to cover potential generation outages. *Nonspinning reserves* are generation units that are usually kept offline because of relatively high operating costs but can ramped up within 10 minutes to meet peak loads. *Frequency regulation* balances the supply and demand for active power and controls the number of cycles of alternating current per second for proper grid operations. *Voltage regulation* balances the supply and demand for reactive power.

1.3 BENEFITS OF DER

DER can have many financial, economic, environmental, and social benefits for utilities, power markets, and end users:

Meeting increasing electricity demand at lower cost and in more resilient and sustainable ways. Increased adoption of DER can eliminate or delay the need for investments in new generation, transmission, and distribution infrastructure, reducing capital and financing costs and operating, maintenance, and replacement costs. These cost reductions may allow utilities to charge lower electricity rates over the long term (Agarwal and Jain 2019). In the short term, however, utilities may have to increase rates to recover their infrastructure investment costs. DER can be implemented gradually, scaled as demand grows, and adjusted as technologies and costs change (Levin and Thomas 2016).

E4TheFuture, Peak Load Management Leadership, and the Smart Electric Power Alliance reviewed the experience of 10 U.S. nonwire alternatives projects varying in size, location, technologies, and management approaches. They concluded that nonwire alternatives allowed utilities to 1) defer or avoid large, up-front costs; 2) phase in investments to decrease load growth uncertainty; and 3) adopt more flexible or less costly solutions (Chew *et al.* 2018).

Expanding electricity access beyond the macrogrid. Many developing countries have insufficient large-scale power generation capacity or energy supplies to meet their rapidly growing demand for electricity. Many also have geographically limited transmission and distribution grids. These areas can benefit from the ability of DER to support utility-scale or decentralized power generation. Off-grid DER can serve areas where macrogrid expansion to remote or low-income areas would be costly or slow.

Improving the efficiency and reliability of electricity generation, transmission, and distribution:

- *Lower transmission and distribution losses*: Locating generation, storage, and distribution systems closer to the end users may reduce electricity losses in transmission and distribution;
- *Load shifting*: Reducing the maximum electricity demand by moving consumption from peak to off-peak periods;
- *Reliability*: Multiple points of entry for electricity onto the grid can reduce outage risks;
- *Resilience*: Greater ability to operate after extreme weather events or natural disasters;
- *Flexibility*: Better balancing of the quantity of power demanded and the quantity supplied can increase fast response and longer-term response;
- *Voltage regulation*: The ability to maintain the voltage at proper levels increases the quality of electricity, reducing damage to transmission and distribution lines and user electrical equipment;
- *Contingency response*: Maintaining the frequency of current during an unexpected failure or planned outage of system component a generator or transmission line;

- *Less network congestion*: Filling gaps between the power load and quantity of electricity supplied; and
- *Operating reserves*: Generating capacity available to the system operator within a short period of time to meet the load when a generator goes down or there are other supply disruptions.

Reducing negative environmental impacts of fossil fuel generation and transmission and distribution infrastructure. Battery energy storage, demand response, and EE programs can reduce fossil fuel consumption in power generation and the associated air and water pollution and greenhouse gas (GHG) emissions. By reducing the need for new generation, transmission, and distribution infrastructure, DER can reduce the habitat loss and fragmentation that may, displace species, alter population dispersal patterns, and facilitate the introduction of non-native species, including invasive species. Transmission and distribution infrastructure can also generate restrictions on land use, which can lead to social conflict (Agarwal and Jain 2019).[1]

Greater domestic energy security. Many countries heavily depend on imported fossil fuels for electricity generation. Oil and gas markets are volatile and priced in hard currency. When developing country currencies lose value, imported fuels become more expensive, even when world market prices in hard currency remain unchanged. Domestic energy security can be enhanced by reducing energy consumption, increasing RE and battery storage use, and diversifying the types and sources of energy (Yepez-Garcia, Rigoberto, and Dana 2012; IEA 2019).

DER deployment has grown in developing countries, mainly through distributed generation and demand response and EE programs. Smart meters and electric vehicles (EVs) will become increasingly important. Demand response and EE programs are particularly important in developing countries with large projected increases in power demand and inefficient technologies that use electricity.

Potential revenues from sales of ancillary services. Ancillary services have value for the power system, even if they are not specifically remunerated. In some developed and developing countries, power generators, utilities, and grid operators may be able to obtain additional revenues from sales of ancillary services. However, markets for ancillary services have not yet emerged in most developing countries.

1.4 TYPES OF DER

Colman, Chung, and Wilson (2017) listed six types of DER: 1) distributed generation, 2) transmission and distribution grids, 3) energy storage, 4) EVs and charging infrastructure, 5) demand response, and 6) EE. Table 1 indicates the multiple capabilities of various DER.

[1] For example, the Government of Costa Rica set a national goal of carbon-neutral electricity generation by 2021 and provided tax incentives to help achieve this goal (IEA 2018). RE sources provided 99.6 percent of the country's electricity in 2019, including 78.3 percent from hydropower, 10.3 percent from wind power, 10.2 percent from geothermal, and 0.8 percent from solar or biomass sources. This was the third year when all of the country's electricity was from RE sources for at least 300 days of the year (Reve Wind 2020).

TABLE 1. Capabilities Matrix for Distributed Energy Resources

TECHNOLOGIES	ENERGY	GENERATING CAPACITY	DISTRIBUTION CAPACITY	VOLTAGE REGULATION	FREQUENCY REGULATION	LOAD FOLLOWING	BALANCING	SPINNING RESERVES	NON-SPINNING RESERVES	BLACK START
DISTRIBUTED SOLAR	Energy Generator	◔	◔	○	○	○	○	No	No	No
DISTRIBUTED SOLAR + ADVANCED INVERTER FUNCTIONALITY	Energy Generator	◔	◔	●	●	◔	○	No	No	No
BATTERY STORAGE	Energy Storage	●	●	●	●	●	●	Yes	Yes	Yes
INTERRUPTIBLE LOAD	Load Shaping	◐	○	○	○	○	●	Yes	Yes	No
DIRECT LOAD CONTROL	Load Shaping	◐	◐	○	◐	●	●	Yes	Yes	No
BEHAVIORAL LOAD SHAPING	Load Shaping	◔	◔	○	○	◔	◔	No	No	No
ENERGY EFFICIENCY	Reduce Load	◐	◔	○	○	○	○	No	No	No

○ Unsuitable for reliably performing the specified service.

◔ May be able to perform a service, but is not well suited or can provide partial support.

◐ Able to perform a service, but may be limited by factors such as availability or customer behavior.

● Well suited to perform a service; may exceed legacy technologies for providing the service.

Source: Smart Electric Power Alliance, 2016

Source: Deora *et al.* 2017

1.4.1 DISTRIBUTED GENERATION

Distributed generation includes grid-connected and off-grid RE applications (U.S. EIA 2019b). Grid-connected utility customers have various motivations for buying their own distributed generation systems: lower electricity costs; new revenues from sale of surplus power; more consistent power quality; greater service reliability and resilience to system disruptions from extreme weather, fires, or human-caused disasters; avoiding the need for diesel generators; decreasing air and water pollution or GHG emissions; reducing dependence on imported fossil fuels; and promoting new technologies (Colman, Chung, and Wilson 2017). Subsidies, financing, and tax incentives have also been important motivators.[2]

Solar panels and most small wind turbines produce direct current (DC) electricity, but most end users require alternating current (AC). AC is also needed for efficient, long-distance transmission. *Inverters* convert DC electricity into AC and are an essential component in off-grid and grid-connected solar and small wind power systems. *Smart inverters* have a digital architecture, bidirectional communications capability, and software to send and receive data with the distributed generator owner and transmission

[2] Establishment Labs, a medical implant manufacturer in Costa Rica, relies on distributed generation and grid power. It installed a microgrid that integrated a 276 KW PV system, battery energy storage system, and optimization software to allow continued manufacturing operations during macrogrid power outages. The company still uses electricity from the macrogrid to supplement its own solar generation. It also stores electricity for use during supply disruptions. When an outage occurs on the macrogrid, the company's microgrid disconnects from the main grid and operates in standalone mode. The company previously relied on two diesel generators for back-up power. The microgrid has lower operating costs and GHG emissions than the diesel generators (EnelX 2018).

and distribution companies. Smart inverters also allow service technicians to diagnose operating and maintenance problems and upgrade some parameters remotely (Belur 2014).

In some countries, government subsidies and tax deductions or credits may offset some of the capital costs for end users that purchase distributed generation systems. Regulatory agencies may require utilities to offer partial rebates for distributed generation purchases out of their potential cost savings from deferring investments in new utility-scale generation or transmission. Regulators can also authorize utilities to increase the price of electricity to cover the cost of customer incentives for distributed generation.

The incentives for installing distributed generation can be increased through net metering. *Net metering* allows distributed generation owners to offset their consumption of power from the grid with the value of their surplus power that they deliver to the grid. Many utilities do not allow net metering or only offer it when required by law. Net metering policies vary in how long banked credits can be retained and whether the credits are valued at a retail or wholesale price. Many U.S. states with net metering requirements place limits on how much of the surplus capacity of a generator qualifies for net metering.[3]

High upfront system costs, intermittent RE resource availability and dispatchability, limited availability of grid, connections, and grid capacity limitations can reduce the incentives for on-grid customers to install distributed generation. Some regulators or utilities have imposed additional charges on grid-connected customers with DER for generation capacity that they do not use.

1.4.2 TRANSMISSION AND DISTRIBUTION GRIDS

Power grids vary in, size, types of connections, and operating characteristics. Some terms for the different types of grids are in common use, although the definitions have varied. A *macrogrid* (*mains*) is a large, centralized power grid. A country may have one or more macrogrids. Some macrogrids have interconnections with others in different countries, states, or provinces to increase the reliability of electricity supplies and take advantage of the lowest delivered power costs.

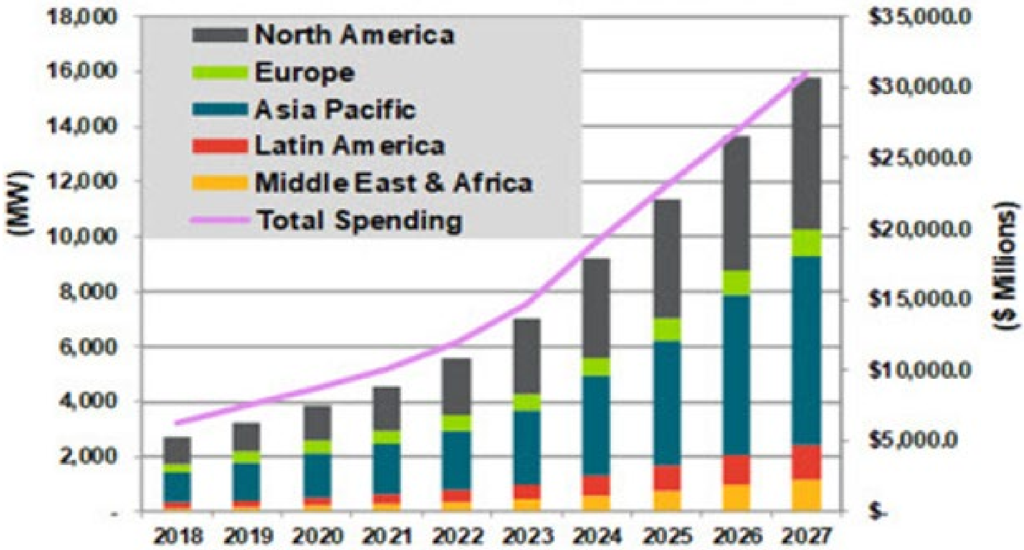
The U.S. Department of Energy (U.S. DOE) defined *microgrids* as loads connected to a macrogrid that can also operate in a disconnected mode. The World Bank defined *minigrids* as relatively small, isolated distribution units not connected to a macrogrid. Eller and Gantlett (2017) defined *nanogrids* as very small, localized grids in remote areas that lack access to a macrogrid.

Figure 1 shows projected increases in annual investments and capacity for connected and isolated microgrids by region. In 2018, total world capacity of microgrids included 1,463 megawatts (MW) with macrogrid connections and 1,231 MW off-grid. By 2027, this is projected to increase to 11,576 MW with macrogrid connections and 4,230 MW off-grid (Wood 2018).

---

[3] For example, New Jersey limited net metering for residential customers to 100 percent of baseline consumption up to 10 MW. Maryland allowed any amount of net metering up to 200 percent of baseline consumption. New Jersey only allowed community or aggregated net metering for public sector entities while Maryland allowed 2,000 MW and the District of Columbia allowed 5,000 MW (PEPCO Holdings 2016).

FIGURE 1. Projected Microgrid Capacity and Capital Investment by Region, 2018-2027



Source: Wood 2018

Smart grids include a variety of digital technologies for advanced sensing and measurement, and two-way communications to improve decision making, and automated control. Smart grids can improve

- *Observability*: Accurate and timely monitoring of the grid status;
- *Controllability*: Ability to manage the grid effectively;
- *Timely analysis and automated decision making*;
- *Self-adapting and self-healing*: Avoiding or fixing power supply disturbances and equipment breakdowns and identifying locations with problems;
- *RE integration*: Efficient and safe use of power from centralized and distributed generation (International Telecommunication Union 2011).

The benefits of smart grids include

- *Robustness*: More continuous and stable electricity flows with disruptions and accidents and self-healing abilities. Greater resilience to natural disasters, extreme weather, and human errors or deliberate damage breakage;
- *Secured operation*: Improved communications and information security for the electricity grid;
- *Compatibility*: Better integration of distributed generation and microgrids, improved demand response, two-way communications with prosumers;
- *Economical energy usage*: More effective electricity markets and trading, increased grid efficiency, and reduced electricity wastage;
- *Integrated system*: Better and more timely information on grid status and standardized and more effective management;
- *Optimization*: More efficient operations and use of assets to reduce costs; and
- *Green energy*: Increased use of RE to reduced GHG emissions and pollution and increased energy security (International Telecommunications Union 2011).

The Smart Electric Power Alliance (SEPA) has an online catalog of standards and practices relevant for the development and deployment of a robust, interoperable, and secure smart grid. It was prepared as a resource for U.S. utilities, manufacturers, regulators, consumers, and other stakeholders.[4]

Smart grids often have computerized, *supervisory control and data acquisition* (SCADA) systems that collect and analyze real-time information to monitor and control generation or transmission and distribution equipment. SCADA systems can extend to the substations, feeder lines, and end user levels to maintain reliable power supplies over a large geographic area. Specific advantages of SCADA systems in power distribution include

- Timely recognition of faults to avoid equipment damage;
- Continuous monitoring and control of distribution network from remote locations;
- Lower labor costs from eliminating manual operation of distribution equipment;
- Shorter outage times because system-wide monitoring and alarms allow quicker resolution of problems;
- Faster ability to restore service after temporary faults;
- Automatically improve the voltage profile through power factor correction and reactive power controls;
- Facilitating analysis of historical data; and
- Lower labor costs from reducing the staff needed for meter reading.[5]

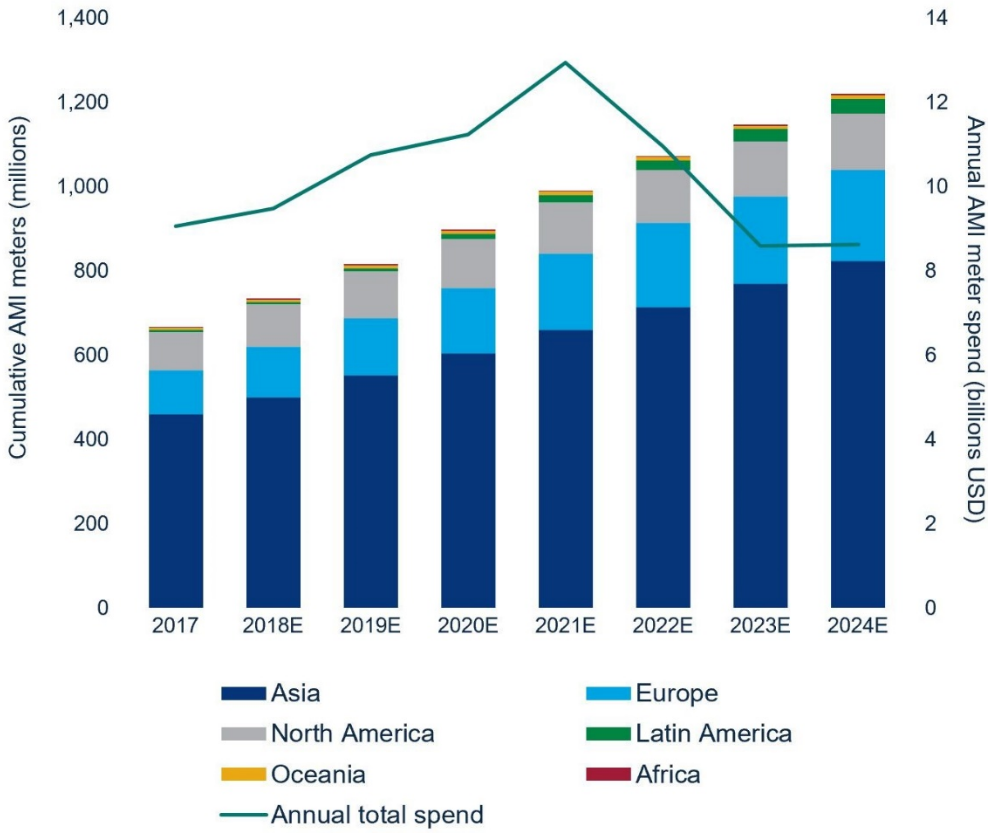
Potential barriers for transmission and distribution grid improvements include dispatchability, rate design, interconnection, hardware and software costs. Smart grids face the following challenges:

- High power system loading;
- Increasing distance between generation and load;
- Fluctuating renewables;
- New loads (electric vehicles);
- Increased use of distributed energy resources;
- Cost pressure;
- Utility unbundling;
- Increased energy trading;
- Transparent consumption and pricing for consumers; and
- Significant regulatory push (International Telecommunications Union 2011).

[4] https://sepapower.org/knowledge/catalog-of-standards/
[5] https://www.electricaltechnology.org/2015/09/scada-systems-for-electrical-distribution.html

Smart grids may also have *advanced metering infrastructure* (AMI) that integrates smart meters, communications networks, and data management systems for two-way communications between utilities and customers. AMI allows utilities to automatically and remotely measure electricity use, connect and disconnect service, detect tampering, identify and isolate outages, and monitor voltage. Previously, some of these tasks were not possible remotely or had to be performed manually. Figure 2 shows actual and projected installations and investments in AMI by region between 2017 and 2024. Asia is expected to have the largest AMI investments over this period.

FIGURE 2. Actual and Projected Cumulative Installations and Investments in Advanced Metering Infrastructure by Region, 2017-2024



Source: Menonna and Holden 2019

AMI can be combined with customer-owned smart technologies, such as in-home displays and programmable communicating thermostats. When AMI and customer-owned smart technologies work together, utilities can offer time-based rates and incentives to reduce peak demand and total energy consumption and costs. Potential benefits of AMI include

- Lower costs for metering and billing;
- Faster ability to connect or disconnect service and diagnose meter issues;
- More timely and accurate billing for greater customer satisfaction with fewer disputes and faster dispute resolution;
- More accurate customer prepayment and budget payment plans;
- Reduced risk of meter tampering and better ability to detect electricity theft;
- More customer control over electricity consumption, costs, and bills;

- Lower capital expenditures for utilities due to reduced peak demand and more efficient asset use and maintenance;
- Lower outage identification costs due to precise dispatching of repair crews;
- Less customer inconvenience due to more timely and accurate public communications and faster service restoration after disruptions;
- More effective automated controls for voltage and reactive power management; and
- Ability to integrate data collection and analysis with geographic information services (U.S. DOE 2016).

A government grant program for utility early adopters of advanced metering infrastructure in the U.S. identified the following lessons learned:

- The cost per smart meter installed was lower for larger scale implementation than pilot projects;
- Communication network upgrades for additional smart grid functionalities beyond AMI increased the costs and the value of the investment and set the stage for future grid modernization;
- The cost of enabling multiple smart meter features and integrating AMI with a larger number of systems was higher, but the additional benefits improved the business case for the investments;
- The costs depended on a utility's baseline communications, data management, and metering systems;
- Geographically dispersed utilities in the U.S. with low customer densities had a favorable business case for AMI due to the operating cost savings; and
- Customer outreach and education contributed to overall cost and varied considerably (U.S. DOE 2016).

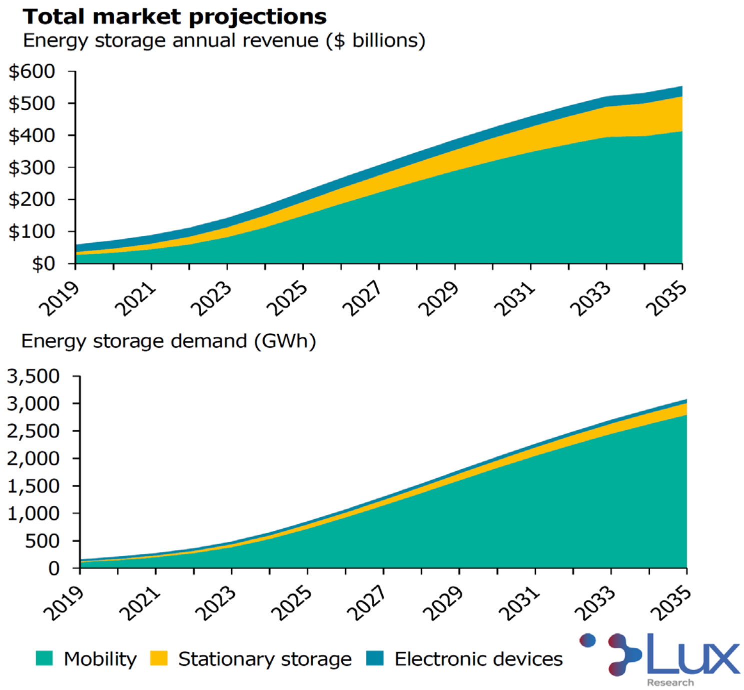
1.4.3 STATIONARY ENERGY STORAGE

Figure 3 shows the projected annual market value and volume of energy storage for stationary, mobility, and electronic device applications.[6] Holzinger *et al.* (2019) forecast that the total annual market value of energy storage would increase from $59 billion in 2019 to $546 billion in 2035 as annual deployment of new capacity increases from 164 GWh to 3,046 GWh. The annual market share for stationary energy storage is projected to grow steadily over this period.

Stationary energy storage includes front-of-the-meter and behind-the-meter applications for non-transportation uses. Figure 4 shows projections for stationary energy storage by location. Holzinger *et al.* 2019 forecast that the total annual market value of new stationary energy would increase from $9.1 billion in 2019 to $111.8 billion in 2035, a 17.0 percent annual growth rate. New deployments of stationary energy storage would increase from 15.2 GWh storage in 2019 to 222.7 GWh in 2035, an 18.3 percent annual growth rate. In 2035, stationary applications may constitute 20.5 percent of the energy storage market value and 7.3 percent of new energy storage deployments. Over 40 percent of the projected growth in stationary storage between 2019 and 2035 is expected to be in China, India, Southeast Asia, and Africa.

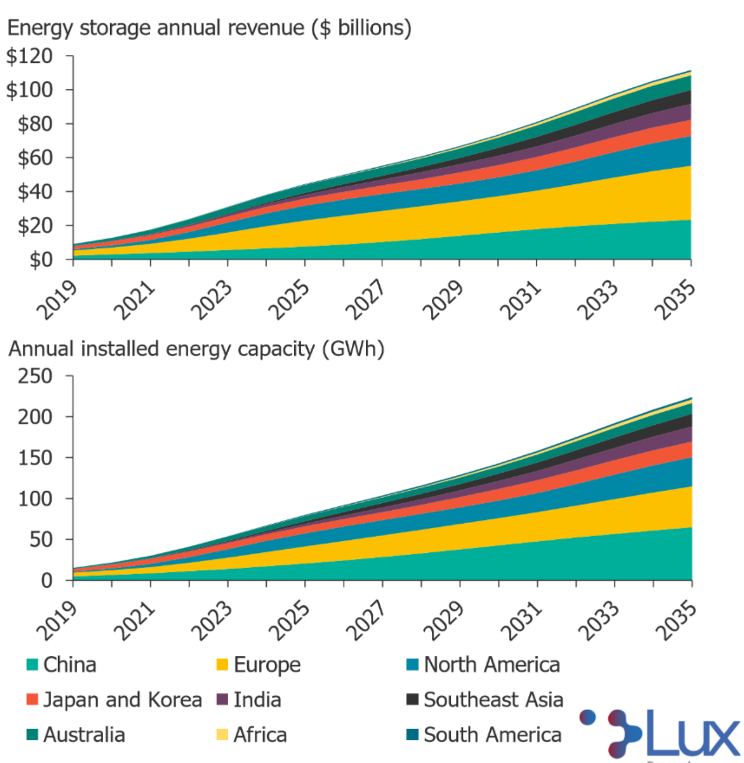
[6] *Electronic devices* include battery-powered laptops, tablets, smart phones, smart watches, and drones.

FIGURE 3. Projected Annual Market Value and Volume of Energy Storage by Use, 2019-2035



Source: Holzinger *et al.* 2019

FIGURE 4. Projected Annual Global Stationary Energy Storage Revenues and Installed Capacity



Source: Holzinger *et al.* 2019

Electricity may be wasted or sold at a zero price when there is insufficient, immediate demand or transmission and distribution capacity. Energy storage can allow more variable RE to be accommodated on the grid without curtailment. Increasingly, distributed solar generation will be combined with battery energy storage systems (BESS) for more reliable local use and dispatchability of surplus power on the grid (Fu, Margolis, and Remo 2018). Energy storage can also help meet spikes in power demand and provide back-up power during outages caused by storms or maintenance problems. Electricity can also be stored in electrical, mechanical, electromechanical, chemical, or thermal systems. Table 2 summarizes characteristics and applications of examples of these technologies.

TABLE 2. Characteristics and Applications of Energy Storage Technologies

	ELECTRICAL		MECHANICAL			ELECTROMECHANICAL			CHEMICAL	THERMAL
	Superca-pacitors	SMES	PHS	CAES	Flywheels	Sodium Sulfur	Lithium Ion	Redox Flow	Hydrogen	Molten Salt
Maturity	Develop-ing	Develop-ing	Mature	Mature	Early commer-cialised	Commer-cialised	Commer-cialised	Early commer-cialised	Demon-stration	Mature
Efficiency	90-95%	95-98%	75-85%	70-89%	93-95%	80-90%	85-95%	60-85%	35-55%	80-90%
Response Time	ms	<100 ms	sec-mins	mins	ms-secs	ms	ms-secs	ms	secs	mins
Lifetime, Years	20+	20+	40-60	20-40	15+	10-15	5-15	5-10	5-30 years	30 years
Charge time	s - hr	min - hr	hr - months	hr - months	s - min	s - hr	min - days	hr - months	hr - months	hr - months
Discharge time	ms - 60 min	ms - 8 s	1 - 24 hs+	1 - 24 hs+	ms - 15 min	s - hr	min - hr	s - hr	1 - 24 hs+	min - hr
Environmen-tal impact	None	Moderate	Large	Large	Almost none	Moderate	Moderate	Moderate	Depend-ent of H2 production method	Moderate
Possible applications by technologies										
Power quality	✓	✓			✓	✓	✓	🤞		
Energy arbitrage			✓	✓	🤞	✓	✓	✓	🤞	✓
RES integration		✓			✓	✓	✓	✓	✓	
Emergency back-up					✓	✓	✓	✓	🤞	
Peak shaving			✓	✓		✓	✓	🤞	🤞	🤞
Time shifting			✓	✓		✓	✓	🤞	🤞	🤞
Load leveling			✓	✓		✓	✓	🤞	🤞	🤞
Black start						✓	✓	✓	🤞	🤞
Seasonal storage			🤞	✧					🤞	🤞
Spinning reserve		🤞			🤞	✓	✓	🤞	🤞	
Network expansion			✓	🤞		✓	✓	🤞	🤞	🤞
Network stabilisation	🤞	✓			🤞	✓	✓	🤞		
Voltage regultation	🤞	🤞			🤞	✓	✓	✓		
End-user services	🤞	🤞			🤞	✓	✓	🤞		

Sources: Interviews, Schmidt et al. (2019), Das et al. (2018)
H2 = Hydrogen, RES = Renewable energy source, RE = Renewable energy, SMES = Superconducting magnetic energy storage, PHS = Pumped hydroelectric storage, CAES = Compressed-air energy storage
Note: The Council has reviewed available literature to build this table. In our review, technology specifications differ greatly based on the source.

✓ for proven
🤞 for promising
✧ for possible

Source: Blanc *et al.* 2020

Pumped storage converts surplus hydroelectricity into mechanical energy by moving water to reservoirs at higher elevations. When the quantity of electricity demanded (load) increases or prices rise, the pumped water is released to flow downhill and passes through the turbines to generate more electricity. Pumping water uphill uses a large amount of electricity, but it increases the value of the electricity that can be sold (Manion *et al.* 2019). In 2017, pumped storage comprised 95 percent of all electricity storage in the United States (Zablocki 2019).

In 2020, the Great River Energy wholesale power cooperative in rural Minnesota used *thermal storage*. It linked thousands of 100-gallon water heaters to heat water at night when wind farm output is high and the power load is low. This relatively simple system allowed households to keep the grid power supply to the water heaters turned off during the morning surge in hot water consumption (Casey 2020). Molten salt is another form of thermal storage that can be a good choice for concentrating solar power facilities (IRENA 2017a).

BESS can be behind-the-meter (at the locations of electricity end-users) or front-of-the-meter (utility-scale installations). Both types of BESS have important implications for DER planning because of their potential transformative effects on power generation and transmission and distribution systems. Utility-scale BESS is rated in megawatts and hours of duration. For example, a system with a rated capacity of 20 MW and a four-hour duration can store 80 MWh of usable electricity. Usable electricity reflects energy losses in storage and discharging.[7]

In late 2018, approximately two-thirds of BESS capacity in California was behind-the-meter (Zablocki 2019). Customers are often motivated to purchase behind-the-meter BESS to supplement their distributed solar or wind power generation. Some BESS purchasers in California have been motivated by planned or unplanned utility service outages associated with pervasive wildfires.

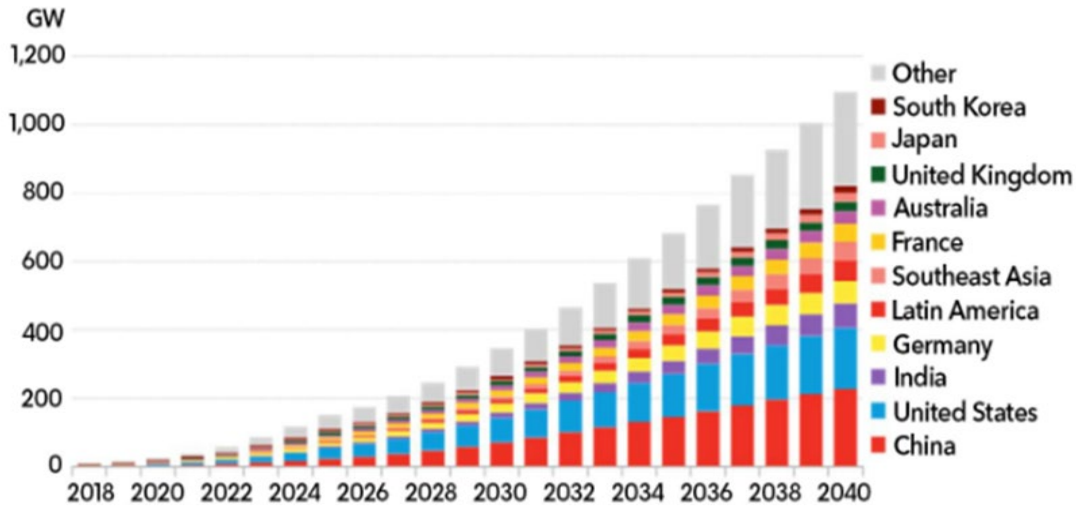
Figure 5 shows BloombergNEF projections of total BESS capacity in major country and regional markets rising from 9 GW (17 GWh) in 2018 to 1,095 GW (2,850 GWh) in 2040. Utility-scale, grid-connected BESS with lithium-ion (Li-ion) batteries has already proven to be financially viable. For example, it has helped firm up RE capacity or generation to increase service reliability or reduce costs (Australia, Brazil Roraima State, Thailand, United Kingdom, U.S., and Western Europe). It has helped meet peak load requirements (Australia, Chile, India, Mexico, and the U.S.), and defer expensive investments in transmission infrastructure in Baja California in Mexico. BESS has provided marketable ancillary services (Australia, United Kingdom, U.S., and some countries in Western Europe), but markets for ancillary services do not yet exist in most developing countries (Maurer *et al.* 2020).

Approximately 80 percent of utility-scale battery storage worldwide has used Li-ion technology (U.S. EIA 2018). The storage duration of Li-ion batteries is typically two to four hours, but has improved and is expected to reach five hours in EDF Renewables' planned Arrow Canyon Project (St. John 2019). Utility-scale BESS has grown rapidly due to large decreases in the costs of Li-ion batteries and improvements in their efficiency, power density, performance, and availability.

---

[7] Key characteristics of battery storage technologies include rated power capacity, energy capacity, storage duration, cycle life, self-discharge rate. *Rated power capacity* is the maximum energy discharge rate that can be obtained from a fully charged state. *Energy capacity* is the maximum amount of energy that the system can store. *Storage duration* is the amount of time that BESS can be discharged at its rated power capacity before the energy capacity is depleted. *Cycle life* is the amount of time or cycles a battery storage system can provide regular charging and discharging before failure or significant degradation. *The self-discharge* rate is percent of stored energy reduced through internal chemical reactions that is no longer available for use. *Round-trip efficiency* is the percent of energy charged to the battery that can be discharged (Bowen, Chernyakhovskiy, and Denholm 2019).

FIGURE 5. Projected Battery Energy Storage Capacity by Location, 2018-2040



Source: BloombergNEF 2019

Although battery storage costs of have declined rapidly, BESS are still expensive. BESS costs are expected to continue falling, but it is unclear whether future cost reductions will continue at the same rate. For a high battery use rate and value stacking potential, BESS should be designed to provide multiple grid services (Bowen, Chernyakhovskiy, and Denholm 2019). *Value stacking* is the ability to generate revenues from the multiple services that storage can provide, including ancillary services. Policy and regulatory changes are needed to create remunerative markets for the full range of services of BESS (Finn-Foley 2020).

Industry practices and policy and regulatory barriers can limit the adoption of utility-scale BESS. In some markets, particularly in developing countries, payments may not be available for the auxiliary services that BESS can provide. The lack of peak load pricing structuring of electricity rates is an important barrier. System and market operator requirements for energy storage device operation and market rules can also be barriers.

Other energy storage technologies have been developed for longer duration storage—flow batteries, aqueous air batteries, stacked blocks, underground compressed air (Spector 2020a; Wesoff 2020) and hydrogen storage. Commercial applications of flow batteries and aqueous air batteries are already being installed. Form Energy developed an aqueous air battery system that reportedly uses safe, abundant, and inexpensive materials and provides long-duration storage up to 150 hours.[8]

Flow batteries store electrical charges in tanks of liquid electrolyte pumped through electrodes to extract the electrons. The spent electrolyte is returned to the tank and recharged by electrons from PV panels or wind turbines. They can also have a wide range of discharge power, recharge power and duty cycle requirement. Flow batteries are easily scalable because the energy storage capacity is determined by the size of the storage tank (Burfeind 2016). Flow batteries typically store energy for 8-12 hours (Scroggin-Wicker and McInerney2020). Service (2018) estimated that the annual market for vanadium and zinc-

---

[8]Form Energy's first commercial pilot project was a 1 MW (150 MWh) storage facility to help Great River Energy replace coal-fired generation with a strong, but highly variable wind power resource. Great River Energy was a wholesale electric power cooperative serving cooperatives with 700,000 customers in Minnesota. Several other long-duration storage startups have faltered due to to unexpectedly rapid price declines for short-duration batteries, but Form Energy expects to be competitive with Li-ion batteries on a dollar-per-kilowatt basis (Spector 2020b). In 2020, the U.K. Government invested $12.8 million in the world's largest aqueous air battery --the 50 MW Trafford project in Manchester. This project will provide long-duration storage to serve 200,000 households (Guest Contributor 2020).

bromine flow batteries would approach $1 billion within five years. However, this rapid growth might increase vanadium prices substantially.[9]

Table 3 shows the net present value (NPV) for Li-ion batteries and flow batteries based on costs in 2020 and other assumptions listed below. This analysis accounted for capital costs, and revenues and operating and maintenance (O&M) costs over a 20-year time horizon. It assumed an 8.5 percent discount rate for the time value of money. Although the capital costs were 97 percent higher for flow batteries than Li-ion batteries, flow batteries offered a 43 percent higher NPV (Scroggin-Wicker and McInerny 2020).

TABLE 3. Net Present Values of Li-Ion and Flow Batteries Over 20 Years at an 8.5 Percent Discount Rate (U.S. Dollars)[10]

NPV Results: 20 MW/160 MWh (net at POI)		
Description	**Li-Ion**	**Flow**
Capital Cost		
Project Capital Cost	$48,770,000	$95,930,000
Owner Costs	Excluded	Excluded
Total Installed Cost	**$48,770,000**	**$95,930,000**
O&M and Other Annual Costs, NPV		
Battery Charging	$39,070,000	$43,380,000
O&M	$12,580,000	$4,640,000
Total O&M/Charging	**$51,650,000**	**$48,020,000**
Life Cycle Cost NPV	**$100,420,000**	**$143,950,000**

Source: Scroggin-Wicker and McInerny 2020

Holzinger *et al.* (2019) anticipated that flow batteries will become more important in front-of-the-meter energy storage in areas with high utility-scale wind power generation. They also projected that solid-state batteries will eventually replace Li-ion batteries in electric vehicles. Solid-state batteries based on polymer, ceramic, or composite materials have a higher energy density and are safer than Li-ion batteries.

[9] Pivot Power hired redT to manufacture and install 2 MW (5 MWh) vanadium redox flow batteries in a hybrid with 50 MW of Li-ion battery capacity for the Energy Superhub Oxford project. This will be the world's largest hybrid flow and Li-ion battery. The Energy Superhub Oxford project received partial financial support from the U.K. Government's Industrial Strategy Challenge Fund (Grundy 2020). Rongke Power in Dalian China was building the world's largest vanadium flow battery (800 MWh). ESS Inc. has sold 33-100 kW iron flow batteries that can provide 12 hours of electricity storage over 20,000 cycles for 25 years with little maintenance.

[10] Assumptions:

- Single-contract, engineer-procure-construct method.
- Owner costs, decommissioning costs, insurance, taxes, and revenues excluded.
- Costs based on Burns & McDonnell experience and vendor information for technology available in 2021.
- Routine maintenance for 20 years is included.
- Year 1 roundtrip efficiency of 70 percent for the flow system and 84 percent for the Li-ion system.
- Annual escalation rate for O&M and energy costs of 2.5 percent.

Hydrogen can be stored for days or weeks and used in stationary fuel cells for dispatchable power generation or motor vehicle fuel cells. Surplus renewable electric power can be stored by using electrolysis to separate water into hydrogen and oxygen. This production method, *green hydrogen*, was only used for 0.1 percent of the global hydrogen supply in 2020 (Flowers 2020).[11] Green hydrogen was more expensive than hydrogen from fossil fuels. Cost parity would require a load factor of at least 50 percent and an electricity cost below $30/MWh. In 2020, the typical load factor for a green hydrogen facility was 20 percent and global average prices for RE were $50/MWh.

By 2030, the capital costs of green hydrogen are expected to decrease by one-third with automated manufacturing of electrolyzers, an increase in electrolyzer efficiency to eight percent, and a five percent drop in feedstock costs. Approximately $365 million has been invested in developing 94 MW of green hydrogen capacity. There was also a 3.2 GW pipeline of new green hydrogen projects (Flowers 2020). The International Energy Agency predicted that wind-powered green hydrogen could be less expensive than natural gas by 2030 (O'Neil 2019). The economics of green hydrogen may be substantially better with a carbon price or tax.

1.4.4 ENERGY STORAGE FOR MOBILITY

Energy storage for mobility applications power land, water, or air transportation. It can be for light-, medium-, or heavy-duty motor vehicles, personal mobility devices (electric scooters and bicycles), ships and boats, and planes. Holzinger *et al.* (2019) projected that the annual market value of energy storage for mobility will reach $43.7 billion in 2035, 74 percent of the total for energy storage. They forecast 175.4 GWh of new energy storage for mobility in 2035, 91 percent of total new energy storage capacity.

A *battery electric vehicle (BEV)* has no back-up internal combustion engine (ICE) and uses only the energy stored in batteries. Since the batteries can be recharged at a home wall outlet or commercial charging station, a BEV may also be described as a *plug-in electric vehicle* (PEV). *A hybrid electric vehicle (HEV)* combines an ICE with an electric propulsion system (drivetrain). The hybrid electric drivetrain improves fuel economy and performance compared to a standard ICE.[12] HEVs generally have batteries that are not rechargeable at home or commercial charging stations. As a result, they have no effect on the power grid.

A plug-in hybrid electric vehicle (PHEV) runs on electric power until the battery is depleted and then automatically switches over to the ICE. PHEV batteries are mostly charged by the engine and, to a lesser extent, regenerative braking. As a result, a PHEV has less impact on the power grid electricity than a BEV. A PHEV battery can also provide emergency power to run a typical U.S. household for a day or more during outages. In 2019, one-third of the operating stock of electric vehicles worldwide were PHEVs, but three quarters of new electric vehicle sales were BEVs (Gorner and Teeter 2020).

BloombergNEF (2020) reported that over 7,000,000 passenger vehicles, 500,000 buses, 400,000 delivery vans and trucks, and 184,000,000 mopeds, scooters, or motorcycles were electric powered in 2020. As a result of the covid-19 pandemic, BEV sales in the first half of 2020 were flat at 3 percent of total

---

[11] Most hydrogen is used for fertilizer production, petroleum refining, petrochemicals, solar panels and glass manufacturing. Approximately 71 percent of global production is *gray hydrogen* from steam methane reformation and most of the rest is brown hydrogen from gasification of coal or lignite. In 2020, gray hydrogen cost $1.00-2.00/kg an an additional $0.50/kg if combined with carbon capture. *Blue hydrogen* from natural gas reforming can also be combined with carbon capture and storage, but the process was not yet widely commercial. (Flowers 2020).

[12] Some HEVs use an ICE to turn an electrical generator to either recharge the vehicle's batteries or power the electric drive motors directly HEVs often use other fuel-saving technologies, such as regenerative brakes. HEVs often use other fuel-saving technologies, such as regenerative brakes that convert kinetic energy to electricity to charge the battery or supercapacitor. Many HEVs have a start-stop system that shuts down the ICE when the car is idling and restarts it when needed. *Full (strong) HEVs* have a relatively large battery and can be run with either the ICE or the battery or both. *Mild hybrids* have relatively small batteries and cannot be driven with the electric motor alone, but are less costly.

vehicle sales despite the 18 percent drop in EV sales. BloombergNEF (2020) estimated that BEV sales would not recover to 2019 levels until 2025 for passenger vehicles and 2022 for commercial vehicles. However, they still projected that EVs would comprise 10 percent of annual global passenger vehicle sales in 2020, 28 percent in 2025, and 58 percent in 2040. PHEVs have an important interim role until BEV prices reach parity with ICE vehicles around 2028. In 2040, most passenger electric vehicle sales are expected to be BEVs.

BloombergNEF (2020) estimated that BEVs in 2040 would consume 1,290 Terawatt-hours (TWh) worldwide for passenger vehicles, 389 TWh for commercial vehicles, 216 TWh for buses, and 69 TWh for two-wheel vehicles. Through 2040, this would require a cumulative investment of $500 million for charging infrastructure and installation costs, about evenly split between China, Europe, the U.S. and the rest of the world. [13]

EV charging can substantially increase the demand for electricity. Unmanaged EV charging can overload the power grid if a large number of people charge their vehicles at the same time, particularly during peak load periods. It could also necessitate large capital expenditures for new power generation capacity and transmission and distribution.

Vehicle–grid integration (VGI) refers to technologies and management solutions that can reduce grid overloading from EV charging or provide energy storage or other benefits to the power grid. These solutions include active bidirectional charging and unidirectional managed charging.

Bidirectional EV battery chargers consume grid electricity when it is readily available and deliver power to the grid as needed. Bidirectional chargers can supply power to the grid faster than fossil fuel generation. Bidirectional chargers are already available at the household and commercial charging station scales. They could be especially beneficial for school buses or industrial trucks that have substantial battery storage and periods of idle time (Brown 2020).

Bidirectional charging is an example of *vehicle-to-grid* (V2G) integration. V2G integration requires specialized hardware, such as bidirectional inverters. It can have relatively high roundtrip energy losses in charging and discharging batteries, and may contribute to EV battery degradation. A utility or transmission system operator can buy this electricity to meet peak loads, offset grid supply reductions from intermittent RE sources, or provide ancillary services. However, the costs of bidirectional charging can exceed the value of the energy transferred to the grid. As a result, all U.S. states have rules for interconnecting bidirectional chargers to the grid.

Bidirectional, local V2G integration helps balance power supply and demand at the end user level during power outages or peak periods with higher utility rates. These local uses of EV battery power include vehicle-to-home, vehicle-to-building, and vehicle-to-everything applications.

Unidirectional managed charging (*smart charging* or V1G) reduces total grid power consumption for BEV charging or shifts its timing to decrease peak loads or supply shortfalls or provide ancillary services. Smart charging does not transfer any energy from mobile storage to the grid, but it can provide similar benefits to the power system at lower cost and technical complexity than bidirectional charging.

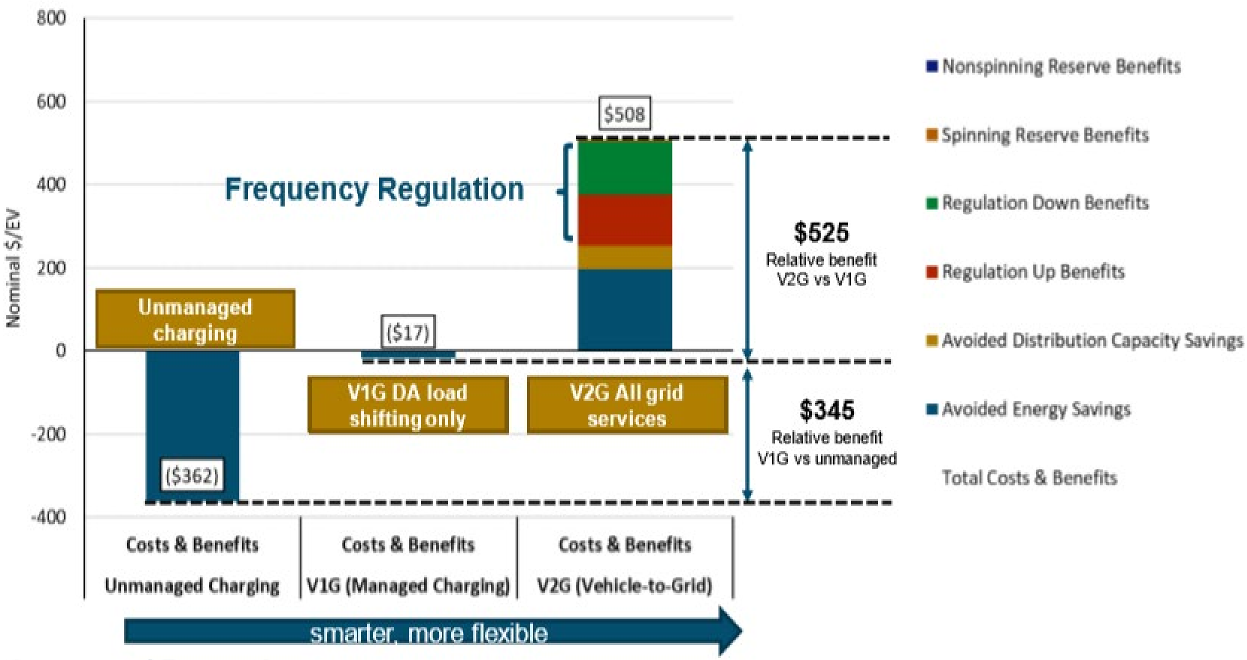
---

[13] Direct current fast chargers (DCFC) with up to 350 kW capacity for light- and medium-duty EVs are available and 1 megawatt (MW) for heavy-duty EVs will soon be available and there are plans to increase charger capacity to 4.5 MW (Wilson et al. 2019). The Tesla Supercharger Network has already set up 1,971 commercial EV charging stations with a total of 17,467 high-speed charging units in Asia, Europe and the Middle East, and North America (https://www.tesla.com/supercharger).

Electrify America plans to have 800 commercial charging stations with a total of 3,500 fast chargers operating in the U.S. by December 2021 (https://www.electrifyamerica.com/how-ev-charging-works/). In 2020, Sacramento Municipal Utility District began a financial partnership with Electrify America for installation of bidirectional charging stations to help smooth peak loads. Electrify America will benefit from lower costs for electricity that it can pass on to charging station customers (Shahan 2020).

Technologies are available for utilities to remotely limit BEV charging or ramp it up or down for individual or multiple systems. It may be possible to time BEV charging to use surplus solar or wind power generation that would otherwise be curtailed. Figure 6 shows the illustrative annual benefits of VGI over unmanaged charging of one BEV. Utilities may need new communication and control technologies to reap these benefits (Fitzgerald, Nelder, and Newcomb 2017).

FIGURE 6. Illustrative Annual Benefits of Smart Charging (V1G) and Vehicle-To-Grid Integration (V2G) Over Unmanaged Charging From One Electric Vehicle



Source: Gridworks 2019

Potential barriers to VGI include the capital costs of a network of bidirectional charging stations and wider adoption of EVs, and charging service prices that are too low or too high. If charging service prices are too low, there will be insufficient incentives for private sector investments in building an extensive network of fast DC charging stations. If charging service prices are too high, the demand for purchasing or leasing EVs may be reduced. Ideally, bidirectional charging stations service prices should vary by time of day and season and vehicle owners should be able to benefit from the revenues from grid services provided by bidirectional charging stations (Nelder 2020).

The Smart Electric Power Alliance (SEPA) surveyed U.S. investor-owned utilities, municipal utilities and cooperatives, equipment manufacturers, government agencies, engineering firms, media companies, not-for-profit organizations, consulting firms, and EV load management operators. The first of two SEPA reports noted that transport electrification is the most significant DER integration challenge for utilities. The accelerating scale and concentration of EV deployment may exceed the capacity of generation, transmission and distribution infrastructure and may require upgrades and new capacity that can take years to develop. The costs and lead times will increase with higher speed EV charging. Alternatives to traditional grid upgrades may be needed, including front-of-the-meter and behind-the-meter BESS.

Many U.S. utilities have not incorporated BEV load growth in their distribution planning or have used relatively unsophisticated forecasting methods. Some utilities can only spend ratepayer money without demonstrating that the expenditures are reasonable and prudent. Consequently, utilities will need to improve forecasting and planning and timely engagement with their regulators, technology and service providers, and stakeholders before making largest investments in vehicle grid integration.

Utilities may also be interested in new revenue sources, such as fees for infrastructure or service upgrades or investments in commercial EV charging stations. Approximately 83 percent of the U.S. utilities SEPA surveyed passed-on system upgrade and new service costs for EV charging infrastructure to their customers. About 43 percent allowed a utility bill credit for customers purchasing BEV charging infrastructure. Some utilities offered rebates or financing to reduce customer costs for line extensions to serve a new load (*contributions in aid of construction*). Utilities will also need to enforce safety and functional standards for EV charging infrastructure and grid interoperability (Wilson *et al.* 2019).

The second SEPA report included six case studies of electric power utilities with established EV programs. It recommended that utilities:

- Start EV infrastructure planning now because infrastructure upgrades could take years to complete;
- Establish a cross-functional EV team for planning and project implementation;
- Emphasize the customer experience;
- Consider EV programs and process improvements to benefit low-income and underserved customers to support transportation and health equity; and
- Ensure that utility and private infrastructure can participate in utility load management programs (Bolduc *et al.* 2020).

The second SEPA report also recommended the following steps in utility EV planning:

- Define the business model for managed charging and analyze the benefits and costs for the utility and EV driver;
- Work to establish industry standards to reduce costs, barriers, and complexity and share information;
- Understand incentives and management strategies for load shifting while maintaining a satisfactory user experience;
- Design flexible managed charging programs, including opt-out and override capabilities and financial benefits for participation;
- Identify where EV resources are located in the distribution system and the costs and benefits of avoided distribution upgrades;
- Engage with customers on electric vehicle supply equipment and network service providers; and
- Understand how utility-run managed charging fits into and can leverage the broader networked charging industry (Bolduc *et al.* 2020).

1.4.5 DEMAND RESPONSE

The demand for electricity (*load*) varies seasonally and over the course of a day. Electricity supplies also vary by season and time of day, especially from variable RE resources, such as solar, wind, and hydropower. Electric utilities in the U.S. have legal requirements to meet peak power requirements. However, installation of new power generation capacity is expensive and can take a long time, especially for thermal or nuclear power plants.

If a macrogrid is connected to other regional, national, or international grids and legal and institutional authority allows, utilities can buy and sell power from larger market areas. Moreover, the peak capacity may only be needed for relatively short periods of time during the year. It is less costly for utilities to manage the demand to reduce the peak loads and resulting supply shortfalls. Furthermore, high peak loads can cause overload the grid, causing outages and equipment damage (Bonneville Power Administration n.d.).

Since the 1980s, utilities in many developed countries have used demand response programs to reduce their capacity constraints, capital costs, and negative environmental impacts. Some state regulatory agencies in the U.S. have mandated demand response programs to reduce the average wholesale or retail cost of electricity and reduce pollution and GHG emissions from electricity generated from fossil fuels. The Peak Load Management Alliance discussed how demand response methods have been incorporated in utility DER solutions (PLMA 2019).

Utilities can reduce or shift peak loads by offering time-based rates or other financial incentives or penalties to encourage customers to shift electricity consumption from peak to off-peak times. The prospects for a significant reduction in the load may be greatest for large industrial users who can change the timing of electricity-intensive operations. A variety of pricing policies for demand response have been used in parts of the U.S., including time-of-use-rates, critical peak pricing, variable peak pricing, and real time pricing (U.S. DOE n.d.).

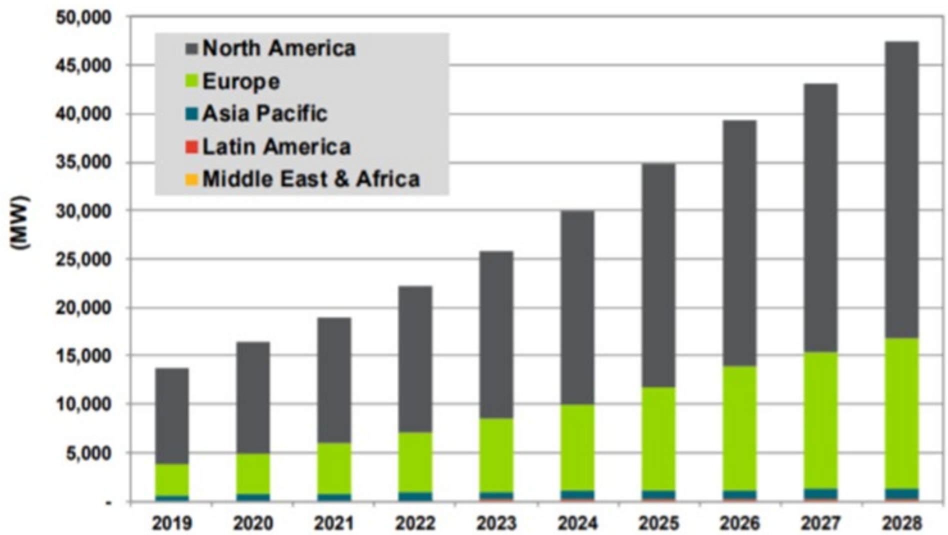
Advances in IT, control, and forecasting capabilities have made demand response an increasingly attractive viable option (O'Connell *et al*. 2014). Technologies to support demand response programs include smart generation to optimize voltage, frequency, and power factor standards in response to feedback from multiple points in the grid; power meters with two-way communications between power customers and suppliers; superconducting cables for long-distance transmission; automated monitoring and controls for power distribution and transmission; and smart appliances and internet-controlled thermostats (Electrical Engineering Department, University of California at Riverside n.d.).

PEPCO Holdings, a U.S. utility, has used direct load control successfully. It provided bill credits to residential and commercial customers who allowed PEPCO to cut off their air conditioners and hot water heaters for a few hours per day on a limited number of peak load days in the summer. PEPCO also provided critical peak rebates for customers who reduced their total daily consumption on expected peak load days announced in advance through automated phone messages.

Figure 7 shows the projected growth of residential demand response programs in developed and developing regions. Continuing cost reductions in many DER technologies are expected through at least 2025, particularly for PV modules, inverters, and balance-of-systems components (Navigant 2019b).

Potential barriers to increasing demand response capacity include regulatory policies, the price elasticity demand, and utility costs for incentives and administration. One of the greatest challenges for demand response is the lack of utility experience with this approach in many countries and the need to make extensive assumptions in modelling this resource (O'Connell *et al*. 2014).

FIGURE 7. Projected Residential Demand Response Capacity By Region, 2019-2028



Source: Navigant 2019

1.4.6 ENERGY EFFICIENCY

It is often much less expensive to reduce electricity consumption by adopting more efficient equipment and processes than to build and operate new power generation, transmission, and distribution capacity. Some utilities in the U.S. and other developed or developing countries have supported EE programs to reduce their capital costs and improve service reliability while helping their customers save money.

Energy conservation can also reduce GHG emissions at a relatively low cost. The International Energy Agency estimated that policies to promote EE could deliver over 40 percent of the emissions cuts needed to reach the goals of the Paris Agreement, without requiring any new technology. The Three Percent Club, a coalition of governments, businesses and international organizations, was formed in 2019 to encourage a three percent annual increase in global energy efficiency. Achieving this target would save households $500 billion per year by 2040 (World Resources Institute 2019).

Pilot programs of Consolidated Edison in New York State and SCE in California demonstrated the cost effectiveness of EE improvements for utilities and their customers (Baatz, Relf, and Nowak 2018).[14] The New York Energy Research and Development Authority (NYSERDA) established portfolio EE standards and programs for small businesses and multifamily dwellings.[15]

The California Public Utilities Commission evaluated state utility EE programs for residential, commercial, industrial, and agricultural customers. It compared different approaches, such as customer

[14] Southern California Edison used competitive procurements to obtain contracts for 24.3 MW of EE improvements in Orange County, California and subsequently started pilots in other locations.
[15] NYSERDA's Small Business Direct Install program identified cost-effective measures for increasing EE through lighting design; building envelope upgrades, heating, ventilation, and air conditioning improvements; and solar energy (https://www.nyserda.ny.gov/ny/PutEnergyToWork/Industry-Energy-Solutions/Small-Business). NYSERDA also offered low-interest participation loans and on-bill recovery financing for EE investments by small businesses and not-for-profit organizations (https://www.nyserda.ny.gov/All-Programs/Programs/Small-Business-Financing). Participating businesses were eligible for a 70 percent subsidy for the costs of installing the identified EE measures. Its Multifamily Performance Program identified opportunities to reduce energy use in buildings with five to 75 housing units by 20 percent and provided owners and managers with $700-$3,500 per unit for EE improvements (https://www.nyserda.ny.gov/All-Programs/Programs/MPP-Existing-Buildings).

rebates, grants for technology research and development, development of energy-efficient building codes and appliance standards, and public outreach and education (CPUC 2018).

In 2018, the American Council for an Energy-Efficient Economy (ACEEE) lauded Mexico as a country that had achieved large EE gains. Mexico's Comisión Nacional para el Uso Eficiente de la Energía (CONUEE) established best available technology standards, and provided consumer education and financial incentives for EE improvements. An Efficiency and Sustainability Program for Cities funded energy-efficient street lighting, municipal buildings, and water use (Castro-Alvarez *et al.* 2018).

Potential barriers to EE improvements include higher upfront costs, electric savings potential, and measurement of savings. Some utilities have often viewed EE and demand response as separate functions outside their core business of service delivery. Increasingly, utilities will need to integrate the planning and customer-facing programs and pricing mechanisms for active load management. They will need to manage power loads temporally and spatially and consider non-wire alternatives (ICF International 2019).

The ACEEE surveyed 31 U.S. electric utilities to find out whether utilities or states have conducted DER planning, whether EE was taken into account in the demand forecasts, and how EE was valued. All surveyed utilities reported that they did distribution system planning, but only half filed these plans publicly with their regulator. Approximately 60 percent of the utilities included EE in distribution system planning, either as reductions in load forecasts or an active resource.

In 2014, the CPUC required California electric utilities to file integrated resource plans that address supply-side and demand-side approaches to meeting projected loads. Oregon, Minnesota, Connecticut, and Massachusetts have also explored changes in planning processes to value EE and demand response in distribution system investment planning (Baatz, Relf, and Nowak 2018).

Baatz, Relf, and Nowak (2018) made the following recommendations to improve integration of EE and demand response in utility and regulatory agency planning:

- Improve methods to capture the full value of EE for the power system, including time and locational aspects;
- Improve load forecasting methods;
- Coordinate planning processes for generation, distribution, transmission, EE and demand response;
- Use the National Standard Practice Manual for the benefit-cost analysis of EE and other DER investments; and
- Use geotargeted EE to complement, but not replace, broad-scale or system-wide efficiency.

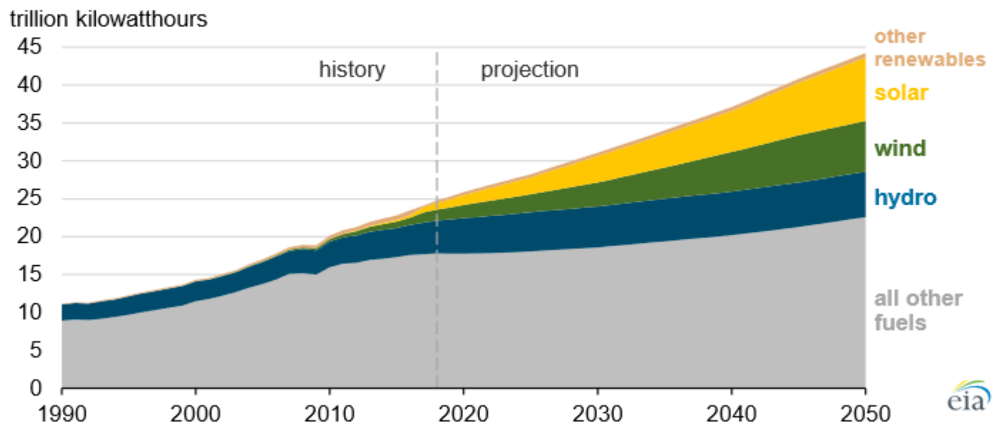
1.5 DRIVERS OF DER GROWTH

Key drivers of DER growth include increasing electricity demand and expansion of utility-scale RE generation, the policy and regulatory environment, and technology improvements and cost reductions.,

1.5.1 INCREASING ELECTRICITY DEMAND AND EXPANSION OF UTILITY-SCALE RENEWABLE ENERGY

The demand for electricity is still growing in most developed and developing countries. The increasing reliance on renewable electric power reflects DER growth and increases the value of other types of DER that make RE generation more beneficial. Figure 8 shows U.S. EIA's projections for worldwide RE growth by type of energy. It estimated that 50 percent of total world total energy consumption will come from renewable sources by 2050.

FIGURE 8. World Net Electricity Generation, 1990-2050



Source: Bowman 2019

1.5.2 POLICY AND REGULATORY ENVIRONMENT

Policies that encourage RE generation are generally favorable for DER. In the U.S., Arizona, California, Massachusetts, and New York led the way with renewable portfolio standards, and Colorado, Texas, and Utah subsequently adopted this approach. Tradable CE certificates, carbon cap-and-trade programs, and carbon prices or taxes can also increase the demand for DER. Some U.S. states have required vertically integrated utilities to divest their ownership of generation facilities and become transmission and distribution companies that serve multiple, competing, private generation companies. Utility structural reforms generally expand opportunities for DER adoption.

DER adoption has been uneven within the United States. The Federal Government and some state governments have adopted policies, incentives, and regulations to expand DER adoption. State governments in California, Hawaii, and New York have been early and active proponents of DER (De Martini 2016). More recently, Converge Strategies (2019) reported that 16 of the 50 states had strong policies for promoting DER.[16]

Subsidies and tax credits may only be needed temporarily to help develop markets and drive cost reductions. For example, the U.S. Government (USG) previously offered a tax credit for wind power generated in the first 10 years of operation for facilities that began construction by the end of 2019. *Viability gap analysis* is a tool for designing and reassessing the level and duration of incentives needed to promote DER adoption if the costs are still higher.

California, Hawaii, Massachusetts, New York, and Texas have state requirements for DER integration. California enacted a law in 2013 that required each investor-owned utility to submit DER plans for approval. These plans had to address 1) DER integration capacity within current distribution system down to the circuit level; 2) quantification of DER locational value; and 3) scenarios for 10-year siting at the substation level and impacts on distribution (Colman, Chung, and Wilson 2017).[17]

Policy changes may be needed to help create a level playing field for DER relative to conventional electricity generation and distribution alternatives. DER investments will need to be sufficiently profitable to allow scaling up (Levin and Thomas 2016). DER investments can be promoted through standardized contracts and favorable pricing (Colman, Chung, and Wilson 2017). Where allowed by

---

[16] Alaska, California, Connecticut, Delaware, Florida, Hawaii, Illinois, Rhode Island, Maryland, Massachusetts, Minnesota, New Jersey, New York, Texas, Vermont, and Washington.
[17] The current California law, as amended, is available at https://leginfo.legislature.ca.gov/faces/billCompareClient.xhtml?bill_id=201320140AB327&showamends=false.

regulators, utilities can offer time-based incentives to address peak load or supply shortfalls through DER (Trabish 2019).

In the U.S., FERC Order 745 of 2011 required wholesale markets to compensate demand response providers for load reductions at the same rates available for generated electricity. However, it allowed state regulators to opt out.

FERC Order 841 of 2018 removed barriers to the participation of energy storage resources in the electricity capacity, generation, and ancillary services markets operated by regional transmission organizations and independent system operators. It required each regional grid operator to revise tariffs to establish a participation model for storage and develop market rules that recognize the characteristics of energy storage. The participation model must ensure that energy resources are eligible to provide all capacity, dispatchable electricity, and ancillary services that they can supply. The rule also required wholesale electricity markets to sell electricity for energy storage and buy it back at the marginal wholesale price for the location.[18] State regulator were not allowed to opt out of these requirements. FERC Order 841 greatly expanded incentives for utility-scale BESS (St. John 2018).

In 2020, NYISO received FERC approval for its *dual participation model* of serving both wholesale and retail markets, which is favorable for DER investments. NYISO took advantage of existing bid rules in energy, capacity, and ancillary services markets and emphasized third-party aggregation of DER through New York Transmission Owners (Konidena 2020).

In 2020, FERC Order 2222 removed barriers to DER participation in electricity capacity, generation, and ancillary services markets operated by regional transmission organizations (RTOs) and independent system operators (ISOs). FERC anticipated that aggregators will coordinate DER and do combined marketing that will make these technologies more competitive with conventional power generation, transmission, and distribution. This order required RTOs to set locational specifications for DER that are "as geographically broad as technically feasible." The basis for the order was to help ensure that electricity users are charged "just and reasonable" rates and obtain reliable services.

FERC did not impose standard interconnection procedures or agreements for DER. These resources will continue to be subject to the interconnection rules of distribution utilities with state regulatory oversight. FERC expected that wholesale markets will address transmission constraints so that aggregators can identify locations for DER that add the most value and avoid reliability problems. FERC also allowed dual participation of DER in both wholesale and retail markets. However, it did not restrict RTOs from limiting compensation for DER that provide the same services to wholesale markets and distribution utilities. FERC required RTOs to set rules for distribution utility reviews of DER, operational coordination, and data sharing (Endemann *et al.* 2020).

FERC Order 2222 did not allow state regulators to opt out, but authorized exemptions for small utilities and electric cooperatives with electricity sales of less than 4 million MW-h per year. The rule will create challenges for utilities, grid operators, and state regulators to align rules for behind-the-meter DER connected to distribution grids serving bulk markets (St. John 2020b). RTOs may need to make changes in their tariffs, systems for settling charges, modeling and dispatch software, and information and communication systems for DER visibility and control. As a result, FERC gave RTOs some leeway to delay the effective date. For example, the Midcontinent Independent System Operator will delay implementation until 2022. FERC Order 2222 may enable companies to demonstrate how aggregated DER can serve as *virtual power plants* that provide capacity and other grid services on a large scale. Successful implementation could accelerate further DER cost reductions and performance improvements that may motivate expansion into other developed and developing country markets (St. John 2020a).

---

[18] https://www.ferc.gov/media/news-releases/2018/2018-1/02-15-18-E-1.asp

1.5.3 TECHNOLOGY IMPROVEMENTS AND COST REDUCTIONS

Some types of DER still have higher financial costs than alternatives, even if they have greater economic and environmental benefits. However, the performance of many DER technologies has improved substantially in recent years and the cost has decreased due to applied research and development, manufacturing innovations, economies of scale in manufacturing, and more efficient price discovery in procurement.

IRENA (2020) analyzed data from 17,000 RE investments and 10,700 auctions and power purchase agreements for RE worldwide. The *levelized cost of energy* (LCOE) is the net present value of costs over the expected lifetime of a facility divided by the discounted projected production of electricity. The annual costs and electricity production are discounted to reflect the time value of money. The LCOE can also be described as the average revenue per unit of electricity generated needed to recover the capital and operating and maintenance costs plus the opportunity cost of money. The LCOE is an imperfect measure for comparing generation technologies that produce power with different dispatchability, but it will become a better measure with increasing use of energy storage to complement intermittent RE availability.[19]

Figure 9 compares the LCOE of utility-scale RE technologies in 2010 and 2019 in the absence of subsidies. It also shows how they varied by capacity size and compared to fossil fuel generation costs. IRENA assumed a discount rate of 7.5 percent for Organisation for Economic Co-operation and Development member countries and 10 percent for most other countries. Between 2010 and 2019, the LCOE decreased 82 percent for PV power, 47 percent for concentrating solar power, 40 percent for onshore wind power, and 29 percent for offshore wind power. By contrast, fossil fuel generation costs increased substantially over that time period.

In 2019, the LCOE per KWh in 2019 was $0.047 for hydropower, $0.053 for onshore wind power, $0.066 for bioenergy, $0.068 for utility-scale PV power, $0.073 for geothermal power, $0.115 for offshore wind power, and $0.182 for concentrating solar power. In 2019, 56 percent of newly commissioned utility-scale RE had a lower LCOE than the least expensive fossil fuel generation. IRENA 2020) noted that replacing the most costly 500 GW of coal-fired generation capacity with solar and wind power would reduce annual costs by $23 billion and decrease annual carbon dioxide emissions by 1.8 metric gigatons.

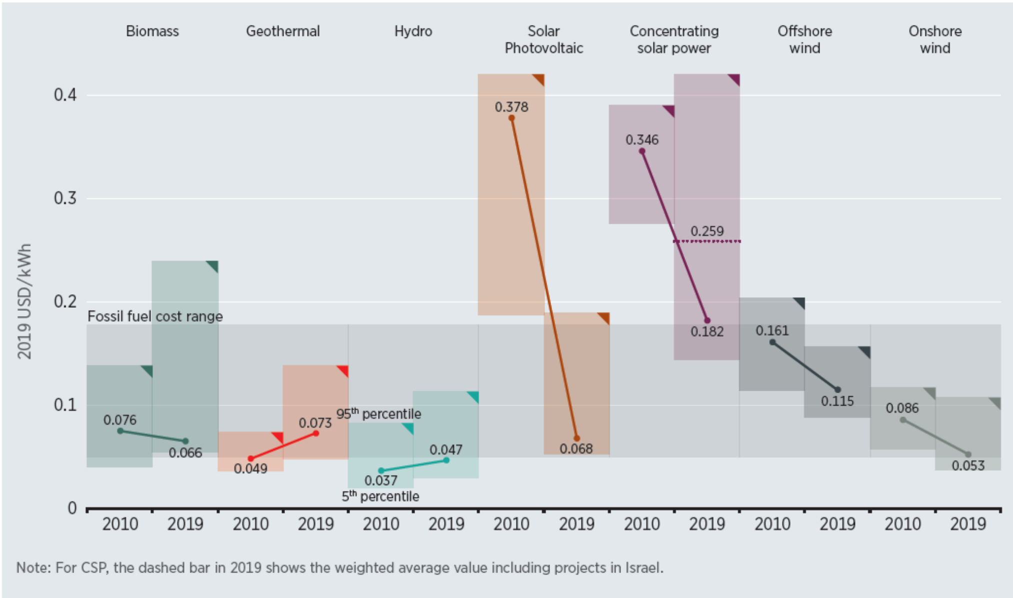
Figure 10 shows changes in the LCOE for utility-scale PV, wind power, and BESS between 2010 and 2019. Over this period, Li-ion battery system prices decreased from $500/MWh to $150/MWh, an average annual decrease of about 13 percent per year.

Holzinger *et al*. (2019) projected that lower battery costs, expansion of wind and solar power to one-third of global electric power capacity, and liberalization of electricity markets will drive BESS growth. They assumed that future cost reductions for Li-ion batteries will decline to 2-4 percent as more manufacturing capacity shifts from stationary storage to EV batteries. Further development of technologies for other types of batteries could reduce BESS costs or expand the range of viable applications in the future.

---

[19] U.S. EIA (2019a) recommended using the levelized avoided cost of electricity (LACE) or the LACE-to-LCOE ratio for comparing the competitiveness of different power generation technologies.

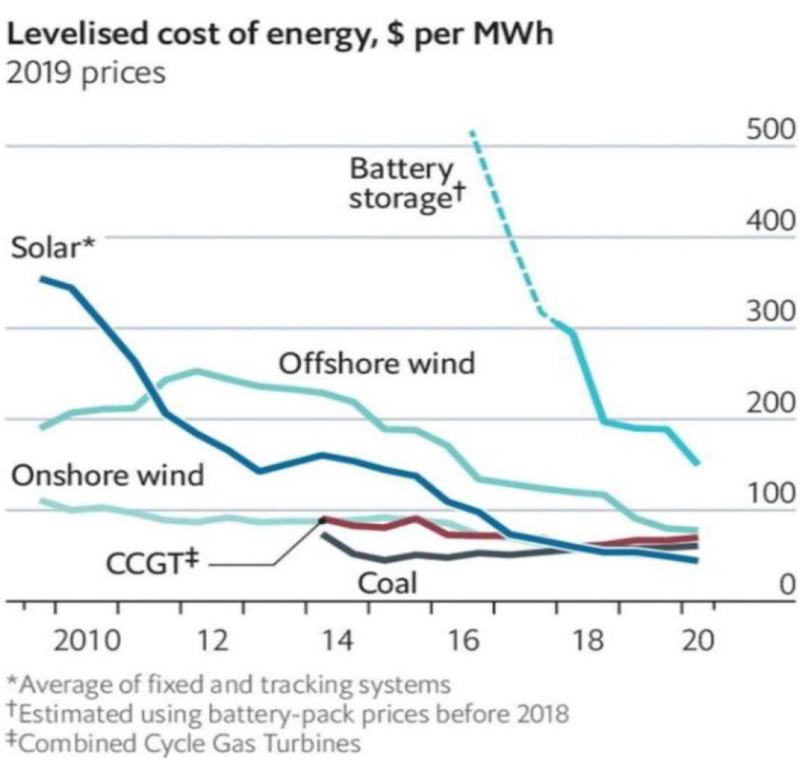
FIGURE 9. Global Weighted Average Levelized Cost of Energy for Newly Commissioned Utility-Scale RE Generation Technologies, 2010-2019



Note: This data is for the year of commissioning. The thick lines are the global weighted-average LCOE value derived from the individual plants commissioned in each year. The project-level LCOE is calculated with a real weighted average cost of capital (WACC) is 7.5% for OECD countries and China and 10% for the rest of the world. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

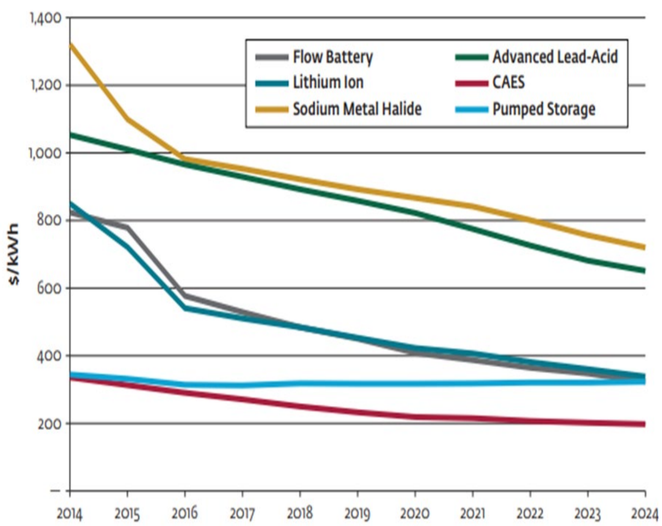
Source: IRENA 2020

FIGURE 10. Levelized Cost of Energy from Utility-Scale Photovoltaics, Onshore and Offshore Wind Power, and Battery Storage, 2009-2019



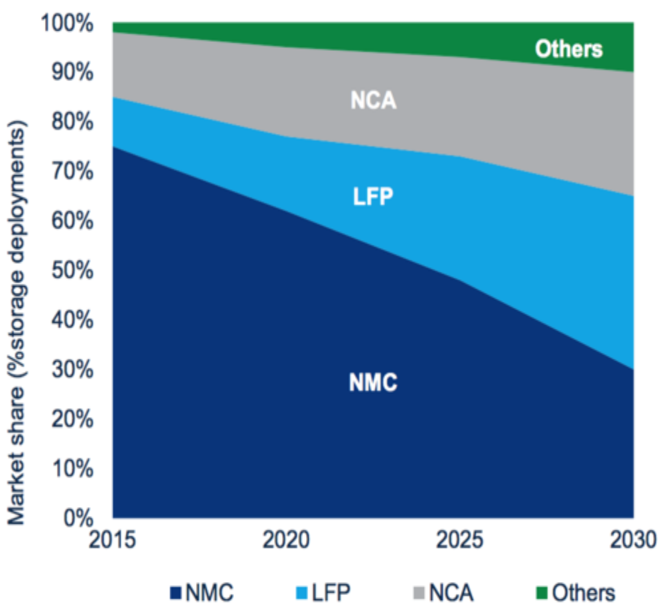
Source: BloombergNEF 2019b

FIGURE 11. Actual and Projected Capital Costs of Six Energy Storage Technologies, 2014-2024



Source: Eller and Gantlett 2017

FIGURE 12. Market Shares of Major Stationary Energy Storage Batteries, 2015-2030



Source: Gupta 2020

EPRI (2018) observed that the unit costs of solar and wind power, BESS, EVs, communication and control devices, software, and other DER technologies have decreased due to government incentives, research and development, economies of scale in manufacturing, and lower cost manufacturing locations. DER can also reduce power transmission and distribution costs and improve grid reliability.

Figure 11 compares the upfront capital costs of six energy storage technologies between 2014 and 2024. In 2016, the capital costs were lowest for compressed-air energy storage and pumped storage; intermediate for Li-ion batteries and flow batteries, and highest for advanced lead-acid batteries and sodium halide batteries. Over this time period, the capital costs are expected to increase for pumped storage and decrease for the other five technologies. This would result in similar capital costs for pumped storage, Li-ion batteries, and flow batteries by 2024 (Eller and Gantlett 2017).

Figure 12 shows that lithium-iron-phosphate batteries may overtake lithium-manganese-cobalt-oxide batteries as the dominant Li-ion type for stationary energy storage by 2030, increasing from 10 percent of this market to 30 percent. Li-ion batteries are expected to continue to dominate storage for mobility applications over the next 10 years. Lithium-iron-phosphate batteries may become more attractive for passenger vehicles due to improvements in their energy density and concerns over cobalt and nickel supplies. Lithium-nickel-cobalt-aluminum oxide batteries are similar to lithium-manganese-cobalt-oxide batteries in specific energy, specific power, and life span although they cost more and pose higher safety risks (Gupta 2020).

2. DER PLANS AND ROADMAPS

2.1 IMPORTANCE AND USES

A *DER roadmap* is a planning study, guidance document, or action plan that can help government planners and regulators, utilities, grid operators, and market operators make better decisions on distributed energy investments and use. DER growth projections should be taken into account in developing policies and regulations and in designing, financing, implementing, and monitoring operations, investments, and programs (Colman, Chung, and Wilson 2017; Agarwal and Jain 2019).

A roadmap may address all types of DER technologies or a limited subset. For example, Hawaiian Electric and the State of California have prepared roadmaps that focused on transport electrification. The Philippine Department of Energy was preparing a roadmap on smart grids (Colthorpe 2019b). Australia and the U.S. have prepared national roadmaps for hydrogen energy development (Bruce *et al.* 2018; FCHEA 2020).

Energy plans and roadmaps may have various time horizons. For example, the Government of Chile issued a long-term, energy plan with targets for 2035 and 2050 (Ministry of Energy of Chile 2015). It subsequently released a short-term energy roadmap for 2018-2022, consistent with the long-term plan (Ministry of Energy of Chile 2018).

A DER roadmap or plan can help achieve various desired outcomes for the power generation and transmission and distribution systems:

- **Affordability**: Lower costs for customers;
- **Environmental and social sustainability**: Reduction in negative environmental and social impacts (including GHG emissions; air, water, and land pollution; biodiversity losses, and displacement or harm to marginalized populations);
- **Flexibility**: Ability of the electric power system to respond to future changes;
- **Reliability**: Fewer and shorter service interruptions and power quality problems;
- **Resiliency**: Ability to adapt withstand or recover rapidly from extreme weather, natural disasters or accidents; and
- **Security**: Ability to resist external disruptions to electric power infrastructure from physical or cyberattacks or limited access to critical materials.

DER can be disruptive for vertically integrated utilities or power transmission and distribution utilities. They can alter the net load profile and reduce utility revenues as well as capital and operating, maintenance, and replacement costs. Capacity constraints can result in slow grid interconnection times for DER and safety and reliability issues.

Good planning can reduce the cost of the disruptions and expand the benefits. Proactive planning can increase the benefits and reduce the challenges and risks of DER. Planning and coordination can increase the incentives for long-term investments in less costly, more reliable, environmentally preferable, and safer generation, transmission, and distribution services to increase sustainable economic growth and customer satisfaction (De Martini 2016; Colman, Chung, and Wilson 2017).

DER need to be appropriately located and procured under suitable contract terms for maximum cost effectiveness. DER roadmaps and plans should discuss

- Available and emerging technologies;
- Technology research and development priorities;
- Gaps in human and institutional capacity that need to be addressed for successful implementation;
- Impacts of current and new policies or regulations;
- The value of DER investment decisions for the public and private sectors and communities; and
- Coordination and monitoring of DER investments and use.

A DER plan or roadmap can help utilities develop consensus on objectives, targets, technologies, and location-specific priorities, and plans for procurement, financing, and implementation of investments and programs. This can reduce regulatory delays and increase public and private sector support and investments. Key stakeholders include national or subnational regulators, other government agencies, executive and legislative branch officials; utilities and other power generators; industrial, commercial, and residential users; community-based organizations; environmental organizations; and consumer advocacy organizations. It is important for utilities to keep these stakeholders informed about the planning process and available data and analyses.

2.2 CHALLENGES IN DER PLANNING

Previously, power distribution utilities only had to manage unidirectional flows of electricity from centralized bulk generation to customers. DER makes it necessary to consider power customers as both consumers and generators of electricity (*prosumers*). Future growth in BEV use may impose large additional demands on power generation and distribution systems as well as some potential for smoothing out peak loads. Some of the main challenges include

- **Multidirectional power flows**. Distribution utilities have to monitor and adjust the voltage and frequency along distribution lines. They may need to change the band of acceptable operating voltages and manage voltage reserves to accommodate voltage increases from distributed generation (Martinot, Erickson, and Kristov 2015).
- **New generation sources and load profiles**. DER complicate conventional load forecasting methods and transmission and distribution modeling (Colman, Chung, and Wilson 2017).
- **DER are difficult to categorize using conventional energy definitions**. For example, regulators have debated whether BESS should be defined as generation, load, or both. There are also debates on whether interconnected BEV charging should follow the same rules and tariffs as stationary energy storage (Navigant 2019a).
- **Changes in the relationship between utilities and customers**. Vertically integrated utilities, independent power generators, distribution utilities, and owners of distributed generation or behind-the-meter BESS have different financial interests. DER owners do not want to lose control over their resources. Government planning and regulatory agencies have a broader economic perspective, but most developing country governments have not adequately addressed incentives for supply surplus electricity from distributed generation to the macrogrid (Lehr 2017).

- **Utility business models and rates.** Utilities may have difficulty recovering their sunk capital costs if distributed generation comprises a large proportion of total power consumption (NARUC 2016; Lehr 2017). Increasing competition from distributed generation can limit the ability of utilities to raise their rates. As a result, some utilities may seek to adopt or increase flat-rate service or connection charges. However, utilities may be able to reduce or defer new capital expenditures for power generation and transmission and distribution. Utilities may also have lower operating costs with greater DER use. Utilities may also have new revenue opportunities from DER. Utilities and regulators may need to review rate-setting criteria and decision processes (Chew *et al.* 2018).
- **Importance of location-specific assessments**. DER can improve macrogrid congestion and resilience (McCallister *et al.* 2019). The value of DER to the grid is location-specific. Utilities can control the locations of their own investments, but not where their customers install DER. Utilities will need forecasts of private DER in their service areas to plan their own investments in DER and other infrastructure and technologies. Location-specific information on DER may also help utilities develop rate proposals (Succar 2018). However, utilities may face regulatory restrictions on differential pricing within their service areas.
- **Coordinated planning of power generation, transmission, and distribution**. In many places, a single utility is responsible for power generation as well as transmission and distribution. In some places, reforms have broken up these monopolies to encourage price competition, new investment, and adoption of innovative technologies and operations. Regional or cross-national grid integration and markets have also developed in some areas. More coordinated planning by the various service providers, regulator, or system or market operators may be needed after structural reforms. Better coordination of power generation with transmission and distribution is also important in developing countries with large service area gaps. Better planning can reduce bottlenecks between utility-scale generation and transmission and distribution, redundancy, obsolescence, and costly overbuilding (EPRI 2018).
- **Reliability of the bulk power system.** Increasing DER use can change how the distribution system interacts with the bulk power system for safety, reliability, and communications. These issues may bring challenges for operations and planning. Some power system models and operating tools have not adequately addressed the effects of aggregated DER and could result in unanticipated power flows and demand forecasting errors. An unexpected loss of aggregated DER could cause frequency and voltage instability. The variable power output from distributed generation can contribute to ramping and system balancing challenges for system operators who cannot fully observe or control the DER in the bulk power system (NERC 2017). Reliability issues that may need to be addressed include
    - Inadequate data on DER investments and operations;
    - Coordination between the bulk power system and DER;
    - Improved modeling practices and capabilities;
    - Effects of DER daily generation profiles on system unit commitment and ramping; and
    - Effects of grid-connected, distributed solar and wind power on day-ahead load forecasts (U.S. FERC 2018).
- **Data and cybersecurity**. Grid modernization brings increasing use of digital technologies and larger amounts of data to manage, analyze, and secure. SCADA systems can manage and control power generation and interconnections, but may increase cybersecurity risks to residential, industrial, and commercial resources. There will be a greater need for cybersecurity risk assessments, intrusion detection systems, cybersecurity risk mitigation plans and infrastructure, and data ownership and privacy regulations.

- **EV load and smart charging incentives.** Utilities will have to ensure the power grids can handle the increasing load from BEV charging. The impact of vehicle charging on the power system depend on the timing in relation to the load profile and available generation and transmission and distribution capacity. Price incentives may be needed to promote charging during off-peak times and smart charging solutions (Brown 2020).
- **Need for interconnection codes and standards and a streamlined interconnection process.** New codes and standards may be needed to improve the integration and interoperability of the power system and its safety and reliability.
- **Recycling and disposal**. PV panels, electric batteries, and smart grid components can create disposal and recycling challenges, particularly in developing countries, where appropriately designed and managed facilities may be absent. Regulations may also be needed to address waste management.

Other common constraints to DER deployment include

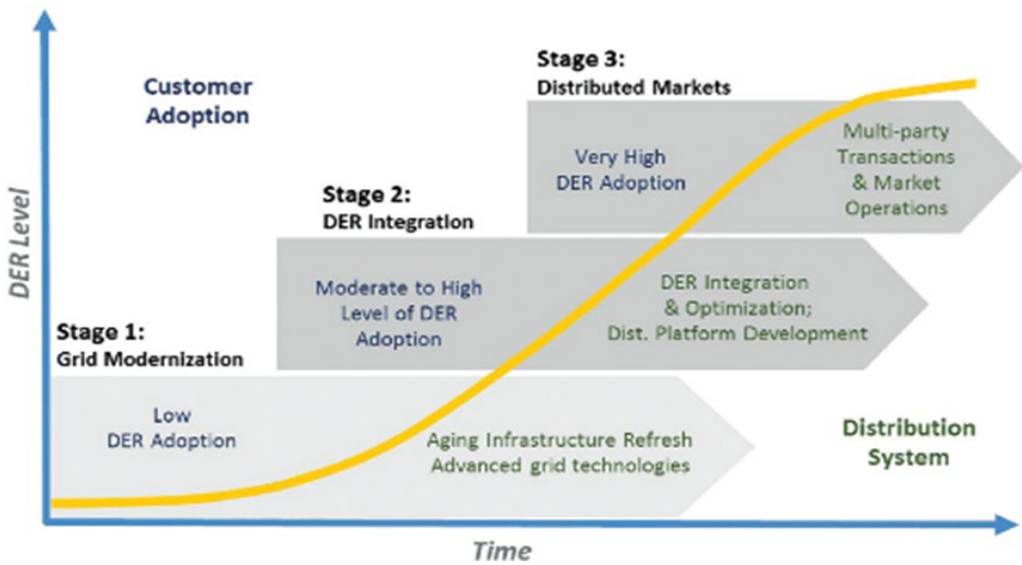
- **Costs and financing**. Capital and operating, maintenance, and replacement costs can be high even if the benefits can make the investments financially and economically viable. Financing remains a constraint for DER adoption in developing countries. Barriers include transaction costs for small-scale DER and limited markets to monetize the full value of potential grid services from utility-scale DER.
- **Fiscal impacts**. In many countries, government expenditures, tax incentives, and subsidies have often favored large-scale fossil fuel and hydropower generation. The macroeconomic environment, fiscal conditions, and competing priorities in many developing countries may not conducive for large new expenditure, tax incentives, or subsidy programs for DER.
- **Remuneration for DER services**. Some DER services, especially BESS and bidirectional EC charging, do not receive sufficient remuneration in many markets. Peak load pricing and the development of ancillary service markets can increase incentives for grid-connected distributed generation and energy storage to supply the grid during peak periods (Twichell 2019). FERC Order 841 required U.S. wholesale power markets to value all the services of BESS fairly, but it did not apply to retail markets. Many developing countries do not have wholesale power markets or payments for ancillary services.
- **DER performance characteristics**. Some types of DER cannot replace baseload power generation. For example, the best Li-ion batteries can only discharge energy for four to six hours. Future cost reductions may make longer duration storage technologies (flow batteries or compressed-air energy storage) cost-effective for replacing baseload generation.
- **Uncertainty**. Most developing countries have limited operating experience with DER technologies to support estimates of their lifecycle costs, value, and useful life. There is also uncertainty about future price declines and performance improvements and the potential for other new technologies.
- **Conflicting financial interests of utilities and their customers**. Utilities can lose potential revenues when they allow customers to install grid-connected DER, but may also reduce their capital costs. Transmission and distribution utilities may have better incentives for encouraging customers to adopt DER than vertically integrated utilities. Regulators can approve tariffs that allow utility customers to benefit from DER investments while maintaining grid reliability and safety (Colman, Chung, and Wilson 2017; EPRI 2018).

  Regulated utilities are typically allowed a fixed return on their own approved capital investments. They may also be allowed to expense fuel and maintenance costs, but not general operating expenses. Some regulators classify utility investments in DER as operating expenditures that cannot be considered in setting permitted revenue levels. In those cases, vertically integrated utilities will continue investing in conventional generation, transmission, and distribution infrastructure instead of DER.

- **Coordination of grid-connected DER.** Regulators can require utilities to accommodate grid-connected distributed generation and offer net metering as an incentive. Regulators generally allow utilities to require advance approval for many types of grid-connected DER to ensure safe and reliable grid operations. Nevertheless, utility and customer siting decisions on DER might not be well coordinated. Increasingly, U.S. utilities are using sophisticated software to aggregate all types of installed DER and monitor and forecast their contributions to macrogrids.

Figure 13 shows an S-curve of DER adoption by utility customers over time, starting with grid modernization and moving to DER integration, and then distributed markets.

FIGURE 13. S-Curve of DER Adoption by Utility Customers



Source: De Martini and Kristov 2015

Stage 1: A low DER adoption rate by utility customers can be accommodated in the transmission and distribution system without major infrastructure or operations changes. Government planning and regulatory agencies and utilities should forecast DER adoption rates by location and their implications for grid interconnection requests and power distribution planning. *Locational value assessments* can help identify where DER investments would benefit the power supply system most by providing real-time, operating services or the ability to defer capital investments.

Stage 2: DER adoption approaches a threshold that requires new capabilities (such as real-time operation and distribution system planning, more advanced protection and control technologies, and management of bidirectional power flows). At this stage, DER have the potential to provide substantial system benefits, although changes in grid planning and operations may be needed. Distribution utilities may be able to obtain flexible DER services to increase reliability, diversify revenues, or provide ancillary services to the bulk power system. Better coordination between distribution utilities and transmission system operators may be needed.

Stage 3: Providers and prosumers go beyond providing services to the wholesale market and the distribution utility and engage in direct energy transactions with others. Regulators may need to allow retail energy transactions across the distribution system or within a single substation. The system operator may need to take on additional market facilitation services, such as financial clearing and settlement.

3. EXAMPLES OF DER PLANS AND ROADMAPS

3.1 UNITED STATES

In the U.S., DER roadmaps are typically prepared at the state level. In many U.S. states, major public sector planning processes are initiated through a legislative directive or an executive order. Although state government staff have the lead role, federal government officials may be included or consulted. The time horizon, geographic scope, level of detail, technical depth, and time and resources for state DER roadmaps has varied.

3.1.1 CALIFORNIA

California is a large state served by multiple utilities operating in different contexts. It has a deregulated power generation system that restructured vertically integrated utilities into transmission and distribution utilities. California Assembly Bill 327 of 2013 required the state's utilities to file plans for including DER in planning and operations. The California Public Utilities Commission initiates rulemaking proceedings after soliciting feedback from stakeholders to help utilities plan, procure, and implement DER successfully. Regulators and distribution utilities in the state regularly consult and plan with independent system operators, regional transmission operators, environmental organizations, consumer advocates, and community-based organizations.

The California Energy Commission began preparing a DER roadmap in mid-2019 that was expected to be completed in 2020. Box 1 shows the scope of this report. California's Independent System Operator also developed DER plans to help avoid RE curtailment. It promoted DER aggregation by allowing small companies to join together in contracts with distribution utilities to reduce total or peak loads and supply smart meters and advanced control systems.

BOX 1. Scope of the California Energy Commission's DER Roadmap

Technology Strategy Review

- Characterization of technology and strategy
- Advantages and disadvantages
- Technical specifications and requirements
- Recent and current research and development activities

Critical Success Factors

- Commercial readiness, including current market participation
- Federal and state policy influencers
- Barriers to further development

Identify Research and Development Needs

- Actions to bring high-impact technologies and strategies to market

Focus Technologies

- Energy storage
- Electric vehicle integration and smart charging
- Grid optimal load assets
- Smart inverters
- Distribution grid communications
- Distributed grid management
- DER aggregation for nonwire alternatives

Source: California Energy Commission 2019

The California Working Group prepared a plan for coordinated transmission and distribution operations for a high DER grid. This working group included CAISO, Pacific Gas and Electric (PG&E), SCE, and San Diego Gas and Electric. This plan considered three time periods: 1) near term (one to two years); 2) medium term (three to five years); and 3) long term (five years and beyond).

The plan analyzed:

1. Resources that participate in the independent system operator (ISO) market;
2. Resources that provide services to distribution operators or end users, but not the ISO; and
3. Resources with multiple use applications that offer services to the ISO, distribution operators, and end users (CAISO *et al*. 2017).

The California Working Group plan focused on *T-D interfaces* — the connections between high voltage electric substations on the transmission network and lower voltage electric distribution lines that deliver power to end users. CAISO had little visibility on the status of DER connected to the distribution side. When distribution-side DER participates in the wholesale market, this lack of visibility can cause the ISO to issue dispatch instructions that the DER unit cannot follow, causing distribution problems. Transmission and distribution system operators need to coordinate for reliable operations. New communication and control technologies enable aggregation of small DER units into larger virtual resources that can participate in wholesale electricity markets and provide grid services.

The California Working Group plan emphasized 1) providing the ISO with greater predictability of DER responses to dispatch instructions at the T-D interface; 2) helping distribution operators under DER behavior to maintain system reliability and safety; and 3) allowing DER providers to participate in all markets they can serve effectively while reducing curtailment risks. This plan recommended:

1. Use of manual procedures for aggregated DER in the near term as organizations conduct pilots and learn by doing;
2. New processes to communicate information on current system conditions to DER providers so they can modify their ISO market bids accordingly and submit outage or derate notifications to the ISO;
3. ISO provision of day-ahead schedules for DER and real-time dispatch instructions in conjunction with new DER management systems;
4. DER communication of performance information to the ISO, including market bids and outage notifications;
5. Establishing integration agreements with aggregated DER providers;
6. Expanding medium-term coordination in anticipation of a high-DER future under various models;
7. Conducting use case analyses to understand impacts on distribution grid safety and reliability;
8. Identifying system protection and control enhancements and mitigation to improve distribution grid safety and reliability; and
9. Developing and piloting methods for short-term operational forecasting of DER activity and impacts at T-D interfaces.

The California Public Utilities Commission prepared a high-level, DER Action Plan (CPUC 2017a). The objectives of this plan were to 1) provide a long-term vision for DER to respond to state GHG reduction and RE targets; 2) identify near-term and medium-term efforts to support the vision; and 3) establish a steering committee for DER coordination and sharing planning resources. The plan will inform rate setting, grid planning and procurement, DER interconnection and market integration, and setting flexible DER targets and milestones.

Although microgrids were just starting up in California and BESS was too expensive at the time for nonspecialized applications, the CPUC included these technologies in the plan because it anticipated growth and cost reductions. It subsequently began a rulemaking process to facilitate microgrid commercialization (CPUC 2019).

In 2019, extensive wildfires led some utilities in Southern California to shut down service in many locations to avoid liability for equipment failures that spread fires. Concerns about the lengthy shutdowns increased business and consumer interest in distributed generation and behind-the-meter BESS. The CPUC changed its Self-Generation Incentive program to increase incentives for locating DER in areas with high fire risks that jeopardize power distribution (Colthorpe 2019a).

In 2020, the CPUC issued a draft roadmap on transportation electrification for public comment. This Transportation Electrification Framework proposed a new process requiring California's investor-owned utilities to develop 10-year investment plans to support EV charging within one year after finalization of the framework. The utilities could then propose pilot programs for transportation electrification through a streamlined advice letter process and full programs through full applications every two years. The CPUC plans to update the Transportation Electrification Framework every five years and require the utilities to revise their plans within two years of each update. It also proposed metrics to track utility progress in contributing to state EV, climate mitigation, air quality, and equity goals.

The Transportation Electrification Framework also addressed data and market analysis requirements and potential unfair competition issues in utility ownership of BEV charging infrastructure in different market segments over time. It required utilities to 1) only support networked charging stations for public or shared private electric vehicle supply equipment (EVSE); 2) make their application processes for distribution upgrades more transparent; and 3) identify strategies to ensure that individual customers do not bear the full cost of supporting EV adoption by multiple customers. The framework also provided guidance on coordination across utilities for vehicle-grid integration.

Other state agencies in California will set EV charging infrastructure safety standards. Investor-owned utilities will need to review whether their own new safety requirements are necessary for consumers and installers and associated workforce training needs. Utilities will also have to meet federal standards for utility cybersecurity and are encouraged to participate in voluntary federal programs (CPUC 2020).

The Sacramento Municipal Utility District (SMUD) prepared a DER Planning Study. The objectives were to 1) assess the implications of DER on electricity use, revenues, grid infrastructure, environmental goals, and energy sources; and 2) respond to increasing customer and third-party DER ownership and associated business risks. This analysis used sophisticated modeling to forecast DER adoption, impacts on the distribution and bulk power systems. It examined opportunities for improving strategies and operations.

SMUD's DER Planning Study concluded that:

1. DER adoption was likely to be widespread, but uneven and clustered, leading to distribution grid hotspots;
2. Expansion of BEV charging and PV power generation may increase the likelihood of distribution transformer overloads;
3. DER can flatten the net load and shift the peak load later in the evening; and
4. DER could reduce utility revenues 10-20 percent (Wilson *et al.* 2017).

SMUD considered providing incentives for increasing DER in areas with large unmet demand (*load pockets*), but has not yet offered these incentives. SMUD also considered incentives for distributed generators who allow the utility district to limit their consumption when power is needed on the grid. However, it found that distributed generation owners were generally unwilling to give up control over their self-generation (Wilson *et al.* 2017). Table 4 shows SMUD's plans for updating its DER roadmap.

TABLE 4. SMUD's Plan for Updating Its DER Roadmap

Task	When to Update	Timing
Assessment of DER potential	If actual data deviate significantly from forecasts or there are major changes in technology changes	As data change, but at least every three years
DER adoption modeling	As needed, based on DER implementation data and changes in strategies or goal	Continuous
Bulk system modeling	Part of the integrated resource plan with assumptions revised based on DER adoption rates. Special analysis if major changes occur. Full analysis as part of integrated resource plan.	When key data change or the integrated resource plan is revised, but at least every three years
Transmission and distribution modeling	Included in demand-side management, with special updates as needed if there are major changes. Full analysis when the integrated resource plan is revised.	As data change, but at least every three years
Rate setting	Regular rate updates, as needed, based on bulk system and transmission and distribution modeling	For rate reviews or as major data change, but at least every three years
Financial analysis	Included in the integrated resource plan analysis and updated as key cost and revenue data change	Every three years or after major changes in costs or revenues
DER goal and target setting	As needed	As targets or goals change, but at least every three years

Source: Adapted from Wilson *et al.* 2017

Southern California Edison prepared a Distribution Resources Plan in 2015 that called for five subsequent studies on how DER could augment or replace conventional sources of power:

1. **Dynamic Integration Capacity Analysis:** A computer simulation that estimated the number of individual DER units that could be supported on each section of a distribution circuit before the system needed upgrading (completed in 2016);
2. **Optimal Location Benefit Analysis:** A tool to show where DER could provide better value than new investments in distribution circuits and substation upgrades (completed in 2016);
3. **DER Locational Benefits:** Pilot testing of a wide range of DER to demonstrate whether they could allow deferral of capital investments (new distribution circuits) and provide additional electricity services (expected in late 2019);
4. **High DER Penetration:** A demonstration of how a group of circuits handled increased rooftop solar and BESS owned by the utility or third parties and emerging technologies funded under the California Solar Initiative. A secondary goal was to give operators better information for safe and reliable grid operations with extensive DER use through new equipment and control software (underway in 2019); and
5. **Microgrids:** Installation of a microgrid near a hydropower plant to gain a better understanding of how to deploy this technology (underway in 2019).[20]

[20] https://www.edison.com/content/dam/eix/documents/innovation/drp-demo-fact-sheet.pdf

3.1.2 MID-ATLANTIC STATES (POTOMAC ELECTRIC POWER COMPANY HOLDINGS)

PEPCO is a power transmission and distribution utility operating in several U.S. mid-Atlantic states.[21] Its customers choose their electricity supplier from competing companies that use its transmission and distribution services. The electricity suppliers charge different retail prices and some offer rate guarantees for various contract periods. Some also guarantee partial or full renewable electricity supplies. Table 5 summarizes PEPCO's distributed generation, EE, and demand response programs.

PEPCO's definition of distributed generation included 1) back-up generators; 2) net metering; 3) community RE facilities; 4) qualifying facilities; 5) grid-connected generators selling into the PJM wholesale market; and 6) behind-the-meter generators that are precluded from exporting electricity to the grid. The company's demand response and EE programs varied by service location since they are subject to regulatory approval in different jurisdictions. In service areas with AMI, PEPCO gives customers information in their monthly bills on daily electricity use during the month and a graph of monthly electricity use in the current year and previous year. It also participated in the mandatory demand response curtailment program of the regional transmission organization, PJM Interconnect.

TABLE 5. PEPCO Holdings' Distributed Generation, Energy Efficiency, and Demand Response Programs

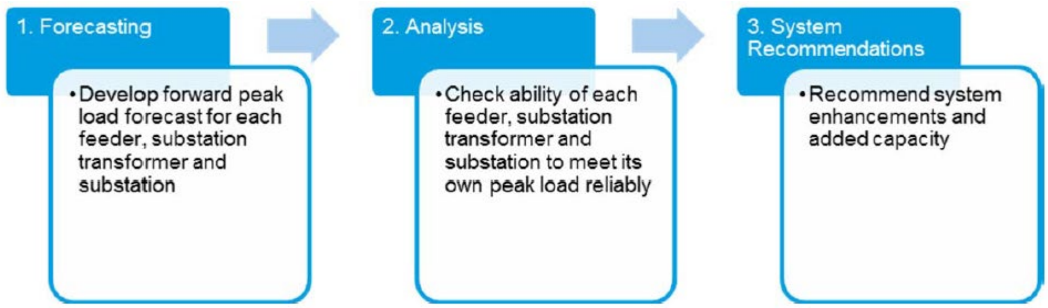
Resource	Description
Distributed Generation	
Photovoltaic distributed generation	Customer-deployed, grid-connected PV generation including systems qualifying for net energy metering, community RE facilities, and generators selling in the PJM market. Can provide a generally predictable power output during daylight hours in the aggregate
Other distributed generation	Customer-deployed generation other than PV to reduce energy consumption, reduce maximum demand, or provide back-up power
Energy Efficiency	
Conservation voltage reduction	Distribution feeder technologies to dynamically decrease voltages on distribution feeders to reduce customer energy consumption
Energy management tools	Help customers understand their energy consumption patterns and opportunities to save energy and reduce costs
Residential energy efficiency and conservation	Lighting, appliances, home check-up, ENERGY STAR, new construction, HVAC, and low-income programs
Commercial and industrial energy efficiency and conservation	Multifamily, multi-dwelling, small business, existing buildings, new construction, retro-commissioning, and combined heat and power
Demand Response	
Energy Wise Rewards	Voluntary direct load control program that cycles customer air conditioners or heat pumps off under one of three cycle time options on peak saving days with high wholesale market prices
Peak Energy Savings Credit	Rebates for customers with advanced metering who reduce consumption on peak demand days

Source: Adapted from PEPCO Holdings 2016

[21] PEPCO serves Washington, DC and suburban Maryland, the Delmarva Peninsula in Delaware and Maryland, and the Atlantic City area in New Jersey. It was acquired by Exelon in 2016.

PEPCO prepared a DER integration plan in 2016, which identified the ability to meet peak loads as a major issue. As a result, PEPCO prepared separate forecasts for each distribution feeder, individual substation transformer, and substation to ensure that individual system components were sized correctly. Figure 14 shows the company's process for forecasting short-term and long-term loads.

FIGURE 14. PEPCO's Process for Forecasting Short- and Long-Term Loads



Source: PEPCO Holdings 2016

PEPCO analyzed the capacity of each component of its distribution system using historical load data and available SCADA and AMI data associated with geographic information system coordinates. It then predicted system failures (such as low voltage and thermal overload) n to the substation level. The peak load forecasts influenced recommendations in the 10-year distribution system investment plan on:

- **Operational measures**: Resetting relay limits and phase balancing;
- **Load transfers**: Field switching to transfer loads to feeders with more spare capacity;
- **Short-range construction**: Feeder extensions, installation of capacitors or voltage regulators, and reconductoring; and
- **Long-range construction**: New feeder extensions, new substation transformers, and new substations.

PEPCO maintained a database on all active and pending applications for grid interconnections to help it forecast future distributed generation capacity. It also set strict interconnection limits for interconnecting feeders to avoid adverse impacts on the distribution system or other customers. The benefits of distributed generation depend on the production characteristics, interconnected distribution components, and timing relative to the peak loads at different distribution feeders. Some of the company's feeders had peak loads before sunrise in the winter, when solar generation was not available.

PEPCO analyzed the historical peak load, feeder peak hour, and PV nameplate capacity and capacity factors. Since 98 percent of the distributed solar systems in its service territory lacked dedicated metering and telemetry, it had to use software to backcast solar generation. *Backcasting models* use a database of historical cloud cover, solar flux, and the PV configuration to estimate total solar generation and hourly capacity factors at the feeder level and the percent of nameplate PV capacity that can reduce the peak load. The models included PV efficiency losses that varied with ambient temperatures, shade cover, and panel tilt and orientation.

The power system also included distributed wind generation, fuel cells, and *synchronous generation* from combined heat and power (cogeneration) and methane digesters. The total capacity from synchronous generation far exceeded the solar capacity in its service areas, but most of this generation was sold on PJM markets. PEPCO assessed these sources separately because some did not meet the regulators' definitions of firm power. The 2016 forecasts did not include energy storage since there were few pending applications for storage installation, but the company expected to forecast energy storage as a load and source in the future. It took two years for PEPCO to analyze its distribution system and it then began the process again with new data on hourly peak loads. It plans to conduct annual reviews of differences between the forecasts and actual experience.

PEPCO carried out stakeholder consultations in each jurisdiction in its service area. The consultations provided an opportunity to publicize distributed solar and grants available for new PV installations and discuss behind-the-meter battery energy storage. The company shared its local stakeholder presentations on the internet and prepared a list of frequently asked questions and answers.

3.1.3 OTHER STATES

In 2018, Hawaiian Electric completed a roadmap for transportation electrification. The roadmap's objectives were to 1) identify ways to increase BEV use and maintain grid safety and reliability, 2) benefit all customers, 3) help achieve the state's 100 percent renewable portfolio standard, and 4) develop partnerships for new electric transport products and services. In preparing the roadmap, Hawaiian Electric conducted a literature review and expert interviews, reviewed government policies on clean energy and transportation electrification, examined utility filings and decisions in other U.S. states, used models, and carried out customer surveys and stakeholder discussions.

This roadmap recommended five short-term steps:

- Increase BEV adoption by working with vehicle manufacturers, dealers, and advocates to reduce unit costs and educate customers;
- Promote BEV charging solutions, starting with bus companies and then trucks and heavy equipment;
- Accelerate development of charging infrastructure, especially at workplaces and multiple-unit housing;
- Develop utility demand response programs and rates to provide incentives for aligning BEV charging with grid requirements; and
- Improve planning and grid modernization (Hawaiian Electric 2018).

In 2014, New York State announced the Reforming the Energy Vision aimed at cleaner, more resilient, and affordable electricity. This vision called for multi-year regulatory proceedings and policy changes to help vertically integrated utilities transition into transmission and distribution operators, establish an open market for power generators, and allow customer-owned DER to supply power to the grid. In 2015, New York State issued an energy plan that emphasized affordability, clean energy, reliability and resiliency, regulatory reforms, environmental justice, and clean and reliable transportation. It included 2030 targets for a 40 percent reduction in GHG emissions from 1990 levels, 50 percent of electricity generation from RE sources, and 600 trillion BTU increase in EE from the 2015 level.

The New York Public Service Commission, NYSERDA, New York Power Authority, and Long Island Power Authority had responsibilities for implementing the plan (NYSERDA 2016). In 2015, New York State also established an Electric Generation Facility Cessation Mitigation Program to compensate communities for some financial losses from shutdowns of coal-fired or nuclear power plants.

In 2017, the state issued the first report on progress in implementation of the energy plan. This Biennial Report to the 2015 State Energy Plan discussed efforts and achievements in RE, building and EE, clean energy financing, sustainable and resilient communities, energy infrastructure modernization, innovation and research and development, and transportation energy.

In 2019, New York State enacted a Climate Leadership and Community Protection Path with more ambitious targets: 70 percent renewable electric power by 2030, 100 percent carbon-free electricity by 2040, and an 85 percent reduction in GHG emissions from the 1990 level by 2050. This law also mandated that disadvantaged communities receive 35 percent of the benefits from RE and EE investments and 40 percent of the benefits from investments in transportation, workforce development, housing, low-income energy assistance, economic development, and pollution reductions.

Later in 2019, the New York State Energy Planning Board issued a draft amendment to the 2015 plan incorporating the requirements of the new law. After reviewing public comments, the New York State Energy Planning Board approved the amended plan in 2020. The amended plan included more specific targets, including 9,000 MW of offshore wind power by 2035, 3,000 MW of energy storage by 2030, 6,000 MW of distributed solar power by 2025, 185 trillion BTU of EE savings from the 2015 level by 2025. The amended plan expanded the Electric Generation Facility Cessation Mitigation Program and required the Public Service Commission to develop a stable funding mechanism for the program. [22]

3.2 DEVELOPING COUNTRIES

3.2.1 COLOMBIA

Colombia has some country-specific motivations for increasing DER use:

- **Grid constraints**: Approximately half of the country lacked connections to the national macrogrid and relies heavily on diesel generators. Areas with grid connections often face capacity limits and congestion restrictions that increase power system costs. Grid expansion plans have been prepared, but implementation has sometimes been delayed due to financing constraints, social conflicts, and environmental approvals.
- **Vulnerability of hydropower to climate risks:** Colombia had 11,918 MW of installed hydropower capacity in 2019 (International Hydropower Association 2020). Between 2013 and 2016, hydropower only generated 70 percent of the country's electricity due to extensive, prolonged droughts (International Hydropower Association 2018).

  Construction of the 2,400 MW Ituango hydropower facility was delayed after heavy rains and landslides in April and May of 2018 caused $2.556 billion of infrastructure and equipment damage. In 2019, local and national government agencies and university studies raised concerns about the continuing risks of dam failure and potential negative environmental and economic impacts.[23] Construction resumed, but $1 billion in cost overruns are anticipated (International Hydropower Association 2020).
- **High solar power potential**, particularly in the northern part of the country along the Caribbean.

In 2014, Law 1715 created the legal framework for RE integration in the electricity market, including small- and large-scale self-supply and distributed generation. It also encouraged expansion of EE and demand response programs and AMI. The Ministerio de Minas y Energía (MME) was responsible for energy policy and planning. It had a planning unit, the Unidad de Planeación Minero Energética (UPME).

The MME had not issued a specific definition for DER. MME Decree 348 of 2017 provided guidelines for efficient energy management and sale of surplus self-generated power to the grid. Resolutions 40072 in January 2018 and 40483 in May 2019 provided guidelines for AMI. In 2019, Law 1964 set targets for electric vehicles. However, Colombia had not set targets for solar or wind power or energy efficiency.

The Comisión de Regulación de Energía y Gas (CREG) regulated the electricity and natural gas markets. Recognizing the changing environment for these markets, CREG has moved toward 1) lighter regulation, 2) greater ex-post control, 3) more flexible market rules with eventual gradual deregulation, 4) supervised self-regulation, 5) identifying principles and conditions for market operations, 6) setting rules

22 https://energyplan.ny.gov/
23 https://en.wikipedia.org/wiki/Ituango_Dam

for market behavior, and 7) differential regulation for vertically integrated utilities and companies with a dominant market share.

CREG has issued regulations on demand response, self-generation up to 5 MW or grid-connected distributed generation, and battery storage (Romero-Grass and Mach 2019). It has also issued reports on power market reforms, complementary services for the grid, and its regulatory agenda (CREG 2018a, 2018b, and 2018c). It was also preparing an analysis on DER aggregation. CREG recognized that it will need to broaden the types of ancillary services recognized in its regulatory framework and develop new markets for these services.

The Superintendencia de Servicios Públicos Domiciliarios oversaw the rights and obligations of utilities and their customers. The Superintendent of Public Domestic Services monitored regulatory compliance and quality standards and technical, administrative, and financial management of utilities. It had authority to require solutions for service failures, verify rates charged, and set penalties for utilities.[24]

XM was the power system operator. It is responsible for grid operations and the electricity market and provides information to support UPME's planning efforts and CREG's regulatory decisions. XM has used scenario modeling to assess the potential impacts of DER on the transmission and distribution grid. It has estimated threshold levels of DER adoption that may have negative effects on grid operations. XM's definition of DER included all technologies that can provide power to the macrogrid and are connected to the distribution network. However, it has not prepared a DER roadmap or plan. XM did not think that special incentives would be necessary for DER aggregators if the market is opened up to them.

Colombia's National Development Plan for 2018-2022 identified electricity, oil and gas production, and mining as cornerstones for regional development and government revenues and included nine strategies for energy development.[25] The Government of Colombia released a thirty-year National Energy Plan for 2050 (UPME 2019).

In 2020, the MME launched an Energy Transformation Mission to prepare a roadmap to implement the changes necessary to achieve the objectives of the National Energy Plan for 2050 and increase flexibility in responding to the market demand.[26] Preparation of the roadmap was expected to take six months. It will inform a revision of the National Energy Plan and identify the need for more specific plans and changes in regulations.

The Energy Transformation Mission will have five focus areas: 1) competition, participation, and market structure; 2) role of natural gas in the electricity transformation; 3) decentralization, digital technologies, and pricing for electricity demand management; 4) closing gaps in coverage and service quality and formulation of efficient subsidies; and 5) a review of the institutional regulatory and framework. Focus area 1 will include technologies for improved RE integration and pricing reforms such as hourly tariffs and incentives for reducing peak loads, and remuneration of power distribution services through separate capacity and consumption charges. Focus area 3 will address smart grids, SCADA, AMI, and demand response and energy efficiency. Focus areas 3 and 4 will include distributed generation, microgrids, and BESS. Focus area 5 will consider restructuring of wholesale and retail market functions. This could include changing business models to facilitate entry of new aggregating agents and technologies, self-generation, and grid-connected prosumers. New promotional measures and investment incentives may be needed for DER (Cadena and Muñoz-Álvarez 2020).

The DER roadmap will involve international and national experts and public consultations. The Consejo Nacional de Operación will include multidisciplinary groups working on DER planning. The Comité Asesor de la Planificación de la Transmisión will support UPME as the link between planning and real-

---

24 https://www.superservicios.gov.co

25 https://www.dnp.gov.co/Plan-Nacional-de-Desarrollo/Paginas/Bases-del-Plan-Nacional-de-Desarrollo-2018-2022.aspx#googtrans/gl/en

26 https://energiaevoluciona.org/transformacion

time operations. Colombia Inteligente is an industry group advised by XM that promotes smart grid and related technology development and standardization.[27] SER Colombia is an association with representatives of 67 domestic and transnational RE companies.[28] Energética 2030 is a collaboration of four Columbian universities, industry, and international research institutes. The Ministry of Science and Technology funded Energética 2030 research and energy demand forecasting; transportation energy; RE technologies, policy, regulation, and markets; and microgrids.[29] Some municipal governments have also conducted local energy planning efforts.

Key challenges for DER planning and implementation in Colombia include

- Need for greater transparency on electricity distribution systems (including the use of assets, operations, and investment plans) to inform the development of new markets, business models, and private investment opportunities;
- The system operator has little visibility on the types, capacity, and location of private DER connected to the grid. XM would like to gain control over grid-connected DER to operate them as part of the system;
- Although various power sector planning and operations models have been used (e.g., PLEXOS, PSR's OptGen, Power Factory's, EPRI's OpenDSS, and Orquideas) there is still a need for increased use of models;
- DER interconnection standards and requirements need to be developed for coordinated operations;
- Smart meters and other digital infrastructure have raised concerns about data and intellectual property ownership;
- More support is needed for education and vocational training to prepare the workforce for DER decision making and installations; and
- Recent studies and consultative processes highlighted the need for a DER aggregator, valuation of DER services, and market development.

3.2.2 MEXICO

Mexico has some country-specific motivations for increasing DER use:

- **Power sector reforms that increased competition as utility-scale RE costs declined.** Between 2013 and 2015, the Government of Mexico (GoM) adopted a comprehensive series of reforms. It split the vertically integrated, state-owned utility, the Comisión Federal de Electricidad (CFE), into separate entities for power generation, grid operations, and provision of basic electricity services. The GoM anticipated that a competitive market open to public and private companies could reduce costs to end users (Chanona-Robles 2016; Wood and Martin 2018). The Centro Nacional de Control de Energía (CENACE) became independent of the CFE and became the independent system operator for the national grid and wholesale market (Nance 2018).
- **Large number of customers paying subsidized electricity rates.** A majority of households and agricultural customers and some public institutions paid low subsidized rates for electricity. Lower generation and distribution costs could reduce the costs of maintaining these subsidized rates (Zinaman *et al.* 2018). Conversely, ending or reducing subsidized rates could increase DER investments, but would be politically unpopular.

---

[27] https://www.colombiainteligente.org/index.php/nosotros/quienes-somos
[28] https://www.ser-colombia.org/index.php/quienes-somos
[29] http://informes.xm.com.co/gestion/2018/investigacion-innovacion-y-desarrollo-de-proyectos/Paginas/energetica-2030.aspx

- **Large potential for increasing utility-scale RE generation as costs declined.** Mexico has abundant RE resources for solar and wind power that were relatively untapped before the policy reforms. The reforms were well timed since utility-scale RE generation costs were decreasing. Mexico also adopted RE auctions for more efficient price discovery.
- **Policy goals and the potential for scaling up renewable electric power**. The reforms aimed to create a level playing field across generation technologies to reduce electricity costs and dependence on fossil fuels (Government of Mexico 2013). In 2014, the GoM Mexico set a national target of reducing GHG emissions 22 percent by 2030.[30] The 2015 Energy Transition Law set a target for 35 percent of electricity from clean energy by 2024.
- **Large potential for energy efficiency improvements**. In 2020, the GoM set targets for annual EE gains of 2.2 percent between 2020 and 2035 and 2.5 percent between 2035 and 2050. These annual improvements were expected to reduce energy consumption at least 30 percent by 2035 and 43 percent by 2050 (SENER 2020).
- **Need to develop ancillary service markets to improve the quality of electricity supplies**. Ancillary services can reduce problems with the quality, reliability, and safety of electricity. Reforms enabled the sale of frequency control and reserve power on the wholesale electricity market at rates based on supply and demand. The GoM also allowed sale of reactive power for voltage support, islanding, and black start at regulated rates set by the Electricity Regulatory Commission (CRE).

The 2014 Electric Industry Law set clean energy quotas for qualified users and retail suppliers. To reduce compliance costs, it established a system of tradable Certificados de Energía Limpia (CELs). Producers received one clean energy certificate per megawatt-hour of electricity generated without fossil fuels. Producers with surplus CELs could sell them to electricity generators who did not generate enough CE to meet their requirements, either through auctions or wholesale electricity market transactions (Viscidi 2018; Molina *et al.* 2018). Distributed generation sources also received CELs, but could only sell them to their power supplier (Zinaman *et al.* 2018).

The Secretaria de Energía de México (SENER) set the minimum proportion of electricity that must be generated from clean energy or offset with purchased clean energy certificates each year. SENER also developed the initial rules for the wholesale electricity market. SENER set a 5.0 percent requirement for clean energy in 2018, which will gradually increase to 13.9 percent by 2022. SENER developed the initial rules for the wholesale electricity market. Other incentives for distributed generation included accelerated depreciation and property tax reductions in some cities.

The Comisión Reguladora de Energía (CRE) was responsible for any subsequent changes in those rules. Other incentives for distributed generation included accelerated depreciation and property tax reductions in some cities (García-Fariña 2017). CRE was the primary federal regulator for electricity with mandate to promote competition, establish minimum service levels; protect end user interests; and ensure the reliability, stability and security of electricity.

In 2017, CRE simplified the interconnection process for distributed generation and interconnection contracts. It also allowed three new compensation mechanisms -- net metering, net billing, and sell-all/buy-all arrangements. Some stakeholders found CRE's permit process for large distributed generation units cumbersome. CRE did not require a permit for small distributed generation units (Chacon 2018).

SENER chaired an advisory council for the energy transition, which advised the government on actions to achieve RE and EE goals. The advisory council included representatives from the CRE, CENACE,

---

[30] https://www.gob.mx/cms/uploads/attachment/file/162973/2015_indc_ing.pdf

CONUEE, industry, universities, and NGOs. There were working groups on energy production, use, storage, and efficiency (SENER 2019a). SENER prepared the national electricity development program (PRODESEN) consistent with the government's plans for electricity generation, transmission and distribution over 15 years (SENER 2019b). In 2018, PRODESEN included a chapter on distributed generation. In 2020, it revised the 15- and 30-year RE and EE targets (SENER 2020). It also issued a report on the Special Energy Transition Program for 2019-2024, with actions to help meet clean electricity targets for 2030.[31]

CRE began looking beyond distributed generation by assessing options to develop specific methods to compensate ancillary services, demand response, and energy storage. NREL provided technical assistance on grid integration studies (Parsons *et al.* 2015) and its Distributed Generation Market Demand model (Katz and Chernyakhovskiy 2020). It also helped CRE compare demand response compensation approaches used in the U.S. (Gagne *et al.* 2018).

The electricity reforms helped Mexico attract $5.8 billion in clean energy asset finance in 2017 and $3.3 billion in 2018 (BloombergNEF 2019). However, a series of policy and regulatory changes between 2018 and 2020 have undermined many key power sector reforms. For example, the GoM cancelled auctions for long-term RE capacity and CELs in December 2018, creating uncertainty about the value of the certificates (Fresh Energy Consulting 2019). Viscidi, Graham, and Phillips 2020 critiqued the following policy changes:

1. Indefinite cancellation of long-term electricity generation auctions (January 2019);
2. Cancellation of auctions for high-voltage, DC transmission lines to connect Baja California to the national grid and move wind power from Oaxaca State's high-resource potential areas to meet the electricity demand in central Mexico (January 2019);
3. Relaxed CFE's strict legal separation, allowing it to share information and employees and coordinate with its subsidiaries (March 2019);
4. SENER amended the regulations that limited CELs to CE facilities with generation permits issued after August 2014. It agreed to provide CELs for older hydro, thermal, and nuclear power plants owned by CFE (October 2019, but later blocked in court);
5. Draft CRE amendment that would block power generators with self-supply permits issued before the electricity reform from modifying their permits or interconnection agreements, including changing the amount of electricity generated or adding new partners (February 2020, under review by the Comisión Nacional de Mejora Regulatoria (CONAMER));
6. CENACE resolution following the Covid-19 pandemic related decrease in electricity consumption that would suspend pre-operational testing of wind and PV power plants, impose electricity volume limits on key transmission lines, review generator licenses for scheduled maintenance, and require participation of "must-run" power plants to control voltage regulation (April 2020, but suspended following lawsuits);
7. SENER proposed a Policy on Reliability, Safety, Continuity and Quality of the National Electric System that emphasized reliability over economic efficiency (the lowest marginal cost of dispatch). This proposal favored dispatch of electricity from CFE-owned fuel oil power plants and curtailed intermittent RE generation (May 2020, but the final rule has been blocked by the courts); and
8. CRE proposed CFE transmission rate increases of 407-775 percent for electricity self-supply with interconnection agreements that preceded the electricity reforms. This change violated the Electricity Industry Law's provision that allowed legacy projects to continue operating under the prior legal framework or opt into the new regime (May 2020, but blocked by court injunctions).

[31] https://www.dof.gob.mx/nota_detalle.php?codigo=5596374&fecha=08/07/2020

According to Aranda, Atkin, and Eliason (2020), SENER's proposed policy on reliability of the national electric system was issued without the required regulatory impact assessment or public consultation process normally conducted by CONAMER. This policy would have also established new ancillary services. However, CRE would set the rates for ancillary services, with the costs borne by RE generators, even when the services benefit other market participants. Solar and wind power generators would no longer be able to participate in the capacity market. This change could increase default rates in existing power purchase agreements, including those awarded through government auctions.

The draft policy on reliability would have re-established CFE's prior role in planning and operations of the national grid and interconnection process. It would have required CENACE to conduct an interconnection feasibility study before the CRE could grant power generation permits. It mandated inclusion of early termination and rescission clauses in generation permits and interconnection agreements. These clauses would require developers to begin and complete energy projects on time, with only limited time extensions possible and no extensions if the CRE had approved a transfer of a generation permit. All pending interconnection requests would have been suspended and would need to be refiled.

The new policy would also require PRODESEN to set area, region, and system limits for RE power stations and distributed generation for expansion or improvement programs for the national transmission and distribution grid. It would allow SENER to designate strategic power generation projects with a higher interconnection priority than other projects already in the queue. Electricity self-supply projects would need to have interconnection studies and cover the costs of new ancillary services and smart inverters (Aranda, Atkin, and Eliason 2020).

In July 2020, SENER published a 2020-2024 Energy Sector Planning Program. This policy planning document revised strategies and objectives to expand the role of the CFE and change wholesale electricity market rules. Viscidi, Graham, and Phillips (2020) argued that these changes would undermine private investment in the power sector. A July 2020 presidential memorandum required regulatory agencies to ensure that the national grid was supplied with electricity from the following sources in decreasing order -- hydropower, CFE's own generation units, private wind and solar power, and private combined cycle plants that are mainly natural gas fired (Viscidi, Graham, and Phillips 2020).

3.2.3 VIETNAM

Vietnam has some country-specific drivers for increasing DER use:

- **High economic growth rates, poverty reduction, and demographic factors have increased the demand for electricity.** Between 2002 and 2018, per capita Gross Domestic Product grew by a factor of 2.7 and reached $2,715 in 2019. Real GDP increased 7 percent in 2019, but was expected to decrease to 3-4 percent in 2020 due to the global pandemic. The poverty rate decreased from over 70 percent to less than 6 percent (at a poverty line of $3.20/day purchasing power parity). Between 1990 and 2016, life expectancy at birth increased from 70.5 to 76.3 years. The number of people 65 years and older is expected to increase 2.5 times by 2050.[32] Although 63 percent of the population lived in rural areas, approximately 100 percent of the population had access to electricity in 2018.[33]
- **Rapid increases in total electricity consumption and peak loads.** Electricity consumption tripled over the past decade and grew faster than economic output. Imbalances between the

[32]https://www.worldbank.org/en/country/vietnam/overview#:~:text=In%202019%2C%20Vietnam's%20economy%20continued,demand%20and%20export%2Doriented%20manufacturing.&text=Nevertheless%2C%20the%20economic%20growth%20is,6.5%20percent%20pre%2Dcrisis%20projections.

[33]https://energypedia.info/wiki/Vietnam_Energy_Situation#:~:text=Currently%2C%20the%20power%20production%20is,fossil%20import%20dependency%20will%20increase.

amount of electricity supplied and demanded may occur as soon as 2021, especially at peak periods (Economist 2020). Peak power constraints will encourage investments in distributed generation and demand response programs.

- **Plans to double electricity generation by 2030.** The Government of Vietnam (GoV) plans to increase power generation from 54 GW to 125-130 GW by 2030 (Vu 2020).
- **Heavy reliance on hydropower and fossil fuels for electricity despite high RE potential**. Drought years have sharply reduced hydropower output since the government placed a higher priority on water availability for agriculture. In 2020, natural gas and coal use in power generation was expected to increase because droughts have affected water availability for hydropower (Vu 2020).

  Vietnam began importing coal for power generation in 2017 (Deloitte Consulting 2019b). It planned to use 720 million tons of domestic coal and 680 million tons of imported coal for electricity between 2016 and 2030 (Vu 2019). However, construction of new coal-fired power plants has slowed due to regulatory delays, local opposition, and flagging investor interest (*The Economist* 2020).

  The GoV set a target of 10.7 percent of electricity generation from solar or wind power by 2030.[34] Even without accounting for the lower environmental costs of RE, the LCOE in Vietnam was already substantially lower for solar and wind power than electricity generation from coal, domestic natural gas, and imported liquefied natural gas. In 2020, hydropower had a slightly lower LCOE than solar or wind power. However, solar and wind power were expected to cost less than hydropower by 2024 (Breu *et al.* 2019).
- **Climate risks and hydropower.** Electricity production accounted for nearly two-thirds of national GHG emissions.[35] Vietnam's Nationally Determined Contributions included targets of reducing GHG emissions reductions 8 percent by 2030 with its own financial resources and up to 25 percent with sufficient international financing (Government of Vietnam 2018).
- **Air pollution:** The World Health Organization attributed 60,000 excess deaths in Vietnam to air pollution in 2016. It estimated that air pollution from fine particulates (PM 2.5) reduced the national life expectancy by one year and caused damage that cost 5 percent of the GDP. In 2019, Hanoi had only eight days with PM 2.5 levels below the national standard of 50 micrograms per cubic meter ($\mu g/m^3$) and Ho Chi Minh City had only 36 days below that level. Although coal-fired power plants contributed to this problem, motor vehicles, and the burning of rice fields after harvesting were also major sources. The National Assembly planned to enact a new Law on Environmental Protection by the end of 2020 (Do 2020).

In 2017, the GoV introduced a feed-in-tariff (FiT) of $0.0935/kWh for up to 4.46 GW of new RE capacity in commercial operation before the deadline. Most of the approved installations were utility-scale PV. The FiT was ineffective in increasing distributed generation because the state-owned utility, Electricity Vietnam (EVN), charged low electricity rates that made rooftop PV unprofitable. The solar and wind power FiTs did not include any limits by zone or locational incentives. They resulted in excess generation capacity in two provinces. Only 41 percent of the approved solar power capacity and 1 percent of the approved wind power capacity in these two provinces are expected to be absorbed by the grid in 2025 (Deloitte Consulting 2019b). Provincial governments in Vietnam have approved power

[34] https://ieefa.org/vietnam-is-accelerating-drive-for-renewable-energy/#:~:text=Vietnam%2C%20however%2C%20has%20bold%20ambitions,at%20German%20investment%20firm%20DEG.

[35]https://www.worldbank.org/en/country/vietnam/overview#:~:text=In%202019%2C%20Vietnam's%20economy%20continued,demand%20and%20export%2Doriented%20manufacturing.&text=Nevertheless%2C%20the%20economic%20growth%20is,6.5%20percent%20pre%2Dcrisis%20projections.

generation projects based on near-term considerations, without considering the long-term targets in the national power development plans.

In late 2019, the GoV replaced the FiT with competitive auctions for utility-scale RE.[36] It did not propose any incentives for distributed generation.[37] However, there was a target of installing 100,000 rooftop PV systems by 2025 (Government of Vietnam 2019).

Other types of DER have been slow to penetrate the market. EVN experimented with voluntary demand response and identified the need for a broader rollout and better incentives to motivate participation. It planned to reduce the national peak load by 90 MW in 2020 and 300 MW in 2025 (Vietnam Electricity 2019). Vehicle electrification has been constrained by power generation and transmission and distribution capacity. The grid also faces power stability and voltage problems due to insufficient primary and secondary reserves and uneven voltages. These challenges were increased by the lack of compensation for ancillary services (Deloitte Consulting 2019b). RE curtailments may provide an incentive for investments in utility-scale BESS.

The Ministry of Industry and Trade (MOIT) was the lead agency for a series of long-term Power Development Plans (PDPs) in collaboration with the national utility. EVN also prepared five-year plans as well as annual plans. The one- and five-year plans were based on the PDPs.

In 2017, the GoV and some donors established the Vietnam Energy Partnership Group to strengthen cooperation and information exchanges in the electricity sector. This has been the only platform for major stakeholders to provide data and influence government decision making.

Vietnam's Seventh Power Development Plan (PDP-7) called for a $150 billion investment in new generation and grid capacity by 2030. The generation investments included 45 GW of new coal-fired capacity and 18 GW of RE capacity. Under this plan, imported coal would provide 57 percent of electricity generation and 47 percent of capacity by 2030. However, the coal power plant build-out was well behind schedule, increasing risks of cost increases and supply reliability.

McKinsey & Company proposed an alternative Renewables-Led Pathway with 39 GW of new wind power capacity and 61 GW of new solar power capacity by 2030. This pathway would be combined with removal of fuels subsidies for electricity, 6 GW of additional natural gas fired generation, and more BESS to firm the RE supplies. Through 2030, the Renewables-Led Pathway would reduce levelized costs 10 percent, imported fuel use in electricity generation 60 percent, GHG emissions 32 percent, and particulate emissions 33 percent. It would also create 465,000 more jobs. The cost and pollution reductions and increased employment would be higher through 2040 (Breu *et al.* 2019).

McKinsey & Company recommended changes to increase private investment and develop RE markets on the scale needed in Vietnam:

1. Extend the eligibility period for projects approved for the FiT. These projects must begin commercial operations by the end of 2020 to be eligible for FiT rates. A majority of these projects may never be built due to lack of financing;
2. Recruit experienced international firms to build the first large-scale RE generation units and develop local capacity;
3. Increase the ease and transparency of the project approval process;
4. Conduct a detailed grid capability assessment and identify optimal sites for new RE generation;
5. Accelerate RE projects, especially those large enough to influence the market; and
6. Identify and begin discussions with potential large-scale private investors that can provide $50-$150 billion of new capital (Breu *et al.* 2019);

[36] Notification No. 402/TB-VPCP on November 22, 2019
[37] MOIT adopting Decision 2023/QĐ-BCT effective July 5, 2019

The USAID-funded Vietnam Low Emission Energy Program (V-LEEP) provided technical assistance to help the GoV improve PDP-8 covering 2021-2030. Deloitte Consulting (2019a) concluded that the methods used in PDP-7 would be inadequate for the Eighth Power Development Plan (PDP-8). PDP-7 was prepared without sufficient data on the demand, intermittent RE generation, and transmission capacity to allow *operations modeling* – production cost and reliability simulations. The MOIT has received support from the World Bank, GiZ, and other donors to improve local data on solar and onshore wind resources. Table 6 compares the methods used in preparing PDP-7 to international good practices for power sector planning.

TABLE 6. Methods Used in Preparing PDP-7 Vs. International Good Practices

	International Leading Practices	Methods Used for PDP7/RPDP7	Notes
Bottom-up load forecasting	Yes	Limited	Unclear how to consolidate top-down and bottom-up results
Generation costs	Yes	Yes	
Demand-side management options and costs	Yes	No	Only national-level EE program
Transmission and distribution costs	Yes	Limited	Only transmission (500 kilovolts (kV) and 220/110 kV)
Risks of fuel price volatility, drought, and carbon taxes	Yes	Limited	Sensitive analysis only with deterministic fuel costs
Public involvement throughout process	Yes	Limited	Draft PDP development report only, not during the process
Scenario and sensitivity analysis to ensure least cost alternatives under different cost and demand assumptions	Yes	Limited	PDPAT II with typical day/week only

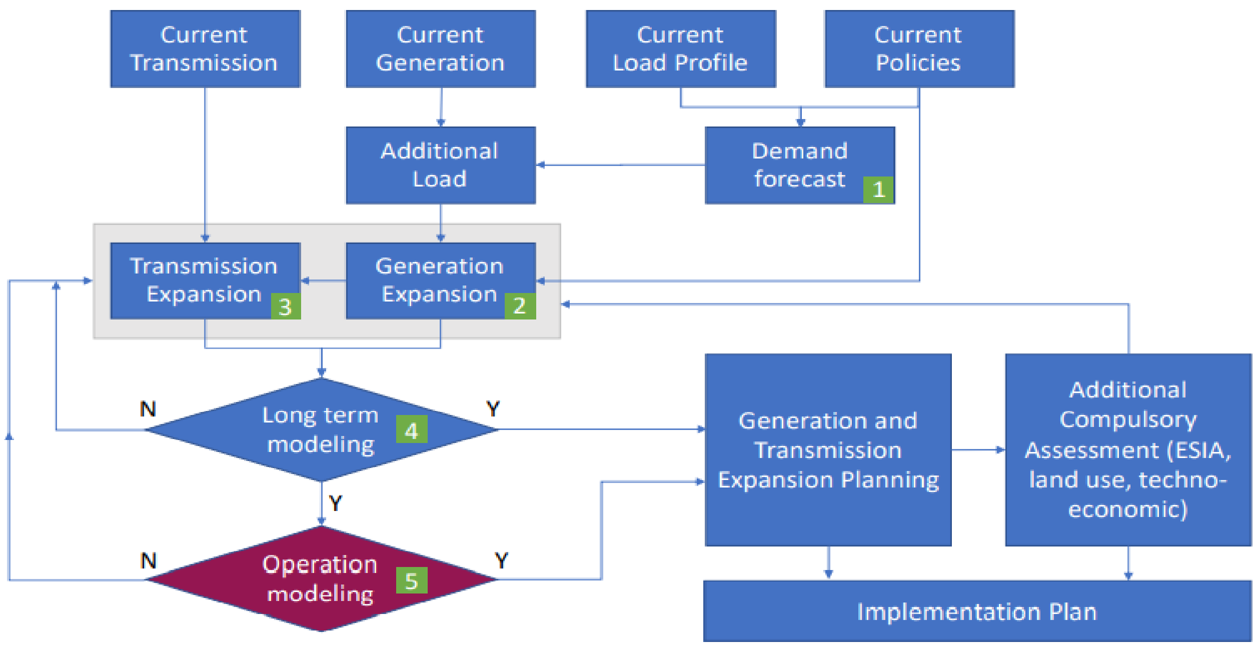
Source: Adapted from Deloitte Consulting 2019a

V-LEEP recommended having at least one full year of data on power demand and electricity generation and transmission and distribution operations over one-hour or half-hour periods. It also suggested restructuring the geographic regions to reflect differences in the marginal costs of power generation, rather than legislatively mandated regions or the regions used in the previous plans. These changes will improve the analysis of transmission and distribution system congestion. V-LEEP noted that additional work would be needed to screen areas suitable for solar and onshore and offshore wind power development based on terrain and land uses (Deloitte Consulting 2019a). Figure 15 diagrams of proposed methods for PDP-8. Figure 16 shows V-LEEP's recommended process for preparation of this plan.

PDP-7 used a top-down approach to demand forecasting that focused on conforming loads that fit the typical load profile. V-LEEP recommended that PDP-8 use a hybrid of the top-down and bottom-up approaches to demand forecasting with regional load profiles and disaggregation to hourly or sub-hourly periods. The bottom-up approach would require data on nonconforming loads with atypical shapes and time profiles, such as industrial parks, factories, ports, mines, agriculture, street lighting, electric trains, and BEV charging.

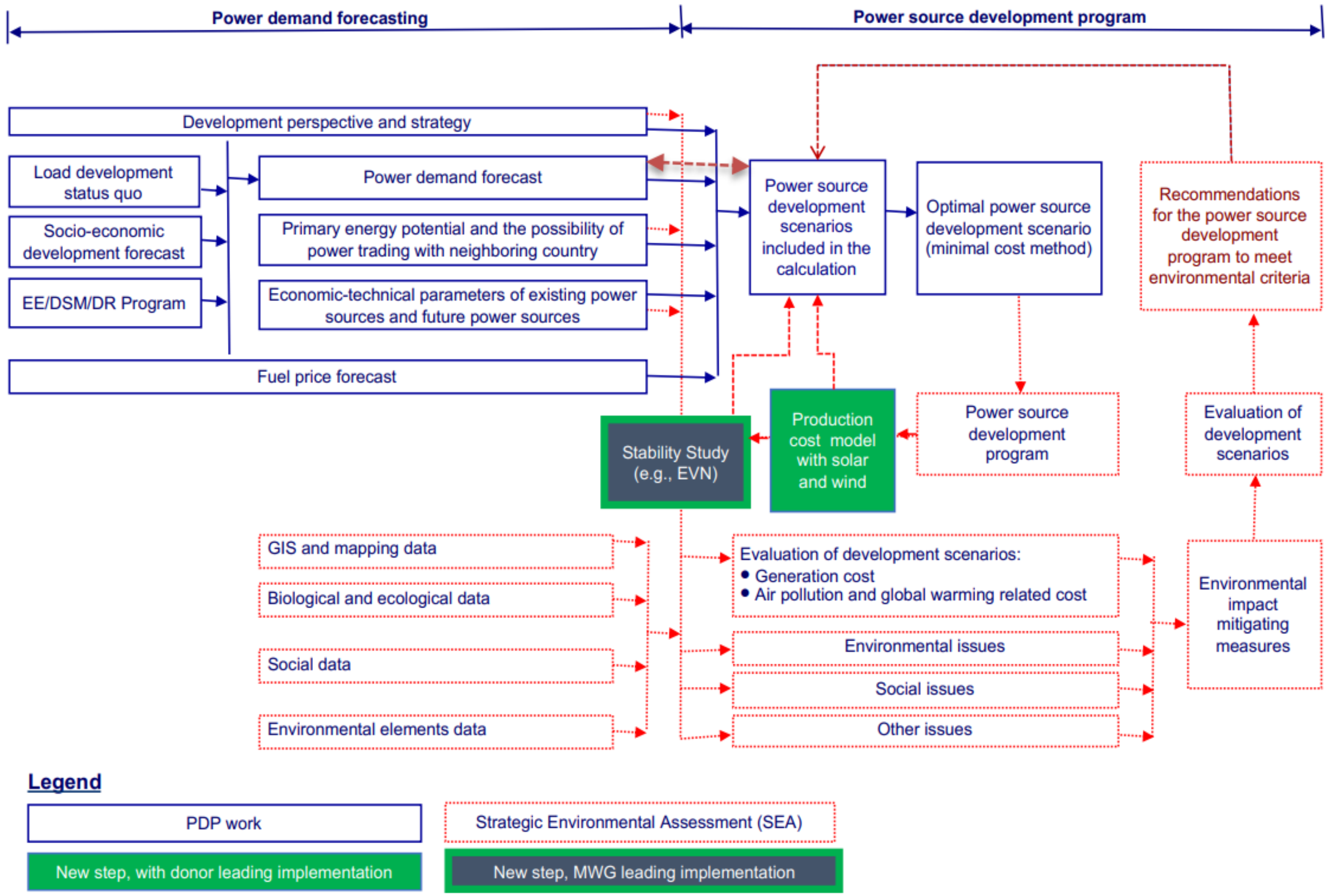
V-LEEP identified operational analyses and production cost modeling as the most important new components for PDP-8. Generation capacity expansion would support the peak load and a reserve margin. The transmission and distribution systems would need to accommodate the peak load. The operational and production cost analysis should assess the need to increase flexibility and maintain operating reserves off-peak as the proportion of variable RE grows. This flexibility can be provided through smart grids, demand response, BESS, or other types of DER. A production cost model would also be useful for RE grid integration studies and analyzing power flow, contingency, stability, short circuit, and voltage control issues.

FIGURE 15. Proposed Methods for PDP-8



Source: Deloitte Consulting 2019a

FIGURE 16. Recommended Process for Preparation of PDP-8



Source: Deloitte Consulting 2019a

4. RECOMMENDATIONS FOR THE DER PLANNING PROCESS

CEADIR recommended a three-phase approach for a DER plan or roadmap process. The first phase includes preliminary work to secure buy-in and sponsorship, stakeholder mobilization, scoping, data collection and analysis, and communications. Some of the preliminary work tasks can be done simultaneously. Different organizations or staff may take the lead on the various tasks. The time required for each task will vary with the local context. The second phase is formulation of the DER plan or roadmap. The third phase consists of follow-up activity, including preparation of a budget and schedule for implementation and a plan for updating the DER roadmap.

4.1 PHASE 1: OBTAIN BUY-IN FOR PARTICIPATION AND SPONSORSHIPS

Obtain public and private sector buy-in for participation and make decisions on ownership and leadership for the process. In some jurisdictions, an executive order or legislative mandate may be required to initiate a DER plan or roadmap. Legislative mandates and executive orders are often the product of stakeholder proposals (industry, utility, energy/environmental NGO, etc.) or models that have been adopted by regional partners. Even where a specific administrative or legislative mandate is not required, it may be useful to demonstrate government support for the DER planning process and reduce institutional obstacles to cooperation.

Obtain sponsorships. One or more sponsoring organizations will be needed to cover the costs of DER plan or roadmap preparation and provide administrative and logistical support. Costs will be incurred in data collection and analysis and, organization and preparations for meetings, workshops, and stakeholder consultations. Travel cost support may be needed to obtain participation of some stakeholders in a central location or government and industry staff will have to travel to field sites. It may be necessary to hire expert consultants and purchase hardware and software. In addition to identifying costs it is also important to identify cost recovery mechanisms.

Potential sponsors include vertically integrated utilities, power generation companies, transmission and distribution companies, utility regulators, government energy agencies, national planning agencies, or national finance agencies. Governments in developing countries may be able to obtain financial and technical support from development assistance organizations. It can take a considerable amount of time to obtain support from the government budget or development assistance organizations. Consequently, fundraising efforts should begin well in advance of the desired start of the DER planning process.

4.2 PHASE 1: STAKEHOLDER IDENTIFICATION AND MOBILIZATION

Identify initial key stakeholders from the national and subnational government, economic and development agencies, private sector, nongovernmental organizations, power system regulators, energy sector agencies, environmental agencies, grid operators, vertically integrated utilities, transmission and distribution utilities, electric cooperatives, and power market companies (independent system operator and regional transmission organization).

Identify additional stakeholders for inclusion later: Power industry associations; DER manufacturers, suppliers, and installers; environmental organizations, consumer organizations, and other civil society organizations; universities and research institutes; and large industrial, commercial, and residential power customers or their associations. The process for identifying additional community-based, or civil society organizations typically involves briefings or meetings to discuss the purpose, objectives, and process for developing a DER plan; the impact it could have on a community (decreased electricity prices, jobs, uses for powering schools, hospitals, etc.). This process entices community stakeholders to participate.

Establish a steering committee and assign roles. The steering committee will need to make important decisions on the objectives; scope; strategy; monitoring and evaluation methods; timetable and milestones; and budget for the DER roadmap. The steering committee should also track planning progress, expenditures, and roles and responsibilities. The steering committee can decide whether to hire professional facilitators to help keep major meetings on schedule and ensure that all voices are heard. The steering committee can designate note takers for meetings and report writers.

4.3 PHASE 1: SCOPING

Define the scope and geographic boundaries. A written scope of work should be prepared for DER plans and roadmaps. The appropriate geographic scope depends on the purpose of the plan or roadmap and the interests of the sponsoring and participating organizations. Note geographic boundaries might change after conducting research, based upon load pockets, resource potential, interconnection status, and distribution circuit hosting capacity for example. In addition, if pilot deployment is a first step in the process, pilot results could also inform how future boundaries are drawn. The performance and availability of many DER technologies are still improving and their unit costs are declining. As a result, the scope of work should include future projections of the performance, cost, benefits, and availability of various types of DER.

Establish expert advisory groups and task forces to obtain input on technical and policy, planning, and implementation issues.

4.4 PHASE 1: DATA COLLECTION AND ANALYSIS

Identify existing, pending, and potential national and subnational policies and regulations that may affect DER. How are utilities regulated? What is the structure of the industry? How are electricity rates set? Do retail and wholesale power reflect full costs and a sufficient rate of return? Are there price ceilings or caps on the rate of price increases? Do the tariffs reflect the full costs of generation and distribution? Are there renewable portfolio standards, GHG reduction targets, investment tax credits or deductions, investment grants or subsidies, or technical assistance programs? Assess the magnitude and direction of the impacts of these policies or regulations on the profitability, financing, and implementation of various types of DER.

Collect data on historical baselines and growth trends and forecast future conditions. Identify current, location-specific and time-dependent gaps between the quantity of electricity supplied and the quantity demanded. Does the power grid extend beyond the boundaries of the analysis and what is the degree of market integration across the boundaries? Develop forecasts for the future in line with the time horizon for the DER plan. Consider multiple scenarios of population, economic growth, and DER adoption. Some of the questions to be addressed:

- What electric power generation, transmission and distribution, and grid management technologies are currently in use in the study area?

- What DERs and related investments are pending or planned at the utility scale, and by large customers?
- What are the current wholesale and retail prices of electricity by type of customer and location?
- What are the projected changes in real (inflation-adjusted) prices of electricity by type of customer and location?
- What are the key assumptions and risks?
- What are the key drivers of future changes?
- How is the mix of energy resources for electricity expected to change?
- What changes are expected in the proportions of on-grid and off-grid power use?

An *accompanying gap analysis* will help determine which gaps can be resolved and the steps to resolve them. For gaps that cannot be resolved, limitations should be identified.

Table 7 contains a framework for analyzing DER benefits and costs. Table 8 discusses other potential DER impacts that should be assessed.

With DoE funding, the Lawrence Berkeley National Laboratory and Nexant, Inc. developed a simple tool to help utilities and government agencies estimate the costs of electricity service interruptions and the benefits of service reliability improvements in each U.S. state (https://www.icecalculator.com/home). The interruption cost calculator estimates the costs per interruption event, average kW, and unserved kWh as well as the total cost of sustained power interruptions. The value of reliability improvements is estimated under both static and dynamic conditions. These tools could be useful for DER planning in developing countries, but the parameters or estimates would need to be adjusted.

TABLE 7. A Framework for Analyzing DER Benefits and Costs

Benefits	Rate Impact Measure	Impact on Utility Costs	Impact on Societal Costs
Bulk system			
Avoided generation capacity, including reserve margin	•	•	•
Avoided energy	•	•	•
Avoided transmission capacity infrastructure and operating and maintenance costs	•	•	•
Avoided transmission losses	•	•	•
Avoided ancillary services (e.g., operating reserves and regulations)	•	•	•
Wholesale market impacts	•	•	
Distribution system			
Avoided distribution capacity infrastructure	•	•	•
Avoided operating and maintenance costs	•	•	•
Avoided distribution losses	•	•	•
Reliability and resiliency			
Net avoided restoration costs	•	•	•
Net avoided outage costs			•
External			
Net avoided greenhouse gases			•
Net avoided criteria air pollutants			•
Avoided water impacts			•
Avoided land impacts			•
Net non-energy benefits (e.g., service reliability; bill collections; and impacts on health, employee productivity, and property values not already included)	•	•	•

TABLE 7. A Framework for Analyzing DER Benefits and Costs (Continued)

Costs	Rate Impact Measure	Impact on Utility Costs	Impact on Societal Costs
Program administration costs (including rebates, costs of market interventions, and measurement and verification costs)	•	•	•
Added ancillary service costs	•	•	•
Incremental transmission and distribution costs, including metering and communications	•	•	•
Participant DER costs (reduced by rebates, if not included above)			•
Lost utility revenues	•		
Shareholder incentives	•	•	
Net non-energy costs (e.g., indoor emissions, noise disturbance)			

Source : Adapted from Deora *et al.* 2019

TABLE 8. Distributed Energy Resource Impacts

Benefits		Costs	
Category	**Examples**	**Category**	**Examples**
Customer Impacts			
Load reduction and avoided energy costs	Avoided energy generation and line losses, price suppression	Program administration costs	Program marketing, administration, evaluation, incentives to customers
Demand reduction and avoided capacity costs	Avoided transmission, distribution, and generation capacity costs, price suppression	Utility system costs	Integration capital costs, increased ancillary services costs
Avoided compliance costs	Avoided renewable energy compliance costs, avoided power plant retrofits	DSP costs	Transactional platform costs
Ancillary services	Regulation, reserves, energy imbalance		
Utility operations	Reduced financial and accounting costs, lower customer service costs		
Market efficiency	Reduction in market power, market animation, customer empowerment		
Risk	Project risk, portfolio risk, and resiliency		
Participant Impacts			
Participant non-energy benefits	Health and safety, comfort, tax credits	Participant direct costs	Contribution to measure cost, transaction costs, O&M costs
Participant resource benefits	Water, sewer, and other fuels savings	Other participant impacts	Increased heating or cooling costs, value of lost service, decreased comfort
Societal Impacts			
Public benefits	Economic development, reduced tax burden	Public costs	Tax credits
Environmental benefits	Avoided air emissions and reduced impacts on other natural resources	Environmental costs	Emissions and other environmental impacts

Source: Adapted from Deora *et al.* 2019

4.5 PHASE 1: COMMUNICATIONS

Develop and implement a communication strategy for the planning process. The communication strategy should include outreach to expand public participation through open meetings and written comments. Use multiple communication methods to inform various stakeholders about the DER roadmap process and findings and recommendations.

4.6 PHASE 2: DER PLAN OR ROADMAP DEVELOPMENT

The second phase should include the following steps:

- **Use the data analysis and modeling results** to build consensus on the projections, targets, technology mix; investment and financing plans; and systems for grid integration.
- **Select the range and scope of feasible DER technology options**. Identify critical system requirements and their advantages and disadvantages and compatibility with various DER technologies.
- **Set priorities for the DER technologies**. Which technologies have the best prospects for adoption? What are the main barriers to implementation? What are the key grid integration and decentralization issues?
- **Identify the need for any policy and regulatory changes to increase DER use**. When are they needed and for how long?
- **Develop the rules and regulations for DER operations** (Horowitz *et al.* 2019)**,** including:
    - Interconnection standards, such as FERC 828 or Institute of Electrical and Electronics Engineers 1547. FERC 828 'Requirements for Frequency and Voltage Ride Through Capability of Small Generating Facilities' require newly interconnecting small generating facilities to ride through abnormal frequency and voltage events and not disconnect during such events. The Institute of Electrical and Electronics Engineers (IEEE) 1547 'Standard for Interconnecting Distributed Resources with Electric Power Systems' establishes criteria and requirements for interconnection of distributed resources with electric power systems. It provides a uniform standard for interconnection of distributed resources with electric power systems. It also provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection.
    - Inverter standards, such as Underwriters Laboratories (UL) 1741 for inverters, converters, controllers and interconnection system equipment for use with distributed energy resources.
    - Building electrical codes (e.g., U.S. National Electrical Code).
    - Guidelines for maintaining voltage, such as the American National Standards Institute C84.1, which establishes nominal voltage ratings and operating tolerances for 60 Hz electric power systems above 100 V and includes preferred voltage ratings up to and including 1,200 kV maximum system voltage.
- **Develop policies and incentives** to increase returns on DER investments, such as:
    - Supply contracts and payment and pricing terms for distributed generation and BESS;
    - Time-of-use rates for power consumed or supplied; and
    - Transparent and fair interconnection costs and procedures.

- **Identify markets and mechanisms for DER deployment**, such as:
  - Wholesale markets;
  - Ancillary service markets;
  - Peaking applications; and
  - Value stacking opportunities for battery energy storage.
- **Develop legal, financing, and investment support structures**. Determine new investments, structures, and rules to guide DER specifications, types, and locations that benefit the utilities and DER owners.
- **Develop a procurement, monitoring, evaluation, and verification framework** (bids, bid evaluation, shortlist, review, approval, deployment, monitoring, etc.). Hile *et al.* (2017) provide the following emerging best practices for commercial DER procurement by utilities:
  - Provide useful customer and system data;
  - Provide anticipated device trigger/dispatch and notification requirements;
  - Use demonstration projects to explore subsequent commercial terms;
  - Give DER providers the right amount of lead time;
  - Coordinate with other programs and markets;
  - Offer a vendor pre-qualification process; and
  - Use sample pro forma agreements to explore the optimal commercial standards.
- **Establish incremental milestones, goals, targets and specific, measurable, achievable, relevant, and time-bound indicators**. For example, the targets and indicators may address goals for reducing fossil fuel power generation and increasing RE generation on- and off-the grid; decreasing utility and end user costs, greater reliability of electricity supplies; lower foreign exchange requirements for imported fuels; energy and cost savings from EE and demand response measures; deferred or avoided costs for investments in new power generation, transmission and distribution capacity; reductions in GHG emissions and air, water, and land pollution; and greater reliance on EV. Aim to achieve incremental gains.
- **Prepare the draft DER plan or roadmap**. Obtain feedback from key participants and revise as needed. Submit the revised report to regulatory authorities and other government agencies for approval, where needed.
- **Issue the final DER plan or roadmap**. Make the main report and an executive summary report accessible to the public via the internet.
- **Prepare and disseminate concise communication materials** for a variety of audiences.

4.7 PHASE 3: FOLLOW-UP

Most of the DER plans or roadmaps that CEADIR reviewed contained little information on next steps. However, several did address the importance of follow-up activities. For example, the CPUC established a steering committee for continuing coordination of DER planning, implementation, reporting, public communications, and roadmap revisions. The NYISO continued regular meetings with working groups to monitor progress under and the need for plan revisions.

CEADIR recommends several follow-up activities after preparation of DER plans or roadmaps:

- **Develop an action plan and schedule** for DER planning and implementation, including organizational assignments for various tasks.
- **Prepare medium-term (typically 3-5 years) and long-term (typically 5-20 years) budget frameworks** for financing public sector and utility investments.
- **Monitor and report on milestones, goals, targets, and indicators**. Monitor progress.
- **Update DER plans and roadmaps periodically**. Review the DER roadmap implementation progress at least annually based on monitoring and evaluation data. Revise planned activities, milestones, goals, targets, and indicators as needed. Update plans or roadmaps as economic conditions and technologies change, preferably at least every three years. TABLE 3 showed SMUD's conditional plan for updating its DER roadmap.

Lastly, Chew *et al*. (2018) identified insights from planning and sourcing for the 10 nonwire alternatives (NWA) projects in their study:

- Open and technology-agnostic approaches can help with project success;
- Procurement processes and bidding responses require more time than originally anticipated;
- Uncertainty of load growth is a challenge for utilities but a strength for NWA;
- Know as much about your service territory as possible to inform program recruitment; and
- Utilities often use a benefit-to-cost assessment to evaluate NWA opportunities.

5. KEY THEMES AND RESEARCH NEEDS

Some key themes for DER policies, adoption, and planning are listed below:

- **Most developing countries need to expand electricity generation and transmission and distribution systems and beyond the grid services to increase affordability, reliability, and access and DER can play an important role.** Many also have country-specific reasons for increasing DER adoption. For example, Colombia is heavily dependent on large-scale hydropower that is vulnerable to drought risks and faces grid constraints. Mexico continues to incur high costs for electricity rate subsidies and had relatively high generation costs from fossil fuels despite extensive solar and wind resources. Vietnam has experienced large increases in the demand for electricity due to rapid economic growth and still has limited power transmission and distribution infrastructure. It has also relied heavily on domestic and imported coal for electricity generation and faces major health impacts from severe air pollution problems.
- **Many developing countries were still at an early stage of DER adoption.** Common challenges to DER expansion in developing countries include the absence of wholesale power markets; limited ability for remuneration of ancillary services; the absence of interconnection standards; slow approval processes; the need for greater transparency on electricity distribution systems to inform the development of new markets, business models, and private investment opportunities, limited visibility on the types, capacity, and location of private DER connected to the grid; subsidized electricity rates; and the need for greater data sharing and for greater use of models for decision making.
- **When DER use is low, governments may need to consider policy, regulatory, and market reforms to create a more favorable enabling environment for scaling up DER investment rates**. National policies and regulations can have major impacts on DER investments. In the U.S., FERC Order 745 of 2011 required wholesale markets to compensate demand response providers for load reduction at the same rates available for generated electricityt.

  FERC Order 841 of 2018 increased investments in utility-scale BESS by removing barriers to the equitable participation of storage resources in capacity, energy, and ancillary services markets operated by regional transmission organizations (RTOs) and independent system operators (ISOs). In 2020, FERC Order 2222 broadened these requirements to include the full range of DER technologies.

  Decreasing costs and improving performance of DER technologies have also encouraged policy, regulatory, and market reforms in developing countries. Between 2013 and 2015, Mexico was an exemplary model of major electricity market and policy reforms. However, Mexico reversed many important reforms between 2018 and 2020. Colombia began major electricity reforms in 2014 and has continued to build on them. Vietnam began reforms more recently. For example, , Vietnam replaced feed-in-tariffs with competitive RE auctions in 2017.
- **DER can help balance grid demand and supply** at multiple timescales, enabling utilities to defer or reduce new capital investments in generation, transmission, and distribution. Increased DER use can improve variable RE generation and the ability of utilities to meet peak loads at lower costs. Bidirectional flows from EV charging can also have positive impacts on the power system. DER also increase energy security for countries that rely on imported fossil or nuclear fuels for power generation.

- **DER technologies can be disruptive.** DER can require new approaches to power generation, distribution, and transmission investment and operations. DER can pressure existing utility business models by reducing capital costs as well as revenues and changing the relationship between utilities and their customers. However, DER can strain transmission and distribution systems, especially when data are insufficient on their capacity and location, power production profile, behavior during disturbances, controllability, and impact on regulating voltages.
- **Utilities need to monitor customer adoption of grid-connected distributed generation and forecast future growth to plan their investments.** Utilities will also need to assess the technological and financial feasibility of their own DER and conventional infrastructure investments. The impacts on operations and investments depend on whether utilities are involved in power generation as well as transmission and distribution and es competition from independent power generation companies and customers with their own distributed generation.
- **Utilities need more data from their customers with grid-connected, distributed generation, storage, and EV charging systems to manage and plan their operations.** As DER adoption expands, utilities need real-time data from their customers and market networks to improve system reliability and efficiency. Real-time monitoring of voltages along transmission and distribution lines is important when there are bidirectional electricity flows. Many developing countries need to improve interconnection standards and adopt smart grids and automated, monitoring technologies to overcome data and capacity limitations. Utilities may also needto adopt new practices, such as establishing voltage reserves.
- **DER roadmaps and plans can smooth the transition from a centralized grid to a distributed electric power system.** The complexity of the power system increases as more DER are integrated into the grid. During the early stages with low DER integration, policy making can focus on projecting customer adoption rates and managing interconnections. As DER integration progresses, policies should focus on incentives for distribution network changes that can increase system reliability and the ability to defer conventional generation and distribution investments. With widespread DER integration, policies should focus on improving electricity markets, such as facilitating peer-to-peer transactions, wholesale markets, and regional reliability improvements and cost reductions.

  A DER roadmap can help build consensus on policy goals and the process and milestones needed to achieve them. Proactive planning can help manage the challenges associated with DER integration and take better advantage of the potential savings from avoided capital costs.
- **In the U.S., DER planning is typically done at the state, rather than federal government level.** California, Hawaii, and New York have taken a leading role in DER planning. In some states, government agencies prepare DER roadmaps. Some states require utilities to prepare DER plans instead of or in addition to public sector plans. The Potomac Electric Power Company (PEPCO), is an example of a U.S. transmission and distribution utility that has prepared a DER roadmap for its multistate service area subject to different regulatory frameworks and entities. Some states have multiple DER roadmaps that cover various market segments or political jurisdictions. Multistate power pools may also produce DER plans.
- **DER planning in most developing countries has lagged adoption rates.** Few developing countries have prepared have roadmaps or plans that focus on DER. However, some have prepared long-term or short-term, national energy plans that addressed some DER technologies.

  The Government of Colombia established an Energy Transformation Mission with national and international experts to develop the country's first roadmap for modernization of the electric power system. This roadmap will address DER and broader sectoral topics: 1) competition, participation, and market structure (including RE integration and pricing for system stability and reliability); 2) role of natural gas in the electricity transformation; 3) decentralization and digital technologies in the electric power system and pricing for efficient demand management; 4) closing gaps in coverage and service quality and formulation of efficient subsidies; and 5) review of the institutional regulatory and framework. In Colombia, diverse stakeholders contributed to DER planning through the Consejo Nacional de Operación's multidisciplinary workgroups, Colombia Inteligente, SER Colombia, and Energética 2030.

In 2018, the Government of Mexico included a chapter on distributed generation planning in its national electricity development program, Programa de Desarrollo del Sistema Eléctrico Nacional (PRODESEN) for the first time. However, multiple policy and regulatory changes between 2018 and 2020 have reversed or undermined many of the earlier power sector reforms.

The Government of Vietnam has an extensive history of preparing plans for the electric power system. Vietnam's Ministry of Trade and Industry (MOIT) will be developing the Eighth Power Development Plan (PDP-8), covering 2021 through 2030. The national parastatal utility, Electricity Vietnam (EVN), was also preparing its five-year plan for 2021-2025. The Seventh Power Development Plan and earlier plans were prepared without sufficient data on the demand, variable RE generation, and transmission capacity to allow *operations modeling* – production cost and reliability simulations.

The USAID-funded Vietnam Low Emission Energy Program (V-LEEP) provided technical assistance to improve the eighth plan. It recommended using at least a full year of data on power demand and electricity generation, transmission and distribution operations over one-hour or half-hour time periods. V-LEEP also recommended restructuring the geographic regions to reflect differences in the marginal costs of power generation, rather than legislatively mandated regions or the regions used in the previous plans. This will facilitate the analysis of transmission and distribution system congestion. The MOIT also received support from the World Bank, Deutsche Gesellschaft für Internationale Zusammenarbeit (GiZ), and other development assistance organizations to improve local data on solar and onshore wind resources. Further work will be needed to screen areas suitable for solar and wind power development and identify offshore wind power potential.

- **Diverse stakeholders should be included in a DER roadmap or planning process.** Key stakeholders include national or subnational regulators, other government agencies, executive and legislative branch officials; utilities and other power generators; industrial, commercial, and residential users; community-based organizations; environmental organizations; and consumer advocacy organizations. It is important for utilities to keep these stakeholders informed about the planning process and available data and analyses. Residential, industrial, and agricultural users and consumer organizations often seek subsidies or lower electricity rates. Environmental organizations advocate for air and water quality improvements and GHG emission reductions from fossil fuel use.

Planning and policy issues. DER are rapidly evolving and technologies are improving and unit costs are declining. Although these trends are favorable, they increase uncertainty about optimal adoption rates and timing. Furthermore, many government policy and utility planning issues remain to be determined:

- How to best drive DER to particular locations of optimal deployment?
- How to align compensation, rates, and market structures to better realize the value of DER services?
- How to provide customers with timely and more granular information so that they can make informed decisions about their energy use?
- Whether utilities be allowed to own and operate DER products and services?

- How to evolve utility business models and regulatory models to properly value and take advantage of DER opportunities? (Deora et al. 2017).

Areas for further research.

- DER sourcing best practices;
- Ownership and control of DER;
- Utility contracting benchmarks with technology providers and third-party owners;
- Navigating multiple value streams of, and cost recovery approaches for DER;
- Benefit-to-cost analyses and new incentive models for utilities; and
- DER impacts on the bulk power system (Chew et al. 2018).

Energy Systems Integration Group (2019) recommended research to improve modeling of the relationships between power resource adequacy and the transmission and distribution system; distributed generation, demand response; energy efficiency innovations, storage, electric vehicle charging, and cogeneration. It also called for improvements in the quality of weather and climate data and forecasting for modeling power supply and demand and risks.

The Energy Systems Integration Group noted that modeling results will need to be better integrated into probabilistic tools for planning, outage scheduling, contingency assessments, unit commitment and dispatch, and real-time operations and control. It also recommended reconsidering the design of markets and the regulatory framework to increase incentives for an optimal mix of resources, based on cost efficiency, reliability, and other beneficial attributes as the share of renewable electric power increases toward 100 percent.

Changes will be needed in planning and management of the power transmission and distribution systems as distributed generation and demand-side participation scale up. Decentralization and digitization increase the number of participants in power generation and load response, making it difficult to maintain a command and control distribution system. The expert group observed that the planning process has begun to change for power transmission, but not so much for power distribution.

ANNEX A: COMMON POWER SECTOR TERMS

Active power: The electricity dissipated in a circuit that produces heat, light, or torque in a motor. Active power can be measured in watts or multiples of watts.

Advanced metering infrastructure (AMI): An integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.

Aggregation: Combining the capabilities of individual DER units to increase the cost effectiveness of the power system by meet size thresholds for market participation, reducing transaction costs, and increasing the ability to plan, control, dispatch, and use electricity effectively.

Alternating current (AC): A type of electricity that periodically changes direction, causing the voltage in a circuit to reverse. An *alternator* is a device that produces AC current. AC is commonly used in long-distance power transmission because it is less expensive to transport high-voltage electricity long distances and easy to reduce the voltage in a *transformer* for safer end uses.

Ancillary services: Services that support the generation, transmission and distribution, or usability of electric power. Ancillary services include various types of contingency, regulation, and flexibility reserves, such as black start, spinning reserves, nonspinning reserves, and voltage and frequency regulation.

Apparent power: Electricity used for inductive loads (sustaining a magnetic field). It is measured in kilovolt-amps (see power factor, reactive power, working power)

Battery energy storage systems (BESS): The use of batteries to store on-grid or off-grid electricity for later use. BESS can enhance grid operations when they would otherwise be unable to meet the quantity or quality of power demanded or the costs are relatively high.

Base load: Reliable electricity that is available from a power plant at all times of the day. Regulators have typically defined this to include generation from coal, natural gas, diesel, and nuclear power plants.

Base load power plants: Power generation facility providing base load power.

Behind-the-meter: Electric power generation, storage, or smart technologies at end user locations (see *front-of-the-meter*).

Black start: Process of restoring a power generating unit or part of an electric grid to operation to recover from a total or partial shutdown. Electricity for a black start must be provided without relying on the external transmission network.

Bulk power system: A large, interconnected system of power generation and transmission and their control systems, excluding local distribution. The effects of any bulk power system disruptions are experienced in multiple locations. Technologies for bulk power systems load following (ramping the supply of electricity up or down), resource adequacy, reactive power support, and system inertia response.

Cogeneration (combined heat and power): Generation of electricity from steam, heat, or other by-products of another industrial, commercial, or residential production process.

Demand response programs: Energy efficiency technologies and financial incentives to encourage or require electricity users to reduce power consumption during peak load periods or shift consumption to off-peak periods.

DER roadmap: A planning study, guidance document, or action plan that can help government planners and regulators, utilities, and other stakeholders make better decisions on distributed energy resource investment and use.

Direct current (DC): A type of electricity that only flows in one direction and produces a constant voltage. DC is produced in an AC generator that has a *commutator*. It can also be converted from AC in a *rectifier*. Batteries produce DC from chemical reactions.

Dispatchability: Ability to generate usable power from centralized facilities or DER at places and times that it can be sold on the grid.

Distributed generation: Decentralized production of electricity near the point of use, whether connected to a centralized distribution grid (mains), minigrid, or microgrid or only serving off-grid users. When connected, owners of distributed generation resources may be able to sell their surplus power or ancillary services to the grid. RE technologies are often well suited for distributed generation.

Distributed power technologies: Back-up electric power generation and storage capacity as well as smart technologies for inverters, grid management, and metering.

Distribution capacity: Technologies to increase the reliability of the quantity and quality of electricity provided. Distribution capacity technologies include voltage regulation, reactive power, and power flow control, and measures to improve power reliability.

Distribution generation: One or more electricity generating units in a nonbulk power system at a single location owned or operated by a distribution utility or other supplier.

Energy storage facility: One or more electricity storage units at a single location behind or in front of the meter. Various technologies can be used in energy storage facilities, including electric vehicle charging stations.

Frequency regulation: Technologies to balance the supply and demand for active power and control the number of cycles of alternating current per second. The frequency of AC power must be maintained within tight bounds for the grid operations.

Front-of-the-meter: Utility-scale power generation, storage, or smart grid technologies at centralized production, transmission, or distribution facilities (see *behind-the-meter*).

Generation capacity: The maximum output of electricity that a unit or multiple unit facility can produce under normal conditions. Capacity is measured in megawatts or kilowatts, depending on the size of the facility.

Inverter: A balance-of-system device that converts variable DC electricity from a PV or wind power system into AC that can be used locally or fed into the macrogrid. Inverters for PV and wind power systems should have anti-islanding protection to prevent injuries to utility workers from circuits powered by distributed generation when grid power is disconnected. They may also use maximum power point tracking to increase the efficiency of electricity generation under a variety of conditions (see alternating current, direct current, and *smart inverters*).

Levelized avoided cost of electricity (LACE): U.S. EIA (2019a) recommends this measure of the competitiveness of different electricity generation technologies. LACE is what it would cost to generate the electricity that would be displaced by a new generation project. Avoided cost is a proxy for the potential revenues from sale of the electricity. The avoided costs are summed over the project life and converted to a level annualized value that is then divided by average annual output. LACE accounts for both the variation in daily and seasonal electricity demand in the region and the characteristics of the existing generation fleet. The LACE-to-LCOE ratio may be even better for comparing the economic competitiveness of different technologies (see *levelized cost of energy*).

Levelized cost of energy (LCOE): The LCOE is the net present value of costs over the expected lifetime of a facility divided by the discounted projected production of electricity. The annual costs and electricity production are discounted to reflect the time value of money. The LCOE can also be described as the average revenue per unit of electricity generated needed to recover the capital and operating and maintenance costs plus the opportunity cost of money over the facility life. The LCOE is an imperfect measure for comparing generation technologies that produce power with different dispatchability, but it will become more valid with increasing use of energy storage to complement intermittent RE availability (see *levelized avoided cost of electricity*).

Load: The quantity of electricity demanded on a grid (large grid, minigrid, or microgrid) or set of interconnected grids at a particular time. Load can also refer to the active power requirements of an off-grid electricity user.

Load balancing (load matching or grid balancing): Various approaches to reduce costs by evening out the quantity of power demanded and the quantity supplied by the power grid. These approaches include energy storage at generation or transmission facilities and demand response programs.

Load following power plants: A power generation unit that can adjusts its output as the quantity of electricity demanded fluctuates over the course of a day. Load following power plants typically have an efficiency, speed of startup and shut down, capital cost, unit cost of electricity, and capacity factor of one in between that of base load and peaking power plants.

Load scheduling: Methods for managing the time of power use to reduce peak load requirements.

Macrogrid (large grid, the grid, network, or mains): A large, centralized power grid that may or may not be interconnected with a larger system of multiple grids.

Microgrid: The U.S. DOE defined a microgrid as a "group of interconnected loads and distributed energy resources within clearly defined boundaries that acts as a single controllable entity with respect to the grid." Under this definition, a microgrid has to be linked to a macrogrid. However, a microgrid may be able to operate in either a connected or disconnected (island) mode.

Minigrid: The World Bank defined minigrids as "isolated, small-scale distribution networks typically operating below 11 kilovolts (kV) that provide power to a localized group of customers and produce electricity from small generators, potentially coupled with energy storage system." Under this definition, a minigrid is not connected to a large power grid.

Nanogrid: Eller and Gantlett (2017) defined a nanogrid as "a small electrical domain connected to a grid of no greater than 100 kW and limited to a single building structure or primary load or a network of offgrid loads not exceeding 5 kW. Both categories represent devices (distributed generation, batteries, electric vehicles, and smart loads) capable of islanding and/or power self-sufficiency through intelligent DER management or controls." Although development assistance organizations have funded many nanogrids in developing countries, they are not counted in the Guidehouse Insights' Microgrid Deployment Tracker.

Nonspinning reserves: Power generation units that are usually kept offline because of relatively high operating costs but can ramped up within 10 minutes to meet peak loads (see *spinning reserves*).

Nonsynchronous power source: Wind and PV power can only be connected to an AC power grid after they pass through converters.

Nonwire alternatives (nonwires or nontransmission alternatives): Nontraditional transmission, distribution, and demand response approaches to defer or eliminate the need to upgrade transmission or distribution infrastructure. Examples include distributed generation, energy storage, energy efficiency, demand response, and grid software and controls.

Operating reserves: Generating capacity available to a system operator within a short period of time to meet the load when a generator goes down or there are other supply disruptions.

Peaking power plants: Generation units that can be brought online quickly to meet a sudden increase in the load.

Peak load (peak load contribution): Periods of time when the quantity of power demanded on the grid is relatively high.

Peak load penalty: Additional charges that electricity suppliers may impose on large commercial and industrial customers for periods of high use in addition to the regular charges based on the amount of electricity consumed during the billing period. The peak demand penalty will be higher if loads are not balanced (see *peak load pricing*).

Peak load pricing: A rate structure that includes higher rates for electricity during times of the day or seasons when the quantity of power demanded on the grid is relatively high (see *peak load penalty*).

Power factor: Measure of electricity use effectiveness. It is the ratio of working power for resistive loads (motion, heating, lighting) to apparent power for inductive loads (sustaining a magnetic field) and measured in kilowatts per kilovolt-amps. A high power factor benefits customers and utilities. A low power factor indicates poor electricity use (see *apparent power*, *reactive power*, and *working power*).

Power flow control: The transfer of electricity to different parts of the grid or to different systems.

Reactive power: Electricity used to sustain a magnetic field for an inductive load (a motor, compressor or ballast). This nonworking power is measured in kilovolt-amperes-reactive (see a*pparent power*, *power factor*, *reactive power*, and *reactive power correction*).

Reactive power factor correction: When the power factor for a specific customer falls below a minimum level (generally 0.9), some utilities charge a higher penalty rate for electricity per kilowatt. Some utilities or companies use a service to correct the power factor so that the customer can avoid the penalty rate.

Regulation and flexibility reserve requirements: Regulators may require grid operators to meet net load requirements over a certain time period (such as an hour) despite the variability of intermittent RE generation from hydro, PV, or wind power. Grid operators incur costs in buying power reserve power and may face constraints in its availability. Some power generators do not have the capacity to provide regulation reserves due to their operating practices or lack of equipment to follow a regulation signal.

Reserve capacity: A share of generation capacity that is kept as a margin to cover possible differences between the quantity of electricity supplied and the quantity demanded at a particular time. This extra capacity helps to maintain the reliability of the power system. It can be defined for a one macrogrid location or a larger, interconnected system.

Resource adequacy: A concept that there are adequate electricity resources available to serve demand for all scenarios except the most extreme ones.

Retail market: Direct sales of electricity to end users at relatively high prices.

Smart grids: Transmission and distribution grids that integrate advanced sensing and measurement technologies, information and communication technologies (ICTs), analytical and decision-making technologies, and automatic control technologies.

Smart inverters: Inverters that have a digital architecture, bidirectional communications capability, and robust software that allows them to be adaptive and send and receive granular data with the owner, utilities, and other stakeholders. Smart inverters allow installers and service technicians to diagnose operating and maintenance problems and remotely upgrade certain parameters when needed

Spinning reserves: Back-up power generation units that can be quickly ramped up to meet immediate load requirements on the grid (see *nonspinning reserves*).

Supervisory control and data acquisition (SCADA): SCADA systems for smart grids are computerized systems that gather and analyze real-time data to monitor and control power plant or transmission and distribution equipment over large geographic areas. They can control substations, feeder lines, and end user load.

Synchronization: Process of matching the speed and frequency of an AC power generator to an AC power grid. A DC power generator can be connected to the grid after the current voltage is adjusted to match the grid voltage by adjusting the speed or magnetic field (see *nonsynchronous power source* and *synchronous power source*).

Synchronous power source: Thermal power plants generate AC current and can be connected to an AC power grid without converters (see *nonsynchronous power source* and *synchronization*).

System inertia: The power system's ability to oppose changes in system frequency due to resistance provided by rotating masses.

Value stacking: The ability to provide multiple types of services for the power grid and obtain revenues from the various services.

Voltage regulation: Technologies to balance the supply and demand for reactive power.

Wholesale market: Electricity sales from generators to resellers at relatively low prices. Resellers may include vertically integrated utilities, transmission and distribution utilities, independent system operators, regional transmission organizations, and other intermediary companies

Working power: Electricity used for resistive loads (motion, heating, or lighting), measured in KW.

ANNEX B: RESOURCES AND TOOLS

USAID has supported various toolkits and information resources for the electric power system (https://www.usaid.gov/energy/toolkits). Examples include

- ClimateScope (BloombergNEF. 2019a);
- Renewable Energy Data Explorer (https://www.re-explorer.org/);
- Renewable energy auction toolkit (https://www.usaid.gov/sites/default/files/documents/1865/USAID_SURE_Designing-Solutions-System-Friendly-Renewable-Energy-Competitive-Procurement.pdf);
- Clean Energy Lending Toolkit in English, French, and Spanish for banks (https://www.climatelinks.org/resources/clean-energy-lending-toolkit);
- Electricity sector reform toolkit (http://www.energytoolbox.org/esr/);
- Energy efficiency toolkit (https://www.usaid.gov/energy/efficiency);
- Grid-connected RE generation toolkit (http://www.energytoolbox.org/gcre/);
- Grid integration toolkit (https://greeningthegrid.org/Grid-Integration-Toolkit/quick-reads); and
- Minigrids support toolkit (https://www.usaid.gov/energy/mini-grids/).

The Power Africa Toolbox included 160 tools to unlock obstacles facing private sector power deals in Sub-Saharan Africa. It includes resources from 12 USG agencies and 16 international development partners under six major categories: 1) Transaction assistance; 2) Finance; 3) Policy/regulatory design and reform; 4) Capacity building; 5) Legal assistance; and 6) Information resources (https://www.usaid.gov/energy/mini-grids/).

In 2020, USAID and the National Renewable Energy Laboratory (NREL) provided support for a Global Power System Transformation Consortium. This partnership will give USAID Missions streamlined access to technical support institutions and system operators to assist system operators and utilities in developing countries. The consortium can provide technical assistance and training, embedded advisors, fellowships with system operators in developed countries, joint applied research, and technical policy papers. USAID and NREL have also assessed the impact of covid-19 on long-term power sector transformation in India and Southeast Asia (Chaturvedi and Gaba 2020; Lowder, Lee, and Leisch 2020).

Maurer *et al.* (2020) discussed changes that may be needed in government policies; wholesale and retail market pricing regulations; and RE auction rules, procedures, and rate provisions in RE auctions to allow BESS to compete on level playing field with other DER technologies and nonrenewable electric power. In 2020, Power Africa provided support to the U.S. Department of Commerce Commercial Law Development Program for a handbook with international good practices for integrating BESS in African power systems. This handbook will describe the policies, regulations, and management guidelines for utility-scale and microgrid-scale energy storage systems.

E4TheFuture prepared a manual to compare the costs and benefits of single or multiple DERs and their alternatives. This cost-benefit analysis manual followed a jurisdictional regulatory perspective, but addressed impacts on the electric utility system, host customers, and society. It focused on EE, demand response, distributed generation, distributed storage, and increased electrification of buildings (Woolf *et al.* 2020).

Table B-1 lists some information resources, models, and software that may be useful in DER analysis and planning. Ringkjøb; Haugan; and Solbrekke (2018) reviewed 75 electricity and other energy models. IRENA (2017) provided guidance on models and tools for technical and economic analyses and scenario development for variable RE integration. The IRENA FlexTool can help developing countries conduct power system flexibility assessments for integrating RE on the grid. This free tool has been pilot tested in Colombia, Panama, Thailand, and Uruguay (Taibi *et al.* 2018). IRENA and the Clean Energy Ministerial began a multi-year activity to help governments by providing guidance on best practices and events and webinars to share information on preparing long-term energy planning scenarios (IRENA 2019).

In the U.S., the CPUC led the way in developing standard tools and approaches for distribution system planning and analysis that included EE and demand response. Pacific Power in Oregon piloted a screening tool to compare distributed solar, energy storage, and demand-side management as alternatives for upgrading transmission and distribution infrastructure (Baatz, Relf, and Nowak 2018).

HOMER Energy Ltd. (now part of Underwriters Laboratories) produces software for on- and off-grid electricity management that is commonly used by many U.S. utilities.[1] *HOMER* stands for Hybrid Optimization of Multiple Energy Resources. *HOMER Pro* is the global standard software for optimizing microgrids and distributed energy resources, ranging from village power systems to island utilities, and grid-connected campuses and military bases. *HOMER Grid* optimizes behind-the-meter distributed energy resources to minimize demand charges, model complex tariffs and time-of-use rates, and take advantage of self-consumption, energy arbitrage, and incentives.

HOMER Quick Start is free software for off-grid hybrid power systems. *HOMER Quick Grid* is a free web tool for understanding potential savings from demand charge reduction in behind-the-meter systems. HOMER SaaS Application Programming Interface allows users to develop their own web-based application with access to the components of HOMER Pro or HOMER Grid. A controller manages a microgrid's components to provide power in the most economical way. HOMER's products include a choice of controller algorithms and the flexibility to use an existing controller.

Grid LAB-D is a simulation tool for the design and operation of power transmission and distribution systems and for utility modeling of smart grid technologies, end-user device load behavior, three-phase unbalanced power flows, distributed automation, load management strategies, and retail markets (SourceForge 2020).

The Energy Web Foundation established the EW Chain -- a public blockchain to allow traceability in the electric power system and unlock grid flexibility from customer-owned DER. The EW Chain is one of the only public blockchains in any industry worldwide that relies on validator nodes run by major corporations. By the end of 2019, over 25 companies hosted its validator nodes in 15 countries. The Energy Web Foundation developed a Decentralized Operating System (EW-DOS) based on open-source software and standards to help ISOs and RTOs unlock the full potential of DER.

EW-DOS supports DER participation in electricity markets by assigning decentralized identifiers. These digital passports can facilitate coordination or aggregation of DER assets and enable them to participate in dual or multiple markets without duplicative compensation. The system provides rapid, end-to-end secure messaging for reliable communications between market participants and DER assets and payment settlement functionality based on metering data. It can support implementation of FERC Order 2222 (Morris 2020).

[1] https://www.homerenergy.com/products/index.html

TABLE B- 1. Information Resources, Models, and Software for DER Analysis and Planning

Type	Examples
Distributed solar forecasting and planning	Mills *et al.* (2016) Sterling *et al.* (2013)
Electric vehicle forecasting and planning	Shepard (2017)
Energy efficiency forecasting and planning	Mihlmester and Fine (2016) Neme and Grevatt (2015)
Environmental impacts	LEAP-IBC and WEAP (Stockholm Environment Institute 2019, 2020)
General DER and cost modeling	Blair, Getman, and Zhou (2015) CPUC (n.d.) Frew *et al.* (2017) Hale, Mai, and Stoll (2016) Midwest Independent System Operator (n.d.) NREL n.d. (a and b) Stoll *et al.* (2016) Taylor-Hochber (2017) Woolf et al. (2020)
Load and demand response forecasting and planning	Bonneville Power Administration (2017) Carvallo *et al.* (2016) Hong and Shahidehpour (2015) Interstate Renewable Energy Council (2018) Mills (2017) Satchwell and Hledik (2014)
Power generation	Power Development Planning Assistant Tool (PDPAT) Markal/Times LEAP-IBC (Stockholm Environment Institute 2019)
RE grid integration and off-grid management	IRENA Flex Tool (Taibi *et al.* 2018) HOMER (https://www.homerenergy.com/products/index.html)

TABLE B-1 (Continued)

Type	Examples
Transmission and distribution system and distributed generation planning software	Balmorel Open Source Energy Model (http://www.balmorel.com/) DigSILENT (https://www.digsilent.de/en/) Electric Vehicle Infrastructure Projection Tool, EVI-Pro (Wood, Rames, and Muratori 2018) Energy Web Decentralized Operating System (EW-DOS) (https://energyweb.org/wp-content/uploads/2019/12/EnergyWeb-EWDOS-VisionPurpose-vFinal-20200309.pdf) ETAP (https://etap.com/demo-download) Grid LAB-D (https://sourceforge.net/projects/gridlab-d/files/) Hitachi ABB E7 Power Grids (https://www.hitachiabb-powergrids.com/offering/product-and-system/enterprise) MATPOWER (https://matpower.org/doc) Milano (2019) Oncor Electric Vehicle Charging Planning Tool (https://www.sagewell.com/byoc-ev-load-management.html) OpenDSS Power Distribution System Simulator (https://www.epri.com/#/pages/sa/opendss?lang=en) Panda Power (https://www.pandapower.org) PDPAT (http://210.250.6.22/en/corpinfo/consultant/benefit/6-power-e.html) PLEXOS Market Simulation Software (https://energyexemplar.com/solutions/plexos/) PowerClerk (https://www.cleanpower.com/products/powerclerk/) Smarter Grid Solutions (2018) WattPlan Grid (https://www.cleanpower.com/products/wattplan/grid/)

The Stockholm Environment Institute developed the Long-range Energy Alternatives Planning (LEAP) model to help planners estimate energy consumption, production, and resource extraction in the major sectors of an economy under various scenarios and the resulting emissions of air pollutants and greenhouse gases. It was not designed for operations planning for power generation or transmission and distribution utilities. The LEAP model has been used in analyses or trainings in over190 countries.

LEAP includes a technology and environmental database that describes the characteristics, costs, and environmental impacts of a range of energy technologies including quantitative and qualitative data on commercially available and emerging technologies. The current version also accounts for land use changes in various areas within a country, as well as the impacts on deforestation and forest degradation, woodfuel use, agricultural expansion, and land productivity. LEAP can also be integrated with the Stockholm Environment Institute's Water Evaluation and Planning (WEAP) model. LEAP is free to not-for-profit government agencies, NGOs, and academic institutions and students in low and lower-middle income countries.[2]

The latest version, LEAP-IBC, was developed in collaboration with the U.S. Environmental Protection Agency and University of Colorado, with support from the Climate and Clean Air Coalition. It combines emission projections with a global atmospheric chemistry transport model and exposure-response functions for premature deaths and crop losses from pollution. Approximately 32 countries have used LEAP to create energy and emissions scenarios for their Intended Nationally Determined Contributions for the U.N. Framework Convention on Climate Change. Twelve countries have used LEAP-IBC in national planning for action on short-lived climate pollutants (Stockholm Environment Institute 2019).

Energy Systems Integration Group (2019) recommended research to improve modeling of the relationships between power resource adequacy and the transmission and distribution system; distributed generation, demand response; energy efficiency innovations, storage, electric vehicle charging, and cogeneration. It also called for improvements in the quality of weather and climate data and forecasting for modeling power supply and demand and risks.

The Energy Systems Integration Group noted that modeling results will need to be better integrated into probabilistic tools for planning, outage scheduling, contingency assessments, unit commitment and dispatch, and real-time operations and control. It also recommended reconsidering the design of markets and the regulatory framework to increase incentives for an optimal mix of resources, based on cost efficiency, reliability, and other beneficial attributes as the share of renewable electric power increases toward 100 percent.

Changes will be needed in planning and management of the power transmission and distribution systems as distributed generation and demand-side participation scale up. Decentralization and digitization increase the number of participants in power generation and load response, making it difficult to maintain a command and control distribution system. The expert group observed that the planning process has begun to change for power transmission, but not so much for power distribution.

Synchronization is the process of matching the speed and frequency of an alternating current (AC) power generator to an AC power grid. A DC power generator can be connected to an AC power grid after the voltage is adjusted to match the grid voltage by adjusting the speed or magnetic field. Thermal power plants are a *synchronous source*. Wind and PV power are *nonsynchronous sources* that can only be connected to the power grid after they pass through converters. Some modern load sources are also nonsynchronous.

The Energy Systems Integration Group expected that the existing AC power system will remain over the short to medium term, with expanded use of grid-forming power electronic converters or synchronous condensers. However, it raised questions about the appropriate, long-term balance between AC and DC applications and how they can be planned and operated together or transitioned to a DC-based system.

EVN has used the PLEXOS, PROMOD, and Power System Simulation for Engineers models in previous operational and transmission planning. The GoV used generation capacity expansion models, such as Strategist and Balmorel, in PDP-7. It will need to replace Strategist with the improved version, Capacity Expansion (New Strategist). Table B-2 contains V-LEEP observations on potential models for PDP-8.

---

[2] The LEAP model and training resources are available at www.energycommunity.org. The WEAP model can be downloaded at https://www.weap21.org/

TABLE B- 2. V-LEEP Observations on Potential Models for PDP-8

Model	Applicability to Vietnam Power Development Planning
ABB E7	• Provides capabilities to model cascading hydro systems at both long and short timeframes • Custom hydro generator efficiency, maximum capacity and minimum capacity as a function of storage level is not available • PROMOD HD has the capability to model nodal transmission systems. Limitations from PROMOD IV in this regard should have been upgraded • Energy and reserves are fully co-optimized, also an upgrade from PROMOD IV • PROMOD HD has the capability to model a range of power markets, including power pools
PLEXOS	• PLEXOS has a detailed and sophisticated hydro modeling methodology, including cascading hydro over long term and short-term timeframes, as well as stochastic hydro modeling • PLEXOS models generator efficiency as a function of storage level • PLEXOS fully models nodal transmission networks and computes nodal prices reflecting energy, loss, and congestion prices. N-1 or custom-defined contingencies are modeled. • Energy and reserves are fully co-optimized • PLEXOS has the capability to model a range of power markets, including power pools and nodal energy markets, and in addition has several pre-defined market structures that simulate generator bidding behavior, and which can also be customized. • PLEXOS has significant gas pipeline (and fuel delivery) capabilities
Balmorel	• Balmorel models long term hydro capacity expansion; however, custom constraints in the General Algebraic Modeling System (GAMS) modeling language would need to be added (and tested/validated) for detailed cascade hydro modeling • Custom generator efficiency as a function of storage level is not available but could be added (and tested/validated). This essentially becomes a software/model development exercise, along with associated software debugging and testing. Given the time frame for the PDP study, time for software development is unrealistic. • Operational reserves are not modeled, though custom constraints in GAMS could be added. There is an existing add-on unit commitment module that was developed by an academic institution, but technical support is likely not available. This module has likely undergone little use and testing, compared to other models. • It appears that Balmorel models only zonal power systems, with zonal prices set by marginal units. Nodal transmission constraints cannot be represented. • Balmorel has no capability to model a real-world power market.
PDPAT	• PDPAT does model hydro generation, but does not appear to have the ability to model cascaded hydro generation • It is not known if hydro generation efficiency is modeled, and no documentation on the hydro modeling in English is available • PDPAT models zonal rather than nodal systems • Reserves are modeled, but they are not part of the optimization. Reserves are not cooptimized • Given the structure of the Japanese market, it is likely that PDPAT primarily focuses on modeling fully integrated generation, transmission, and distribution systems • There does not appear to be any capability to model power markets
Markal/Times	• MARKAL/TIMES models hydro systems at a relatively high level, with limited detail as cascade hydro or generator efficiency • MARKAL/TIMES does not model nodal transmission networks. • Detailed reserve co-optimization with energy is not modeled • Power markets are not represented

Source: Deloitte Consulting 2019a

ANNEX C: RELATED CEADIR WORK

CEADIR analyzed experiences with RE reverse auctions in six countries, focusing on the policy and regulatory environment, characteristics and results of the auctions, and financing of winning bids. That report was based on interviews with investors and representatives of financial institutions and governmental entities in El Salvador, Mexico, and Peru and secondary information on Brazil, India, and South Africa (Molina, Scharen-Guivel, and Hyman 2018).

In a separate report, CEADIR interviewed developers and investors who participated in the 2017 RE auctions in Thailand and Malaysia. That report assessed the cost-effectiveness of these auctions in mobilizing private investment and finance and participant perceptions and recommendations for improving future auctions. The recommendations focused on 1) achieving government objectives for energy reliability and security; 2) addressing grid access and interconnection challenges; 3) improving transparency in the bidding process; 4) promoting improved technologies, innovation, and sustainability; 5) increasing financial incentives; 6) expanding foreign investment to expand the market for larger-scale RE projects; and 7) addressing post-award requirements (O'Mealy, Sangarasri *et al.* 2020).

CEADIR hosted a Renewable Energy and Smart Grid Suppliers Forum to engage U.S. firms interested in beginning or expanding business in developing country markets on May 1, 2018. The forum focused on sales of equipment and services for utility-scale wind and solar power, smart transmission and distribution, related information and communication technologies (ICTs), demand-response tools, and energy storage. It also focused on provision of technical services for utility and grid planning, reverse auctions, grid integration of variable RE, and RE zones. The forum engaged 71 participants from U.S. companies, trade associations, nongovernmental organizations, and USG agencies.[3]

The forum report highlighted recommendations and insights from private sector leaders that have successfully expanded sales of RE, smart grids, and energy storage products and services in developing countries. It also identified the types of assistance and support offered by USG agencies to help U.S. firms assess market opportunities and enter or increase sales in developing countries (Enriquez *et al.* 2018).

On March 7, 2019, a CEADIR webinar addressed opportunities for U.S. suppliers of smart grid and minigrid technologies in Africa. This webinar included speakers from the West Africa Power Pool; GRIDCo (a utility in Ghana); PowerGen Renewable Energy (a company in Kenya); the USG's Power Africa Initiative, U.S. Department of Commerce's International Trade Administration, and U.S. Trade and Development Agency.[4]

On March 12, 2019, CEADIR convened a forum on opportunities for U.S. smart grid, mini-grid, and energy storage suppliers and sources of financing. This forum focused on:

1. Emerging markets in Africa, Asia, and Latin America for smart grid, mini-grid, and energy storage products and services;

[3] The presentations are available at https://www.climatelinks.org/content/renewable-energy-and-smart-grid-suppliers-forum-emerging-market-opportunities-us-firms
[4] These presentations are available at https://dec.usaid.gov/dec/GetDoc.axd?ctID=ODVhZjk4NWQtM2YyMi00YjRmLTkxNjktZTcxMjM2NDBmY2Uy&pID=NTYw&attchmnt=VHJ1ZQ==&rID=NTIyNDA5

2. Business models to overcome barriers in emerging markets for expanding sales and investment;
3. Strategies and opportunities for U.S. suppliers of technologies, services, and financing; and
4. Available U.S. Government assistance for American and developing country companies.

This forum engaged 117 participants from U.S. companies and USG agencies. The forum report highlighted recommendations and insights from private sector leaders that have successfully deployed smart grid, mini-grid, and energy storage technology products and services in developing countries. It also identified the types of assistance and support offered by USG agencies to help U.S. firms assess market opportunities and enter or increase sales in developing countries (O'Mealy, Bauer, *et al.* 2020).[5]

Parametric insurance can help RE generators reduce the financial risks from insufficient resource availability. However, parametric insurance is a relatively new product that may only be feasible for hydropower and large-scale PV or wind power generators (Enríquez *et al.* 2020).

CEADIR has also prepared a report on creating a level playing field for utility-scale BESS in the policy and regulatory environment and RE auctions (Maurer *et al.* 2020).

[5] The forum presentations are available at: https://dec.usaid.gov/dec/GetDoc.axd?ctID=ODVhZjk4NWQtM2YyMi00YjRmLTkxNjktZTcxMjM2NDBmY2Uy&pID=NTYw&attchmnt=VHJ1ZQ==&rID=NTIyNDEz. Other CEADIR webinars on renewable energy and energy efficiency technologies, policies, and financing can be found at https://www.climatelinks.org/project/ceadir-series-navigating-climate-economy

REFERENCES

Agarwal, Umesh, and Naveen Jain. 2019. "Distributed Energy Resources and Supportive Methodologies for their Optimal Planning under Modern Distribution Network: A Review." *Technology and Economics of Smart Grids and Sustainable Energy* 4(1): 1-21. https://link.springer.com/article/10.1007/s40866-019-0060-6

Alstone, Peter; Jennifer Potter; Mary Piette; Peter Schwartz; Michael Berger; Laurel Dunn; Sarah Smith; Michael Sohn; Arian Aghajanzadeh; Sofia Stensson; Julia Szinai; Travis Walter *et al.* 2016. *Final Report on Phase 2 Results: 2015 California Demand Response Potential Study.*

Aranda, Daniel; Jeffery Atkin; and John Eliason; 2020. "New Policy on the Reliability of the National Electrical System (NES) in Mexico." National Law Review, 10 (144), May 23. https://www.natlawreview.com/article/new-policy-reliability-national-electrical-system-nes-mexico

Baatz, Brendon; Grace Relf; and Seth Nowak. 2018. "*The Role of Energy Efficiency in a Distributed Energy Economy*. Washington, DC: American Council for an Energy Efficient Economy, Report U1802. https://www.aceee.org/sites/default/files/publications/researchreports/u1802.pdf

Belur, Raghu. 2014. "What Is a Smart Solar Inverter?" *SolarPowerWorld*, January 10. https://www.solarpowerworldonline.com/2014/01/smart-solar-inverter/

Blair, Nate; Dan Getman; and Ella Zhou. 2015. *Electricity Capacity Expansion Modeling, Analysis and Visualization: A Summary of Selected High-Renewable Modeling Experiences*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy16osti/64831.pdf.k

Blanc, Pauline; Marzia Zafar; Jean Levy; and Prachi Gupta. 2020. Five Steps to Energy Storage: *Innovation Insights Brief*. London: World Energy Council and California Independent System Operator. https://www.worldenergy.org/publications/entry/innovation-insights-brief-five-steps-to-energy-storage

BloombergNEF. 2019a. *Climatescope: Emerging Markets 2019. Energy Transition in the World's Fastest Growing Economies*. London: BloombergNEF. Prepared for UK Aid. http://global-climatescope.org/assets/data/reports/climatescope-2019-report-en.pdf

———.2019b. "Battery Power's Latest Plunge in Costs Threatens Coal, Gas." *BloombergNEF Blog*, June 19. https://www.bloomberg.com/professional/blog/battery-powers-latest-plunge-costs-threatens-coal-gas/.

———.2020. *Electric Vehicle Outlook 2020*. https://bnef.turtl.co/story/evo-2020/?teaser=yes

———. n.d. "Vietnam: Clean Energy Investment." *Global Climatescope*. http://global-climatescope.org/results/VN#clean-energy-investment

Bnamericas. 2020. "Colombia Presents Recommendations for 'Energy Transformation' Plan." *Bnamericas*. January 29. https ://www.bnamericas.com/en/news/colombia-presents-recommendations-for-energy-transformation-plan

Bolduc, April; Mark Von Weihe; Jordan Smith; Skip Dise; Mohammad Alam; Erika Myers; Rusty Haynes; and Peter Toporkov. 2020. Utility Best Practices for EV Infrastructure Development. Washington, DC: Smart Electric Power Alliance. https://sepapower.org/knowledge/sepa-report-provides-utility-roadmap-to-ev-infrastructure-success/

Bonneville Power Administration. n.d. "Energy Efficiency Demand Response." Portland, OR: Bonneville Power Administration. https://www.bpa.gov/EE/Technology/demand-response/Pages/Demand%20Response.aspx

———. 2017. *BPA Distributed Energy Resource Benchmarking Report*. Portland, OR: Bonneville Power Administration (BPA). https://www.bpa.gov/EE/Technology/demand-response/Documents/2017_Distributed_Energy_Resources_Benchmarking_Report.pdf.

Bowen, Thomas; Ilya Chernyakhovskiy; and Paul Denholm. 2019. *Grid-Scale Battery Storage Frequently Asked Questions.* Golden, CO: National Renewable Energy Laboratory, Prepared for USAID. https://www.nrel.gov/docs/fy19osti/74426.pdf

Bowman, Michelle. 2019. "EIA Projects That Renewables Will Provide Nearly Half of World Electricity by 2050." *Today in Energy*, October 2. U.S. EIA. https://www.eia.gov/todayinenergy/detail.php?id=41533.

Breu, Marco; Antonio Castellano; David Frankel; and Matt Rogers. 2019. "Exploring an Alternative Pathway for Vietnam's Energy Future." *McKinsey & Company Featured Insights*. January 23. https://www.mckinsey.com/featured-insights/asia-pacific/exploring-an-alternative-pathway-for-vietnams-energy-future

Brown, Alex. 2020. "Electric Cars Will Challenge State Power Grid." *Washington Post*, January 27. https://www.washingtonpost.com/science/electric-cars-will-challenge-state-power-grids/2020/01/24/136a2a30-32e6-11ea-a053-dc6d944ba776_story.html

Bruce, S.; M. Temminghoff; J. Hayward; E. Schmidt; C. Munnings; D. Palfreyman; and D. Hartley. 2018. National Hydrogen Roadmap. Canberra, Australia: Commonwealth Scientific and Industrial Research Organisation.

Cadena, Ángela and Daniel Muñoz-Álvarez. 2020. *Report 2 of the Consultancy to Define the Scope of the Mission of Energy Transformation and Modernization of the Electric Industry: Road Map for the Energy of the Future*. Washington, DC: Inter-American Development Bank, Prepared for the Colombia Ministry of Mines and Energy. https ://www.minenergia.gov.co/documents/10192/24126247/Report+2+Mission+Transformation+-+English+%281%29.pdf

CAISO, Pacific Gas and Electric, Southern California Edison, San Diego Gas & Electric, and More Than Smart,. 2017. *Coordination of Transmission and Distribution Operations in a High Distributed Energy Resource Electric Grid*. Folsom, CA: California Independent System Operator. http://www.caiso.com/Documents/MoreThanSmartReport-CoordinatingTransmission_DistributionGridOperations.pdf

Capehart, Barney. 2016. *Distributed Energy Resources (DER)*. Washington, DC: National Institute of Building Sciences. https://www.wbdg.org/resources/distributed-energy-resources-der

Carvallo, Juan Pablo; Charles Goldman; Peter Larsen; and Alan Sanstad. 2016. *Load Forecasting in Electric Utility Integrated Resource Planning*. Berkeley, CA: Lawrence Berkeley National Laboratory. https://emp.lbl.gov/publications/load-forecasting-electric-utility.

Casey, Tina. 2020. "Off-the-Radar Renewable Energy Explosion After Covid-19 Dust Settles – CleanTechnica Interview." CleanTechnica. March 28. https://cleantechnica.com/2020/03/28/off-the-radar-renewable-energy-explosion-after-covid-19-dust-settles-ct-exclusive-background-interview/

Castro-Alvarez, Fernando; Hannah Bastian; Jen King; and Shruti Vaidyanathan. 2018. *The 2018 International Energy Efficiency Scorecard*. Washington, DC: American Council for an Energy-Efficient Economy. https://www.aceee.org/sites/default/files/publications/researchreports/i1801.pdf

Chacon, Daniel. 2018. *Solving Mexico's Electricity Subsidy and Energy Poverty Granting Solar Bonuses for PV Solar Rooftops*. Mexico City: Iniciativa Climática de México. http://www.iniciativaclimatica.org/solving-mexicos-electricity-subsidy-and-energy-poverty-granting-solar-bonuses-for-pv-solar-rooftops/

Chanona-Robles, Alejandro. 2016. *Tracking the Progress of Mexico's Power Sector Reform*. Washington, DC: Wilson Center Mexico Institute. https://www.wilsoncenter.org/sites/default/files/media/documents/publication/tracking_progress_of_mexicos_power_sector_reform.pdf

Chaturvedi, Apurva and Vikas Gaba. 2020. Impact of Covid-19 on the Indian Power Sector. Washington, DC: USAID and KPMG Advisory Services. https://pdf.usaid.gov/pdf_docs/PA00WHT7.pdf

Chew, Brenda; Erika Myers; Tiger Adolf; and Ed Thomas. 2018. *Non-Wires Alternatives: Case Studies from Leading U.S. Projects*. Washington, DC: Smart Electric Power Alliance, PLMA, and E4TheFuture. https://e4thefuture.org/wp-content/uploads/2018/11/2018-Non-Wires-Alternatives-Report_FINAL.pdf

Colman, Andy; Daisy Chung; and Dan Wilson. 2017. *Beyond the Meter: Planning the Distributed Energy Future, Volume I: Emerging Electric Utility Distribution Planning Practices for Distributed Energy Resources*. Washington, DC: Black & Veatch and Smart Electric Power Alliance. https://sepapower.org/resource/beyond-the-meter-planning-the-distributed-energy-future-volume-i/

Colthorpe, Andy. 2019a. "California Offers Extra Solar, Storage Incentives after Wildfires and Shut-Offs." *Energy Storage News*, October 28. https://www.energy-storage.news/news/california-offers-storage-incentives-after-wildfires-and-shut-offs

———. 2019b. "New DOE Framework Puts Energy Storage at Heart of Philippines' Energy Reforms." *Energy Storage News*, April 3. https://www.energy-storage.news/news/new-doe-framework-puts-energy-storage-at-heart-of-philippines-energy-reform

Cong, Vu Tan. 2019b. "Preparing Legal Framework for the Future of Electric Vehicles." Vietnam Investment Review, December 20. https://www.vir.com.vn/preparing-legal-framework-for-the-future-of-electric-vehicles-72609.html

Converge Strategies. 2019. *The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices*. Washington, DC: Converge Strategies, Prepared for the U.S. Department of Energy. https://pubs.naruc.org/pub/531AD059-9CC0-BAF6-127B-99BCB5F02198

Cook, Jeffrey; Kristen Ardani; Robert Margolis; Eric O'Shaughnessy; and Brittany Smith. 2018. *Expanding PV Value: Lessons Learned from Utility-led Distributed Energy Resource Aggregation in the United States*. Golden, CO: National Renewable Energy Laboratory. https://www.osti.gov/biblio/1483067-expanding-pv-value-lessons-learned-from-utility-led-distributed-energy-resource-aggregation-united-states

CPUC. 2017a. *California's Distributed Energy Resources Action Plan*: Aligning Vision and Action. San Francisco: California Public Utilities Commission. https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Commissioners/Michael_J._Picker/DER%20Action%20Plan%20(5-3-17)%20CLEAN.pdf

———. 2017b. *Final Vehicle Grid Integration (VGI) Glossary of Terms*. San Francisco: California Public Utilities Commission. https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442455744

———. 2018. *Energy Efficiency Portfolio Report*. San Francisco: California Public Utilities Commission. https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442459323

———. n.d. *Guide to Production Cost Modeling in the Integrated Resource Plan Proceeding*. San Francisco: California Public Utilities Commission. http://cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442455821.

———. 2020. *Transportation Electrification Framework: Energy Division Staff Proposal.* San Francisco: California Public Utilities Commission. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M326/K281/326281940.PDF

CREG. 2018a. *Agenda Regulatoria Indicativa 2019*. Bogotá: Comisión de Regulación de Energía y Gas http://www.creg.gov.co/sites/default/files/documento_agenda_regulatoria_indicativa_2019.pdf

———. 2018b. *Consultoría Para el Análisis de los Servicios Complementarios Para el Sistema Interconectado Nacional (SIN). Informe Final*. Bogotá: Comisión de Regulación de Energía y Gas.

———. 2018c. *Consultoría Para el Estudio Para la Modernización del Despacho y el Mercado Spot de Energía Eléctrica – Despacho Vinculante y Mercados Intradiarios. Informe Final.* Bogotá: Comisión de Regulación de Energía y Gas.

Davar, Zoheb. 2020. "The Path to a Vehicle-to-Grid Future." Washington, DC: Smart Electric Power Alliance. https://sepapower.org/knowledge/the-path-to-a-vehicle-to-grid-future/

DeAngelo, Michael; Mark Avangrid; Steve Fine, Richard Barone; and Erik Gilbert. 2018. "Non-Wires Alternatives Lessons and Insights from the Front Lines." Discussion at the 36th PLMA Conference, Cambridge, MA, November.

Deloitte Consulting. 2019a. *Assessment and Recommendations on Methodology for Power Development Plan (PDP)*. New York: Deloitte Consulting, Prepared for USAID-funded Vietnam Low Emission Energy Program (V-LEEP). https://pdf.usaid.gov/pdf_docs/PA00WFR3.pdf

Deloitte Consulting. 2019b. Vietnam Low Emission Energy Program (V-LEEP) *Technical Report: Energy Storage Study (Consolidated)*. New York: Deloitte Consulting, Prepared for USAID. https://pdf.usaid.gov/pdf_docs/PA00WFR7.pdf

De Martini, Paul, ed. 2014. *More than Smart: A Framework to Make the Distribution Grid More Open, Efficient and Resilient*. Sacramento, CA: Greentech Leadership Group. https://gridarchitecture.pnnl.gov/media/white-papers/More-Than-Smart-Report-by-GTLG-and-Caltech.pdf

———. 2016. *Integrated Distribution Planning*. Fairfax, VA: ICF International, Prepared for the Minnesota Public Utilities Commission. https://www.energy.gov/sites/prod/files/2016/09/f33/DOE%20MPUC%20Integrated%20Distribution%20Planning%208312016.pdf

De Martini, Paul and Lorenzo Kristov. 2015. *Distributed Systems in a High Distributed Energy Resources Future*. Washington, DC: Lawrence Berkeley National Laboratory, Report No. 2. https://emp.lbl.gov/sites/default/files/lbnl-1003797.pdf

Deora, Tanuj; Vazken Kassakhian; Lisa Frantzis; and Coley Girouard. 2017. *Beyond the Meter: Recommended Reading for a Modern Grid*. Washington, DC: Smart Electric Power Alliance, AEE Institute, and the Rocky Mountain Institute. https://info.aee.net/hubfs/PDF/SEPA_AEE_RMI__BTM-Recommended.pdf

Do, Thang Nam. 2020. "Vietnam's Big Air Pollution Challenge: Bold Action is Needed to Address the Country's Problem." The Diplomat. March 30. https://thediplomat.com/2020/03/vietnams-big-air-pollution-challenge/

Doetsch, Christina and Jens Burfeind. 2016. "Vanadium Redox Flow Batteries." In *Storing Energy With Special Reference to Renewable Energy Sources, edited by Trevor Letcher*. Amsterdam: Elsevier. info:1fSw0yVikpMJ:scholar.google.com

Duke Energy. 2018. "Duke Energy to Invest $500 Million in Battery Storage in the Carolinas Over the Next 15 Years." Press release, October 10. https://news.duke-energy.com/releases/duke-energy-to-invest-500-million-in-battery-storage-in-the-carolinas-over-the-next-15-years

Economist. 2020. "Vietnam Grapples with an Unexpected Surge in Solar Power." *The Economist*, January 25. https://www.economist.com/asia/2020/01/25/vietnam-grapples-with-an-unexpected-surge-in-solar-power

Electrical Engineering Department, University of California at Riverside. n.d. *The Future of Smart Grid Technologies*. Riverside, CA: Electrical Engineering Department, University of California at Riverside. https://engineeringonline.ucr.edu/blog/the-future-of-smart-grid-technologies/

Eller, Alex and Dexter Gantlett. 2017. *Energy Storage Trends and Opportunities in Emerging Markets*. Chicago: Navigant Research, Prepared for the International Finance Corporation and World Bank Energy Sector Management Assistance Program. https://www.esmap.org/sites/default/files/esmap-files/7151-IFC-EnergyStorage-report.pdf

Endemann, Buck; Kimberly Frank; Elias Hinckley; and Patrick Metz. 2020. "FERC Issues Landmark Order No. 2222 to Facilitate the Participation of Distributed Energy Resources In Wholesale Markets." *National Law Review*, October 27. 10(301). https://www.natlawreview.com/article/ferc-issues-landmark-order-no-2222-to-facilitate-participation-distributed-energy

Energy Storage Association. 2013. "Frequency Regulation." *ESA Blog*, October 24. https://energystorage.org/frequency-regulation/

———. 2017. *25x35: A Vision for Energy Storage*. Washington, DC: Energy Storage Association. https://energystorage.org/wp/wp-content/uploads/2019/06/esa_vision_2025_final.pdf

Energy Systems Integration Group. 2019. Toward 100% Renewable Energy Pathways: Key Research Needs. Reston, VA: Energy Systems Integration Group. https://www.esig.energy/esig-releases-toward-100-renewable-energy-pathways-key-research-needs-report/

EnergyWatch, Inc. n.d. *Peak Load Management: How to Fully Capture the Value of Peak Load Management.* New York: EnergyWatch, Inc.,

Enríquez, Santiago; Eric Hyman; Matthew Ogonowski; José Castro; Enrique Rebolledo; Carlos Muñoz, Gwendolyn Andersen; and Itzá Castañeda. 2016. *Mexico Energy Efficiency Assessment for Greenhouse Gas Emissions Mitigation*. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

Enriquez, Santiago; Mikell O'Mealy; Eric Hyman; Matthew Ogonowski; and Pablo Torres. 2018. *Renewable Energy and Smart Grid Suppliers Forum: Emerging Opportunities for U.S. Firms*. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID. https://pdf.usaid.gov/pdf_docs/PA00TJ54.pdf

Enríquez, Santiago; Eric Hyman; Leonardo Ramírez-Leiva; Eduardo Reyes; Luis Miguel Cardona; and Carlos González-Rivera. 2020. *Parametric Insurance for Renewable Electric Power Producers in Central America.* Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

EPRI. 2015. Contributions of Supply and Demand Resources to Required Power System Reliability Services. Palo Alto, CA: Electric Power Research Institute.

———. 2016. *Time and Locational Value of DER: Methods and Applications.* Palo Alto, CA: Electric Power Research Institute.

———. 2018. *Developing a Framework for Integrated Energy Network Planning (IEN-P): 10 Key Challenges for Future Electric System Resource Planning*. Palo Alto, CA: Electric Power Research Institute. http://integratedenergynetwork.com/wp-content/uploads/2018/07/3002010821_IEN-P_White_Paper.pdf

FCHEA. 2020. *Road Map to a U.S. Economy: Reducing Emissions and Driving Growth Across the Nation*. Washington, DC: Fuel Cell & Hydrogen Energy Association, https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+US+Hydrogen+Economy+Full+Report.pdf

Feldman, Brett. 2017. "Non-Wires Alternatives: What's Up Next in Utility Business Model Evolution." *Utility Dive Opinion*, July 12. https://www.utilitydive.com/news/non-wires-alternatives-whats-up-next-in-utility-business-model-evolution/446933/

Fields, Spencer. 2019. "Black Start: Why It Matters." *EnergySage*, February 7. https://news.energysage.com/black-start-why-it-matters/

Finn-Foley, Dan. 2020. *Energy Storage: Eligibility Transitions to Opportunity*. Edinburgh: Wood Mackenzie.

Fitzgerald, Garrett; Chris Nelder; and James Newcomb. 2017. *Electric Vehicles as Distributed Energy Resources*. Boulder, CO: Electricity Innovation Lab, Rocky Mountain Institute. https://rmi.org/wp-content/uploads/2017/04/RMI_Electric_Vehicles_as_DERs_Final_V2.pdf

Flowers, Simon. 2020. "Future Energy – Green Hydrogen: Could it be a Pillar of Decarbonisation." Wood Mackenzie Edge. February 4. https://www.woodmac.com/news/the-edge/future-energy-green-hydrogen/

Fresh Energy Consulting. 2019. *Implicaciones de la Cancelación de la Primera Subasta de Largo Plazo de 2018*. Mexico City: Plataforma México Clima y Energía. https://34ecec20-bbba-4ccc-9ddc-36880a0d254f.filesusr.com/ugd/72f3e0_8c9633160dc04ab0becb34827b1052de.pdf

Frew, Bethany; Wesley Cole; Trieu Mai; James Richards; and Yinong Sun. 2017. *8760-Based Method for Representing Variable Generation Capacity Value in Capacity Expansion Models*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy17osti/68869.pdf.

Fu, Ran; Robert Margolis; and Timothy Remo. 2018. *2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy19osti/71714.pdf

Gagne, Douglas; Eduard Settle; Alexandra Aznar; and Riccardo Bracho. 2018. *Demand Response Compensation Methodologies: Case Studies for Mexico*. Golden, CO: National Renewable Energy Laboratory, Prepared for GiZ. https://www.nrel.gov/docs/fy18osti/71431.pdf

Garcia, Marie and Olin Bray. 1997. *Fundamentals of Technology Roadmapping*. Albuquerque, NM: Sandia National Laboratories. https://pdfs.semanticscholar.org/e257/8014eb910090ac3dd575772ab18157f3e273.pdf

Garcia-Fariña, Mercedes. 2017. *Mercado de Energía Fotovoltaíca de Baja Escala. Generación Distribuida.* Mexico City: Asociación de Bancos de México and Iniciativa Climática de México. http://www.iniciativaclimatica.org/wp-content/uploads/2017/12/Estudio_MercadoEnergi%CC%81aFotovoltaicaBajaEscala_2017.pdf

Glanzman, Joe. 2019. "Behind-the-Meter Generation: Is It for You?" Chicago: *AEP Energy Customer Insights*. https://www.aepenergy.com/2019/07/25/behind-the-meter-generation-is-it-for-you/

Gorner, Marine and Jacob Teeter. 2020. Tracking Report: Electric Vehicles June 2020. Paris: International Energy Agency. https://www.luxresearchinc.com/the-electric-vehicle-inflection-tracker-2020-edition

Government of Mexico. 2013. *Reforma Energética: Resumen Ejecutivo*. Mexico City: Government of Mexico. https://www.gob.mx/cms/uploads/attachment/file/164370/Resumen_de_la_explicacion_de_la_Reforma_Energetica11_1_.pdf

Government of Vietnam. 2012. *Viet Nam National Green Growth Strategy*. Hanoi: Government of Vietnam. https://www.giz.de/en/downloads/VietNam-GreenGrowth-Strategy.pdf

———. 2018. *Intended Nationally Determined Contribution of Vietnam*. Hanoi: Government of Vietnam. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Viet%20Nam%20First/VIETNAM%27S%20INDC.pdf

———. 2019. *Decision on the Approval of Rooftop Solar PV Promotion Program*. Hanoi: Government of Vietnam. http://vepg.vn/wp-content/uploads/2019/07/2023_QD_BCT_Rooftop_Solar_EN.pdf

Institute of Electrical and Electronics Engineers Power and Energy Society. Open data sets for power consumption, electric vehicles, power quality, PV generation, power reliability, weather, wind-based generation, and general energy data. https://site.ieee.org/pes-iss/data-sets/

Gridworks. 2019. "Vehicle-Grid Integration Initiative." PowerPoint presented at Vehicle Grid Integration Initiative meeting, April 19. https://gridworks.org/wp-content/uploads/2019/05/VGI_4.12-Slides.pdf

Hale, Elaine; Trieu Mai; and Brady Stoll. 2016. "Capacity Expansion Modeling for Storage Technologies." NREL presentation at the INFORMS Annual Meeting in Nashville, TN, November 13. https://www.nrel.gov/docs/fy17osti/67532.pdf.

Grundy, Alice. 2020. "Approved: 5 MWH Vanadium Batteries for Energy Superhub Oxford Showcase in England." *Energy Storage News,* March 11. https://www.energy-storage.news/news/approved-5mwh-vanadium-batteries-for-energy-superhub-oxford-showcase-in-eng

Guest Contributor. 2020. "UK Battery Storage Boost to Power Greener Electricity Grid." *CleanTechnica*, July 24. https://cleantechnica.com/2020/07/24/battery-storage-boost-to-power-greener-electricity-grid/

Gupta, Mitalee. 2020. "WoodMac: A New Battery Chemistry Will Lead the Stationary Energy Storage Market by 2030." GreenTech Media Research Spotlight. August 20. https://www.greentechmedia.com/articles/read/lfp-will-overtake-nmc-for-stationary-storage

Hawaiian Electric. 2018. *Electrification of Transportation Strategic Roadmap*. Honolulu: Hawaiian Electric. https://www.hawaiianelectric.com/documents/clean_energy_hawaii/electrification_of_transportation/201803_eot_roadmap.pdf

Hile, Sam; Dale Murdock; and Matt Robison. 2017. *Procuring Distribution Non-Wires Alternatives: Practical Lessons from the Bleeding Edge*. Fairfax, VA: ICF.

Holzinger, Chloe; Tim Grejtak; Chris Robinson; and Temma Pelletier. *Global Energy Storage Market Forecast*. Boston: Lux Research Inc. https://www.luxresearchinc.com/hubfs/Lux%20Research%20-%20Global%20Energy%20Storage%20Market%20Forecast%202019%20-%20press.pdf

Hong, Tao and Mohammad Shahidehpour. 2015. *Load Forecasting Case Study*. Washington, DC: National Association of Regulatory Utility Commission. https://pubs.naruc.org/pub.cfm?id=536E10A7-2354-D714-5191-A8AAFE45D626.

Horowitz, Kelsey; Sara Baldwin; Michael Coddington; Steven Coley; Fei Ding; Nadav Enbar; Brian Lydic; Zac Peterson; Dnaish Saleem; Chris Schroeder; Ben Sigrin; Sky Stanfield; and Aditya Sundararajan. 2019. *An Overview of Distributed Energy Resource (DER) Interconnection: Current Practices and Emerging Solutions*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy19osti/72102.pdf

ICF. 2019. "Non-Wires Alternatives and Managed Load Programs: The Next Big Thing in Utility Programs." Fairfax, VA: ICF, Webinar Video, June 20.

IEA. 2018. *Regulation on the Efficient Use of Energy and Tax Incentives*. Paris: International Energy Agency.

———. 2019. *Energy Security in ASEAN +6*. Paris: International Energy Agency. https://www.iea.org/publications/reports/energysecurityinASEAN6/

International Hydropower Association. 2018. Hydropower Status Report 2018: Sector Trends and Insights. London: International Hydropower Association. https://www.hydropower.org/publications/2018-hydropower-status-report

———. 2020. Hydropower Status Report 2020: Sector Trends and Insights. London: International Hydropower Association. https://www.hydropower.org/publications/2020-hydropower-status-report

International Telecommunication Union. 2011. *Smart Grid Overview*. Geneva: International Telecommunication Union. https://www.itu.int/en/ITU-T/focusgroups/smart/Documents/smart-o-0034r4-overview-output.doc

Interstate Renewable Energy Council. 2018. "Cornerstone for Next Generation Grid Activities: Forecasting DER Growth." *IREC Insight Blog*. February 9. https://irecusa.org/2018/02/cornerstone-for-next-generation-grid-activities-forecasting-der-growth/.

IRENA. 2017. *Planning for the Renewable Future: Long-Term Modelling and Tools to Expand Variable Renewable Power in Emerging Economies*. Abu Dhabi: International Renewable Energy Agency https://www.irena.org/publications/2017/Jan/Planning-for-the-renewable-future-Long-term-modelling-and-tools-to-expand-variable-renewable-power

———. 2018. *Power System Flexibility for the Energy Transition*. Abu Dhabi: International Renewable Energy Agency. https://www.irena.org/publications/2018/Nov/Power-system-flexibility-for-the-energy-transition

———. 2019. Long-Term Energy Scenarios for the Energy Transition: A Campaign of the Clean Energy Ministerial. Abu Dhabi: International Renewable Energy Agency. https://www.irena.org/energytransition/Energy-Transition-Scenarios-Network/Long-term-Energy-Scenarios-Campaign

———. 2020. Renewable Power Generation Costs in 2019. Abu Dhabi: International Renewable Energy Agency. https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019

Kahrl, Fredrich; Luke Lavin; Andrew Mills; Arne Olsen; and Nancy Ryan. 2016. "The Future of Electricity Resource Planning." Lawrence Berkeley National Laboratory, Future Electric Utility Regulation Series webinar, September 29. https://eta-publications.lbl.gov/sites/default/files/feur_6_webinar_future_of_resource_planning.pdf

Katz, Jessica and Ilya Chernyakhovskiy. 2020. *Variable Renewable Energy Grid Integration Studies: A Guidebook for Practitioners.* Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy20osti/72143.pdf

Konidena, Rao. 2020. "Three Reasons Why Dual Participation Market at NYISO is Best for Energy Storage." *Renewable Energy World,* March 26. https://www.renewableenergyworld.com/2020/03/26/three-reasons-why-dual-participation-market-model-at-nyiso-is-best-for-energy-storage/

Lamont, David and John Gerhard. 2013. The Treatment of Energy Efficiency in Integrated Resource Plans: A Review of Six State Practices. Montpelier, VT: Regulatory Assistance Project, Prepared for the Lawrence Berkeley National Laboratory. https://www.raponline.org/wp-content/uploads/2016/05/rap-lamont-gerhard-treatementofeeinirp-2013-jan-28.pdf.

Lantero, Allison. 2014. "How Microgrids Work." Washington, DC: U.S. Department of Energy. https://www.energy.gov/articles/how-microgrids-work

Lowder, Travis; Nathan Lee; and Jennifer Leisch. 2020. Covid-19 and the Power Sector in Southeast Asia: Impacts and Opportunities. Golden, CO: National Renewable Energy Laboratory, Prepared for USAID. https://www.nrel.gov/docs/fy20osti/76963.pdf

Levin, Todd and Valerie Thomas. 2016. "Can Developing Countries Leapfrog the Centralized Electrification Paradigm?" *Energy for Sustainable Development* 31(April): 97-107. https://www.sciencedirect.com/science/article/pii/S0973082615301599

Manion, Michelle; Eric Hyman; Jason Vogel; David Cooley; Gordon Smith. 2019. *Greenhouse Gas and Other Environmental, Social, and Economic Impacts of Hydropower: A Literature Review*. Washington, DC: Crown Agents-USA and Abt Associates, Prepared for USAID.

Martinot, Eric; J. Erickson; and Lorenzo Kristov. 2015. "Distribution System Planning and Innovation for Distributed Energy Futures." *Current Sustainable/Renewable Energy Reports* 2(April): 47-54. https://link.springer.com/article/10.1007/s40518-015-0027-8

Maurer, Luiz; Patrick Doyle; Eric Hyman; Loretta Bauer; and Pablo Torres. 2020. *Creating a Level Playing Field for Battery Energy Storage Systems Through Policies, Regulations, and Renewable Energy Auctions.* Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

Menonna, Francesco and Chloe Holden. 2019. "WoodMac: Smart Meter Installations to Surge Globally Over Next 5 Years. GreenTechMedia, July 30. https://www.greentechmedia.com/articles/read/advanced-metering-infrastructure-to-double-by-2024

Midwest Independent System Operator. n.d. "Electric Production Cost Modeling." PowerPoint. Carmel, IN: Midwest Independent System Operator, PowerPoint presentation. http://home.eng.iastate.edu/~jdm/ee590-Old/ProductionCostModleFundamentals_EE590.pdf.

Migden-Ostrander, Janine; Max Dupuy; Camille Kadoch; Carl Linvill; and John Shenot. 2018. *Enabling Third-Party Aggregation of Distributed Energy Resources.* Montpelier, VT: Regulatory Assistance Project, Prepared for the Public Service Commission of Arkansas. https://www.raponline.org/wp-content/uploads/2018/04/enabling_third_party_aggregation_distributed_energy_resources2.pdf

Mihlmester, Philip and Steve Fine. 2016. *The Locational Value of Energy Efficiency on the Distribution Grid.* Fairfax, VA: ICF International, American Council for an Energy-Efficient Economy Summary Study on Energy Efficiency in Buildings. https://aceee.org/files/proceedings/2016/data/papers/6_858.pdf.

Milano, Federico. 2019. "Power System Analysis Toolbox." La Mancha, Spain: University of Castilla Department of Electrical Engineering, Computing, and Communications. http://faraday1.ucd.ie/archive/psat/psat_presentation.pdf

Mills, Andrew. 2017. "Forecasting Load on the Distribution and Transmission System with Distributed Energy Resources." Lawrence Berkeley Laboratory presentation at the Distribution Systems and Planning Training for the New England Conference of Public Utility Commissioners, September 27-29. https://emp.lbl.gov/sites/default/files/11b._gmlc_mills_forecasting_dg_necpuc_training.pdf.

Mills, Andrew; Galen Barbose; Joachim Seel; Changgui Dong; Trieu Mai; Ben Sigrin; and Jarett Zuboy. 2016. *Planning for a Distributed Disruption: Innovative Practices for Incorporating Distributed Solar into*

Utility Planning. Berkeley, CA: Lawrence Berkeley National Laboratory, Report LBNL 1006047. https://emp.lbl.gov/publications/planning-distributed-disruption

Ministry of Energy of Chile. 2015. *Energy 2050: Chile's Energy Policy*. Santiago: Government of Chile. http://www.energia2050.cl/en/energy-2050/energy-2050-chiles-energy-policy/

———. 2018. *Ruta Energetíca, 2018-2022. Liderando La Modernización Con Sello Ciudadano*. Santiago: Government of Chile. http://www.energia2050.cl/en/energy-2050/energy-2050-chiles-energy-policy/

Molina, Javier; Nadia Scharen-Guivel; and Eric Hyman. 2018. *Analysis of Renewable Energy Auctions in Six Countries*. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID. https://pdf.usaid.gov/pdf_docs/PA00T4QN.pdf

Morris, Jesse. 2020. "FERC Order 2222: A Once-in-a-Lifetime Opportunity for Decentralized Technologies to Accelerate the U.S. Energy Transition." *Energy Web Insights*, September 21. https://medium.com/energy-web-insights/ferc-order-2222-a-once-in-a-lifetime-opportunity-for-decentralized-technologies-to-accelerate-the-c35cf41527cb

Myers, Erika. 2018. A Comprehensive Guide to Electric Vehicle Managed Charging. Washington, DC: Smart Electric Power Alliance. https://sepapower.org/resource/a-comprehensive-guide-to-electric-vehicle-managed-charging/

Nance, Peter. 2018. "Initial Results from the Mexico Electricity Reform, 2013-18." In *Mexico's New Energy Reform,* ed. Duncan Wood. Washington, DC: Wilson Mexico Institute. https://www.wilsoncenter.org/sites/default/files/media/documents/publication/mexicos_new_energy_reform.pdf

NARUC. 2016. *Manual on Distributed Energy Resources Rate Design and Compensation*. Washington, DC: National Association of Regulatory Utility Commissioners. https://pubs.naruc.org/pub/19FDF48B-AA57-5160-DBA1-BE2E9C2F7EA0

Navigant Consulting. 2019a. "California Energy Commission DER Research Roadmap - Public Workshop #1." PowerPoint presentation, March 25. Sacramento, CA: California Energy Commission. https://efiling.energy.ca.gov/GetDocument.aspx?tn=227379&DocumentContentId=58494

———. 2019b. *DER Roadmap - Technical Assessment*. Sacramento, CA: California Energy Commission. https://efiling.energy.ca.gov/GetDocument.aspx?tn=228842&DocumentContentId=60179

Nelder, Chris. 2020. "Electric Vehicle Rate Design." Webinar for the North Carolina Sustainable Energy Association, February 12,, Raleigh, NC.

Neme, Chris and Jim Grevatt. 2015. Energy Efficiency as a T&D Resource: Lessons from Recent U.S. Efforts to Use Geographically Targeted Energy Efficiency Programs to Defer T&D Investments. Hinesburg, VT: Energy Futures Group, Prepared for Northeast Energy Efficiency Partnerships Regional Evaluation, Measurement and Verification Forum. http://www.neep.org/sites/default/files/products/EMV-Forum-Geo-Targeting_Final_2015-01-20.pdf.

NERC. 2017. *Distributed Energy Resources Connection Modeling and Reliability Considerations*. Atlanta: North American Electric Reliability Corporation. https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/Distributed_Energy_Resources_Report.pdf

NREL. n.d. (a). "Distributed Generation Market Demand Model." Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/analysis/dgen/.

———. n.d. (b). "Regional Energy Deployment System Model." Golden, CO: National Renewable Energy Lab. https://www.nrel.gov/analysis/reeds/.

NYISO. 2017. *Distributed Energy Resources Roadmap for New York's Wholesale Electricity Markets*. Rensselaer, NY: New York Independent System Operator. https://www.nyiso.com/documents/20142/1391862/Distributed_Energy_Resources_Roadmap.pdf/ec0b3b64-4de2-73e0-ffef-49a4b8b1b3ca

———. 2018. *Distributed Energy Resources Participation Model*. Rensselaer, NY: New York Independent System Operator. https://www.nyiso.com/distributed-energy-resources-der-

NYSERDA. 2016. *Reforming the Energy Vision (REV)*. Albany, NY: New York State Energy Research and Development Authority. https://www.ny.gov/sites/ny.gov/files/atoms/files/WhitePaperREVMarch2016.pdf

O'Connell, Niamh; Pierre Pinson; Henrik Madsen; and Mark O'Malley, Mark. 2014. "Benefits and Challenges of Electrical Demand Response: A Critical Review." *Renewable and Sustainable Energy Reviews*. 11(1): 686-699. https://doi.org/10.1016/j.rser.2014.07.098

O'Mealy, Mikell; Loretta Bauer; Pablo Torres; Leah Quin; and Alexa Smith-Rommel. 2020. *Emerging Markets for U.S. Smart Grid Suppliers and Investors in Africa, Asia, and Latin America*. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

O'Mealy, Mikell; Tanat Sangarasri; Ezham Khalid; and Eric Hyman. 2020. *Private Sector Recommendations for Renewable Energy Auctions in Thailand and Malaysia*. Washington, DC: Crown Agents USA, and Abt Associates, Prepared for USAID.

O'Neil, Sean. 2019. "Unlocking the Potential of Hydrogen Energy Storage." *FCHEA Blog*, July 22. Washington, DC: Fuel Cell & Hydrogen Energy Association.

Palmintier, Bryan. 2019. "Advanced Inverters: Capabilities, Experiences, and Interaction with Hosting Capacity." NREL presentation at the NRCan Canada–USA–Mexico Workshop on Hosting Capacity with Advanced Inverter Functions Montreal, Québec, February 19. https://www.nrel.gov/docs/fy19osti/73449.pdf

Parsons, Brian; Riccardo Bracho; Jaquelin Cochran; Jessia Katz; and Andrea Watson. 2015. *Renewable Electricity Grid Integration Roadmap for Mexico: Supplement to the IEA Expert Group Report on Recommended Practices for Wind Integration Studies.* Golden, CO: National Renewable Energy Laboratory, Prepared for USAID. https://www.nrel.gov/docs/fy15osti/63136.pdf

PEPCO Holdings. 2016. *Distributed Energy Resources and the Distribution Planning Process*. Washington, DC: PEPCO Holdings, Inc. https://www.pepco.com/SiteCollectionDocuments/Distributed%20Energy%20Resources%20and%20the%20Distribution%20System%20Planning%20Process.pdf

PJM Interconnection. n.d.(a). "Market for Electricity." Norristown, PA: PJM Learning Center. https://learn.pjm.com/electricity-basics/market-for-electricity.aspx

———. n.d.(b). "Ancillary Services Market." Norristown, PA: PJM Learning Center. https://learn.pjm.com/three-priorities/buying-and-selling-energy/ancillary-services-market.aspx

PLMA. 2019. *The Future of Distributed Energy Resources*. New York: Peak Load Management Alliance. https://www.peakload.org/assets/resources/PLMA-Future-of-DER-Compendium.pdf

Pouresmaeil, Edris; Juan Gonzalez; Claudio Canizares; and Kankar Bhattacharya. 2013. « Development of a Smart Residential Load Simulator for Energy Management in Smart Grids» IEEE Transactions on Power Systems. 1-8.Romero-Grass, Andrei and Thomas Mach. 2019. *Foco 3, Fase 1: Descentralización y Digitalización de la Industria y la Gestión Eficiente de la Demanda*. Bogota: Ministry of Mines and Energy of Colombia. https://www.minenergia.gov.co/documents/10192/24166201/3.+Fase+1+Descentralizaci%C3%B3n+y+Digitalizaci%C3%B3n+de+la+Industria+y+la+Gesti%C3%B3n+Eficiente+de+la+Demanda.pdf

Reve News. 2020. "Costa Rica Celebrates 300 Days Living Alone with Renewable Energy." *Reve News*, February 2. https://www.evwind.es/2020/02/02/costa-rica-celebrates-300-days-living-alone-with-renewable-energy/73364

Ringkjøb, Hans-Kristian; Peter Haugan; Ida Solbrekke. 2018. "A Review of Modelling Tools for Energy and Electricity Systems With Large Shares of Variable Renewables." Renewable and Sustainable Energy Reviews. 96 (November): 440-459. https://doi.org/10.1016/j.rser.2018.08.002

Robinson, Christopher and Chloe Holzinger, 2020. *Electric Vehicle Inflection Tracker, 2020 Edition*. Boston: Lux Research. https://www.luxresearchinc.com/the-electric-vehicle-inflection-tracker-2020-edition

Rylander, Matt; Lindsay Rogers; and Jeff Smith. 2015. *Distribution Feeder Hosting Capacity: What Matters When Planning for DER?* Palo Alto, CA: Electric Policy Research Institute. https://www.epri.com/#/pages/product/000000003002004777/.

St. John, Jeff. 2018. "The Shifting Makeup of the Fast-Growing US Energy Storage Market." *Greentech Media News*, December 6. https://www.greentechmedia.com/articles/read/tracking-the-shifting-makeup-of-the-us-energy-storage-market

———. 2019. "NV Energy Gets Green Light for Massive Solar-Battery Projects." *Greentech Media News*, December 5. https://www.greentechmedia.com/articles/read/nv-energy-gets-green-light-for-massive-solar-battery-projects

———. 2020a. "Four Big Challenges Facing FERC's Plan to Open Up Power Markets to Distributed Energy." *Greentech Media News*, October 28. https://www-greentechmedia-com.cdn.ampproject.org/c/s/www.greentechmedia.com/amp/article/4-big-challenges-to-fercs-plan-to-open-energy-markets-to-distributed-energy

———. 2020b. "'Game-Changer' FERC Order Opens Up Wholesale Grid Markets to Distributed Energy Resources." *Greentech Media News*, September 17. https://www.greentechmedia.com/articles/read/ferc-orders-grid-operators-to-open-wholesale-markets-to-distributed-energy-resources

Satchwell, Andrew and Ryan Hledik. 2014. *Analytical Frameworks to Incorporate Demand Response into Long-Term Resource Planning*. Berkeley, CA: Lawrence Berkeley National Laboratory. https://www.sciencedirect.com/science/article/abs/pii/S0957178713000763.

Scroggin-Wicker, Tisha and Kiernan McInerny. 2020. "Flow Batteries: Energy Storage Option for a Variety of Uses." *Power News*, March 2. https://www.powermag.com/flow-batteries-energy-storage-option-for-a-variety-of-uses/

SENER. 2013. *Prospectiva del Sector Eléctrico 2013-2027*. Mexico City: Secretaria de Energía de México. https://www.gob.mx/cms/uploads/attachment/file/62949/Prospectiva_del_Sector_El_ctrico_2013-2027.pdf

———. 2019a. *Consejo Consultivo para la Transición Energética*. Mexico City: Government of Mexico. https://www.gob.mx/sener/acciones-y-programas/consejo-consultivo-para-la-transicion-energetica

———. 2019b. *Programa de Desarrollo del Sistema Eléctrico Nacional (PRODESEN) 2019-2033*. Mexico City: Government of Mexico. https://www.gob.mx/sener/documentos/prodesen-2019-2033

———. 2020. "Acuerdo por el que la Secretaría de Energía aprueba y publica la actualización de la Estrategia de Transición para Promover el Uso de Tecnologías y Combustibles más Limpios, en términos de la Ley de Transición Energética." *Diario Oficial de la Federación*. Mexico City: Government of Mexico. https://www.dof.gob.mx/nota_detalle.php?codigo=5585823&fecha=07/02/2020

SEPA and Nexant. 2016. *Beyond the Meter: Addressing the Locational Valuation Challenge for Distributed Energy Resources*. Washington, DC: SEPA and Nexant. https://sepapower.org/resource/beyond-the-meter-addressing-the-locational-valuation-challenge-for-distributed-energy-resources/

Shahan, Zachary. 2020. "Electrify America Invests in Sacramento-Area Energy Storage Program." *CleanTechnica*, February 5, https://cleantechnica.com/2020/02/05/electrify-america-invests-in-sacramento-area-energy-storage-program/

Shepard, Scott. 2017. "2016 Electric Vehicle Geographic Forecast Methodology." Navigant Research PowerPoint presented to the California Energy Commission, August 3. https://efiling.energy.ca.gov/GetDocument.aspx?tn=220516.

Shipley, Anna and R. Neal Elliott. 2000. *Distributed Energy Resources and Combined Heat and Power: A Declaration of Terms*. Washington, DC: American Council for an Energy-Efficient Economy, Prepared for the U.S. Department of Energy and the Energy Foundation. http://aceee.org/research-report/ie001.

Smarter Grid Solutions. 2018. *Enhanced Hosting Capacity Analysis*. New York: Smarter Grid Solutions, Prepared for the Minnesota Department of Commerce and the Minnesota Solar Pathways Project. http://mnsolarpathways.org/wp-content/uploads/2018/10/mn-solar-pathways_pv-hosting-capacity-report.pdf

SourceForge. 2019. Grid LAB-D (Open Source Power Distribution Simulation Tool). San Diego: Slashdot Media. https://sourceforge.net/projects/gridlab-d/files/

Spector, Julian. 2020a. "The 5 Most Promising Long-Duration Storage Technologies Left Standing." *Greentech Media*, March 31. https://www.greentechmedia.com/articles/read/most-promising-long-duration-storage-technologies-left-standing

———. 2020b. "Long-Duration Breakthrough? Form Energy's First Project Tries Pushing Storage to 150 Hours." *Greentech Media News*, May 7. https://www.greentechmedia.com/articles/read/form-energys-first-project-pushes-long-duration-storage-to-new-heights-150-hour-duration

Sterling, John; Karlynn Cory; Joyce McLaren; and Mike Taylor. 2013. *Treatment of Solar Generation in Electric Utility Resource Planning*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy14osti/60047.pdf

Stockholm Environment Institute. 2019. *The Long-range Energy Alternatives Planning - Integrated Benefits Calculator (LEAP-IBC)*. Stockholm: Stockholm Environment Institute. https://mediamanager.sei.org/documents/Publications/SEI-Factsheet-LEAP-IBC-2.pdf

———. 2020. WEAP: *Water Evaluation and Planning Model*. Stockholm: Stockholm Environment Institute. https://www.weap21.org/

Stoll, Brady; Aaron Bloom; Gregory Brinkman; and Aaron Townsend. 2016. *Analysis of Modeling Assumptions Used in Production Cost Models for Renewable Integration Studies*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy16osti/65383.pdf

Succar, Samir. 2018. *Integrated Distribution Planning: Utility Practices in Hosting Capacity and Locational Value Assessment*. Fairfax, VA: ICF International, Prepared for the U.S. Department of Energy. https://static1.squarespace.com/static/5b736be575f9eeb993c4d5f1/t/5b8f4055032be49d0ccfd2bf/1536114780361/ICF+DOE+Utility+IDP+FINAL+July+2018+%28003%29.pdf

Taibi, Emanuele; Thomas Nikolakis; Laura Gutierrez; Carlos Fernandez; Juha Kiviluoma; Tomi Lindroos; and Simo Rissanen. 2018. *Power System Flexibility for the Energy Transition*. Abu Dhabi: International Renewable Energy Agency. https://www.irena.org/publications/2018/Nov/Power-system-flexibility-for-the-energy-transition

Tait, Daniel. 2017. "Battery Storage and Ancillary Services." *Energy Alabama*, July 11. https://alcse.org/battery-storage-ancillary-services/

Taylor-Hochber, Frederick. 2017. "Electric Production Cost Modeling." PowerPoint presented at the California Public Utilities Commission's Production Cost Modeling Workshop in San Francisco, August 1, 2017. http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/News_Room/News_and_Updates/PCM%20Aug1_fth_v7(1).pdf.

Tierney, Susan. 2016. The Value of "DER" to "D": The Role of Distributed Energy Resources in Supporting Local Electric Distribution System Reliability. Boston: Analysis Group. https://www.analysisgroup.com/Insights/publishing/the-value-of-der-to-d/

Trabish, Herman. 2019. "Renewable' Variability Send Wary Utilities from Traditional DR to DER and Load Flexibility." *Utility Dive News*, August 14. https://www.utilitydive.com/news/renewables-variability-sends-wary-utilities-from-traditional-dr-to-der-and/560669/

U.S. DOE. n.d. "Demand Response." Washington, DC: U.S. Department of Energy. https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/demand-response

———. 2016. *Advanced Metering Information and Customer Systems: Results from the Smart Grid Investment Grant Program*. Washington, DC: U.S. Department of Energy. https://www.energy.gov/sites/prod/files/2016/12/f34/AMI%20Summary%20Report_09-26-16.pdf

U.S. EIA. 2019a. *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2019*. Washington, DC: U.S. Energy Information Administration. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

———. 2019b. "Renewable Energy Explained." Washington, DC: U.S. Energy Information Administration, June 27. https://www.eia.gov/energyexplained/renewable-sources/

U.S. FERC. 2018. *Distributed Energy Resources Technical Considerations for the Bulk Power System*. Washington, DC: U.S. Federal Energy Regulatory Commission. Staff Report Docket No. AD18-10-000. https://www.ferc.gov/CalendarFiles/20180215112833-der-report.pdf

UPME. 2019. *Plan Energético Nacional 2020-2050*. Bogota: Unidad de Planeación Minero Energética. https://www1.upme.gov.co/DemandaEnergetica/PEN_documento_para_consulta.pdf

Vietnam Electricity. 2019. "Why Demand Response Program Must Be Implemented in Vietnam." Hanoi: Vietnam Electricity, April 24. https://en.evn.com.vn/d6/news/Why-demand-response-program-must-be-implemented-in-Vietnam-66-163-1535.aspx

Viscidi, Lisa. 2018. "Mexico's Renewable Energy Future." In *Mexico's New Energy Reform,* ed. by Duncan Wood. Washington, DC: Wilson Center Mexico Institute https://www.wilsoncenter.org/sites/default/files/media/documents/publication/mexicos_new_energy_reform.pdf

Viscidi, Lisa; Nate Graham, and Sarah Phillips. 2020. "Mexican Power Sector Policies: Economic and Trade Impacts." *The Dialogue Brief* (August). Washington, DC: Inter-American Dialogue. https://www.thedialogue.org/wp-content/uploads/2020/08/Mexican-Power-Sector-Policies_Final.pdf

Vu, Khanh. 2019. "Vietnam Will Face Severe Power Shortages from 2021: Ministry." *Reuters.* July 31. https://www.reuters.com/article/us-vietnam-energy/vietnam-will-face-severe-power-shortages-from-2021-ministry-idUSKCN1UQ11M

———. 2020." Vietnam Looks to More Than Double Power Generation Capacity by 2030." *Reuters*. February 19. https://www.reuters.com/article/us-vietnam-energy/vietnam-looks-to-more-than-double-power-generation-capacity-by-2030-idUSKBN20D0ID

Wigand, Fabian; Ana Amazo-Blanco; Bastian Lotz; Tobias Fichter; Sarah Lawson; Arai Monteforte; and Allen Eisendrath. 2020. *Designing Solutions in System-Friendly Renewable Energy Competitive Procurement.* Arlington, VA: TetraTech ARD. Prepared for USAID.

Wilson, Dan; Daisy Chung; Karlynn Cory; and Vazken Kassakhian. 2017. *Beyond the Meter: Planning the Distributed Energy Future, Volume II: A Case Study of Integrated DER Planning by Sacramento Municipal Utility District*. Washington, DC: Black & Veatch and Smart Electric Power Alliance. https://sepapower.org/resource/beyond-meter-planning-distributed-energy-future-volume-ii/

Wilson, Dan; Chanje Stith; Jordan Smith; Erika Myers; April Bolduc; Gavin Novotny; Sonika Choudhary; Dave Tuttle; Alana Lemarchand; and Mike Waters. 2019. *Preparing for an Electric Vehicle Future: How Utilities Can Succeed*. Washington, DC: Smart Electric Power Alliance. https://sepapower.org/knowledge/sepa-report-provides-utility-roadmap-to-ev-infrastructure-success/

Wiser, Ryan; Audun Botterud; Andrew Mills; Todd Levin; and Joachim Seel. 2017. *Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing and Costs*. Berkeley, CA: Lawrence Berkeley National Laboratory and Argonne National Laboratory, Report LBNL-2001082, Prepared for the U.S. Department of Energy. https://emp.lbl.gov/publications/impacts-variable-renewable-energy.

Wood, Duncan and Jeremy Martin. 2018. "Of Paradigm Shifts and Political Conflict: The History of Mexico's Second Energy Revolution." In *Mexico's New Energy Reform.* Washington, DC: Wilson Center Mexico Institute. https://www.wilsoncenter.org/sites/default/files/media/documents/publication/mexicos_new_energy_reform.pdf

Wood, Eric, Clément Rames, and Matteo Muratori. 2018. "New EVSE Analytical Tools/Models: Electric Vehicle Infrastructure Projection Tool (EVI-Pro)." NREL presentation at the Society of Automotive Engineers Government/Industry Meeting on Electric Drive Infrastructure, Washington, DC. January 24. https://www.nrel.gov/docs/fy18osti/70831.pdf

Wood, Elisa. 2018. "What's Driving Microgrids Toward a $30.9B Market?" *MicrogridKnowledge*, August 30. https://microgridknowledge.com/microgrid-market-navigant/

Wood, Johnny. 2019. "India Is Now Producing the World's Cheapest Solar Power." Cologny-Geneva: World Economic Forum, Prepared for the India Economic Summit. https://www.weforum.org/agenda/2019/06/india-is-now-producing-the-world-s-cheapest-solar-power/

Woolf, Tim; Courtney Lane; Melissa Whited; Chris Neme; Mike Alter; Steve Fine; Karl Rabago; Stephen Schiller; Kate Strickland; and Brenda Chew. 2020. *National Standard Practice Manual for Benefit-Cost Analysis of Distributed Energy Resources*. Framingham, MA: E4TheFuture, Prepared for Lawrence Livermore National Laboratory. https://www.nationalenergyscreeningproject.org/wp-content/uploads/2020/08/NSPM-DERs_08-24-2020.pdf

World Resources Institute. 2019. "New Global Effort on Climate Change Targets 3% Increase in Energy Efficiency per Year." Press Release, September 23. https://www.wri.org/news/2019/09/release-new-global-effort-climate-change-targets-3-percent-increase-energy-efficiency-year

Wu, Chenye; Hamed Mohsenian-Rad; Jianwei Huang; and Juri Jatskevich. 2012. *PEV-Based Combined Frequency and Voltage Regulation for Smart Grid*. Paper presented at the 2012 IEEE PES Innovative Smart Grid Technologies (ISGT) Conference, Washington DC, January 16-20. https://ieeexplore.ieee.org/document/6175758

Yepez-Garcia; Ariel Rigoberto; and Julie Dana. 2012. *Mitigating Vulnerability to High and Volatile Oil Prices: Power Sector Experience in Latin America and the Caribbean*. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/486571468224404351/Mitigating-vulnerability-to-high-and-volatile-oil-prices-power-sector-experience-in-Latin-America-and-the-Caribbean

Zablocki, Alexandra. 2019. *Fact Sheet: Energy Storage*. Washington, DC: Environmental and Energy Study Institute. https://www.eesi.org/papers/view/energy-storage-2019

Zinaman, Owen; Alexandra Aznar; Francisco Flores-Espino; and Alejandro Tovar Garza. 2018. *The Status and Outlook of Distributed Generation Public Policy in Mexico.* Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy18osti/71469.pdf