Report 3: Smart Grid – An International Review

REPORT 3

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by

Intelligent Energy Systems (IES) &

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ACRONYMS

AA	Advanced Analytics
AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
ACS-ARR	Average cost of supply – Average revenue
ACT	Active Control Technology
ACT	Australian Capital Territory
ADMS	Advanced Distribution Management System
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
ANU	Australian National University
APRC	Adaptive Power Reference Control
ARENA	Australian Renewable Energy Agency
ARRA	American Recovery and Reinvestment Act
AS	Australian Standard
ASEFS	Australian Solar Energy Forecasting System
AT&C	Aggregate Technical and Commercial
AWEFS	Australian Wind Energy Forecasting System
BAN	Building area networks
CAGR	Compound Annual Growth Rate
CI	Customer Interruptions
CIP	Critical Infrastructures Protection
CIS	Customer Information System
CML	Customer minutes lost
CSIP	Common Smart Inverter Profile
CSIRO	Commonwealth Scientific and Industrial Research Operations
DAS	Distribution Automation Systems
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DCS	Distributed Control System
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
DLR	Dynamic Line Ratings
DMS	Distribution Management System
DNMS	Distribution Network Management System
DOE	Department of Energy
DR	Demand Response
DSO	Distribution System Operators

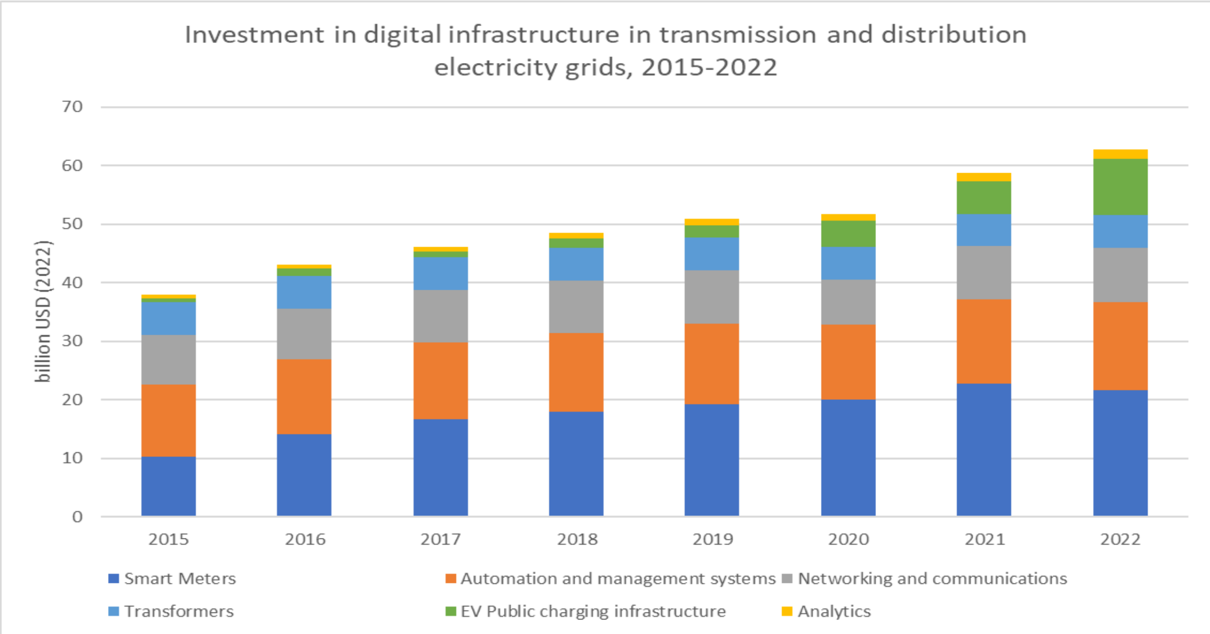
DT	Distribution Transformer
DTCR	Dynamic Thermal Circuit Rating
EHV	Extra High Voltage
EIA	Energy Information Administration
EMDE	Emerging Markets and Developing Countries
EMSS	Energy Management Systems
ENA	Energy Networks Australia
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EV	Electric Vehicle
FAN	Field area networks
FLISR	Fault Location, Isolation, and Service Restoration
FMI	Future Market Insights
GBCA	Green Building Council of Australia
GEB	Grid-interactive efficient buildings
GFLI	Grid-following inverter
GFMI	Grid-forming inverter
GIS	Geographic Information System
G-PST	Global Power System Transformation
GW	Giga Watt
HAN	Home area networks
HEMS	Home Energy Management Systems
HMI	Human Machine Interface
HV	High voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IAN	Industrial area networks
IBR	Inverter-based Resources
IEA	International Energy Agency
IEC	International Electrochemical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
IREC	Interstate Renewable Energy Council
ISGAN	International Smart Grid Action Network
IT	Information Technology
KEPCO	Korea Electric Power Corporation
KPI	Key Performance Indicators
LV	Low voltage
MDAS	Metering Data Acquisition System
MV	Medium voltage
MW	Mega Watt

NAN	Neighbourhood area networks
NARC	North American Electric Reliability Corporation
NEM	National Energy Market
NSW	New South Wales
NZE	Net Zero Emissions
NZS	New Zealand Standard
OMS	Outage Management System
OT	Operational Technology
PFC	Power Finance Corporation Limited
PG&E	Pacific Gas & Electric Corporation
PGE	Portland General Electric
PLC	Power Line Communication
PMU	Phasor Measurement Unit
PV	Photovoltaic
QLD	Queensland
R&D	Research and Development
RDSS	Revamped Distribution Sector Scheme
REC	Rural Electrification Corporation
REI	Renewable Energy Integration
REZ	Renewable Energy Zones
RTPV	Roof top photo voltaic
RTU	Remote Thermal Unit
SA	South Australia
SAS	Substation Automation Systems
SCADA	Supervisory Control and Data Acquisition
SCED	Security Constrained Economic Dispatch
SG	Smart Grid
SGAM	Smart Grid Architecture Model
SVC	Static VAR Compensator
TDSE	Tecnos Data Science Engineering, Inc.
TEPCO	Tokyo Electric Power Company
TSO	Transmission System Operator
UK	United Kingdom
USA	United States of America
UTC	Coordinated Universal Time
VIC	Victoria
VNI	Victoria New South Wales Interconnector
VPP	Virtual Power Plant
WAMS	Wide Area Monitoring System
WAN	Wide area networks

EXECUTIVE SUMMARY

Report 3 is a review of Smart Grid (SG) technologies. SG technologies deployed internationally are reviewed followed by a review of the experience in the selected jurisdictions of the United States of America (USA), European Union (EU) and Australia. These jurisdictions have considerable technical and regulatory experience in implementing SG providing a rich source for the analysis of successes and challenges faced in implementation and drawing lessons that can benefit Viet Nam's circumstances.

Figure 0-1 Investment in digital infrastructure



Source: Drtil, M., Pastore, A., & Evangelopoulou, S. (2023, July 11). Smart grids - IEA. International Energy Agency. Retrieved September 21, 2023, from https://www.iea.org/energy-system/electricity/smart-grids#tracking

The International Smart Grid Action Network (ISGAN) has national experts from 26 countries and the European Commission. ISGAN's member countries, among other countries, are implementing SG to address the challenges posed by the evolving electricity systems. The retirement of traditional fossil fuel assets and increased penetration of variable renewable energy resources primarily to achieve greenhouse emissions reduction targets pose challenges to the security and reliability of electricity systems. These challenges are being addressed by incentivising participants to provide services needed by the power system primarily through valuing services and sending price signals to consumers. Effective integration of distributed energy resources (DER) and opening opportunities for small consumers to participate in a two-way power system and markets for energy and ancillary services are key areas in international SG implementations. Achieving broad participation by DER resources requires addressing technical and regulatory questions. In all the jurisdictions there is considerable effort expended on planning, research, trials and demonstration projects leading to system implementation and evidence-based input to policy and regulatory reform initiatives.

The report reviewed key SG Technologies in the areas of generation, transmission and distribution networks, customer systems and communications. The technologies review included:

- Advanced Distribution Management Systems (ADMS)/Substation Automation Systems (SAS)
- Wide Area Monitoring System (WAMS)
- Static VAr Compensators (SVC)
- Distribution Transformer (DT) Monitoring Systems
- Outage Management Systems (OMSS)
- Demand Response (DR)
- Vehicle-Grid Integration
- Distributed Energy Resources (DER) Integration
- Advanced Analytics (AA) and Artificial Intelligence (AI)
- Dynamic Line Rating (DLR)
- Advanced Metering Infrastructure (AMI) / Smart Meters

The three jurisdictions reviewed are the USA, EU with reference to the UK where appropriate and Australia. Experience with SG deployment in these jurisdictions is considerable which provides a rich source for drawing on lessons that would be valuable to Viet Nam. The reviewed jurisdictions have all recognised the importance of integrating Distributed Energy Resources (DER) into the increasingly two-way power system and market. The expected massive growth in DER; including rooftop PV, storage and EV; makes it imperative to encourage the participation of this capacity in the provision of services to improve security and reliability of the power system. Proper integration of DER will provide benefits of reducing power prices and a more secure and reliable power system. Regulation is a key area to enable this to occur. A fair valuation of the energy and ancillary services that DER can provide (including through aggregating individual resources) will enable providing incentives and the right price signals to participants. The right price signals encourage DER participants to invest in DER in the right areas of the network and to engage in the providing services needed by the system. Regulation has been put in place not only to develop markets for the new services but also to ensure interoperability between devices and systems. Privacy and data ownership regulation has also been an important issue in each of the three jurisdictions reviewed. The experience in these jurisdictions points to the importance of developing a clear strategy before detailed implementation plans are made.

The key lessons drawn that would be helpful for Viet Nam's SG journey are presented in the form of key factors to ensure the success of Viet Nam's SG implementation. The success of SG implementation starts with developing a **strategy** that defines the target, studies the current state and charts the roadmap of getting to the desired target. Thus, one should resist the temptation of jumping into technical solutions that are devoid of strategic context. Technical challenges are often not purely related to technology but are linked to the availability of robust valid data at the right temporal, geographic and system level of granularity. The development of **operational and market models** that faithfully represent the assets connected to the system is crucial if this data is to be used effectively. For example, smart meters that record data with great precision are of limited use unless it is communicated consistently and not compromised by the systems that process the data. **Valid data** cannot be used effectively if the operational models for VRE and other assets have not been developed to reflect and predict the behaviour of the assets under all operating circumstances, particularly during events when the system is under stress.

Integration of systems is a key success factor. For example, Fault Location, Isolation, and Service Restoration (FLISR) is more effective when implemented as part of an Advanced Distribution Management System (ADMS) and integrated with a Geographic Information System (GIS). The right solution is not always a universal choice. For example, FLISR is effective when deployed in a network in that is intermeshed to allow rerouting of paths to resolve outages. Similarly, the choice of central versus distributed control depends on the situation. Distributed architectures have become more dominant in Substation Automation Systems (SAS). Data requirements is also a key consideration. Solutions with heavy data requirements, such as Phasor Measurement Units (PMU), are not effective if the communication infrastructure cannot support such needs.

Interoperability between devices and systems is key. Thus, careful selection of standards is an important consideration to ensure the different parts of the system can work collaboratively. Managing current or legacy systems is an important part of implementation.

Regulatory aspects are an obvious key area to consider. The reviewed jurisdictions have implemented, and continue to implement, regulatory reforms to fairly value and compensate services provided by participants. Ensuring DER participates broadly in a two-way system and market for services is crucial. Some markets, such as markets for demand response or for ancillary services by aggregated small resources, were developed to allow high levels of participation. This was done based on information furnished by trials and demonstrations about the capability of the systems and market design options, considered in the trials, to accommodate and integrate these resources.

Funding and financing mechanisms are important to have in place to adequately propel investment. The reviewed jurisdictions have implemented a combination of government and private funding of projects. The EU for example provided a consistent level of funding for projects but as the system matured and penetration of SG related technologies increased, that consistent level represented a smaller percentage of total funding of projects. In a sense, government took higher risk in projects in the early stages which fell as SG technology implementation rose.

Privacy and ownership of data are also key issues that have been a common thread in the reviewed jurisdictions. It is important to set the right framework to encourage competition and make it easy for consumers to switch providers.

Stakeholder consultation and involvement is a cornerstone of successful implementations. This has been accomplished in international implementations by involving stakeholders in all stages of the process and projects through submissions to consultations, information sessions, participation in trials, demonstrations, research projects and committees.

TABLE OF CONTENTS

1 INTRODUCTION

This report, produced by Intelligent Energy Systems (IES) as part of Deliverable 3 under the project titled *“Development of Vietnam Smart Grid Roadmap for period up to year 2030, with a vision to 2050”*, offers an in-depth analysis of smart grid technology in the global market. It encompasses a comprehensive exploration of Smart Grid related technology and its applications. To ensure the relevance of this international smart grid review to Vietnam's context, we have categorised the areas outlined in Decision No. 1670/QD-TTg, aligning smart grid technologies with (1) Generation, (2) Smart Transmission and System Operation, (3) Smart Distribution Networks, (4) Smart Customer systems, and (5) Smart Metering.

In the second part of this review, IES research delves into specific jurisdictions providing a detailed examination of smart grid implementations. The jurisdictions covered are the USA, the EU with reference to the UK where appropriate, and Australia. The primary objectives of Deliverable 3 are to:

- Assess the maturity level and trends in smart grid technologies and development, covering research directions, deployment rates, and demonstration results.
- Outline deployment roadmaps.
- Examine policies and legal regulations pertaining to smart grids.
- Analyse costs and financing models.

This study seeks to identify valuable lessons for Vietnam and offer insights that can inform the Smart Grid Roadmap. The report will present the findings and outcomes of this review. The review was conducted based on publicly available information.

The remaining sections of the review report are as follows:

- Section 2 contains the review of smart grid technologies,
- Section 3 is a review of SG experience in the USA,
- Section 4 is a review of SG experience in the EU with reference to the UK where appropriate,
- Section 5 is a review of SG experience in Australia,
- Section 6 Draws key lessons for Viet Nam based on the reviewed jurisdictions,
- Section 7 lists the references used in this review, and
- Section 8 is an Appendix that contains a summary Technology Matrix and details of projects and technical standards that may be of interest to some readers.

2 SMART GRID TECHNOLOGIES REVIEW

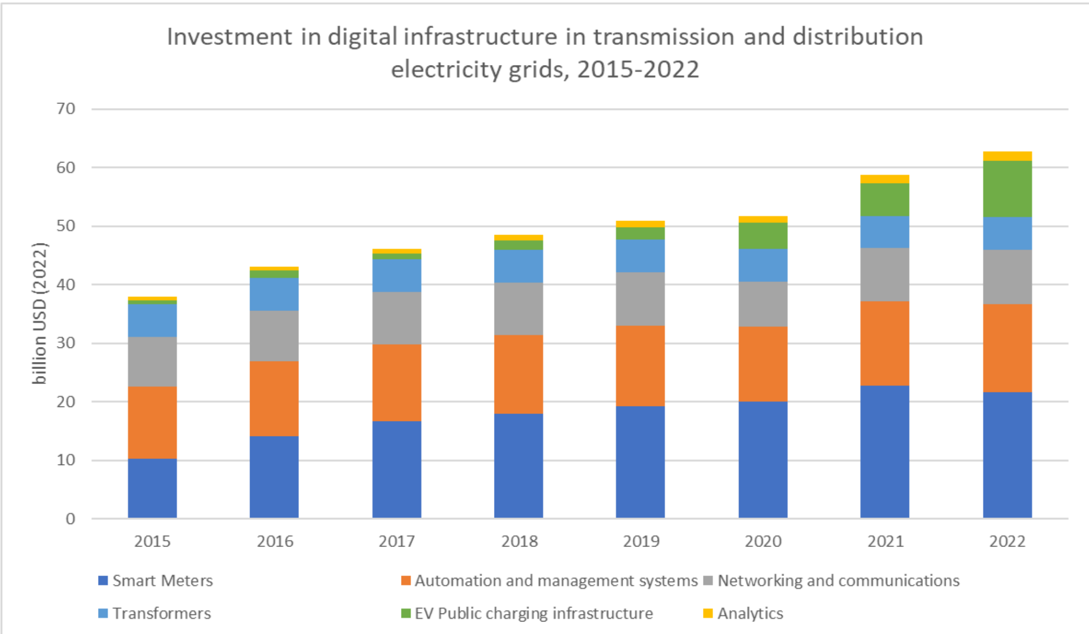
In this section we review SG technologies. First an overview of SG investment across in the world and selected jurisdictions is presented in Section 2.1 to provide an appreciation of the market and efforts related to SG. This is followed by brief descriptions of the various SG technologies and their primary application in Section 2.2. The subsections that follow review SG technologies arranged by main area – Generation, Transmission, Distribution, Customer and Communications. The Technology Matrix in Appendix 8.1 provides a summary of trends, estimated costs and application areas of the SG related technologies in this review.

2.1 Smart grids across the world

Smart grids improve system efficiency by coordinating the needs and capabilities of all generators, grid operators, end users, and electricity market stakeholders. This minimises costs and environmental impacts while maximising system dependability, resilience, flexibility, and stability. Since most of the involved technologies are already mature, monitoring investments offers information on deployment levels.

From Figure 2-1, investment in digital infrastructure (green bar) has increased significantly over the past years with a 7% increase in investment in 2022 over 2021. Innovative digital infrastructure is gaining significance in distribution and transmission electrical grids. The distribution sector accounts for around 75% of all investment in grid-related digital infrastructure, mostly through the deployment of smart meters and the automation of substations, feeders, lines, and transformers through the deployment of sensors and monitoring devices.

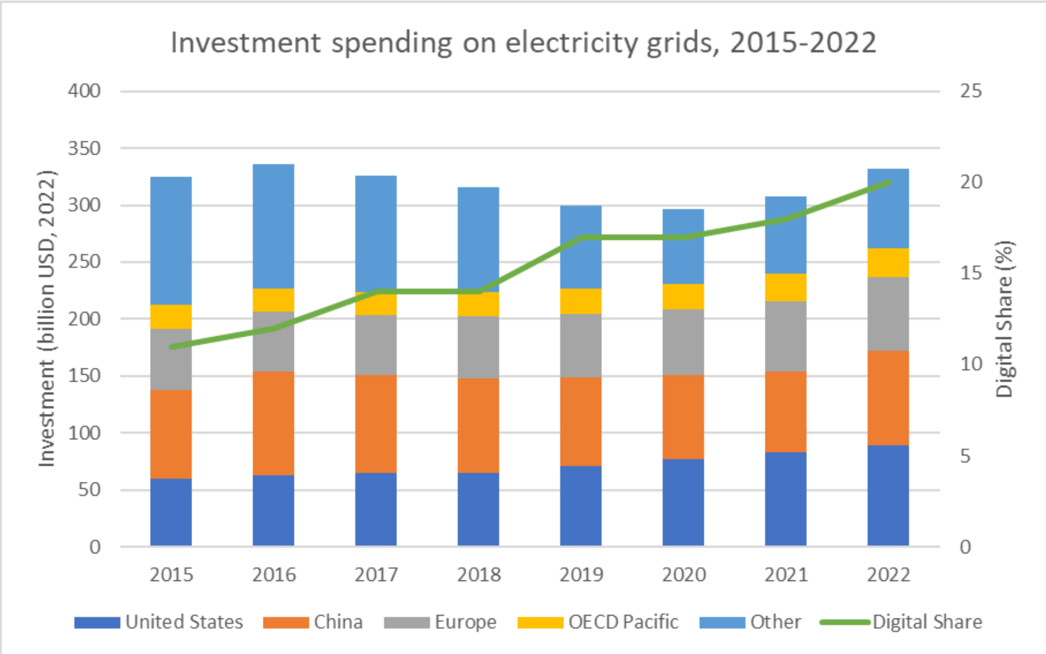
Figure 2-1 Investment in digital infrastructure



Source: Drtil, M., Pastore, A., & Evangelopoulou, S. (2023, July 11). Smart grids - IEA. International Energy Agency. Retrieved September 21, 2023, from https://www.iea.org/energy-system/electricity/smart-grids#tracking

Global investment in electricity grids is increasing, with more ambitious network designs being developed to allow the electrification of the economy and the integration of renewables as can be seen in the Figure 2-2. Electricity grid investment increased by roughly 8% in 2022, with both advanced and emerging nations accelerating investment to support and enable electrification of buildings, industries, and transportation, as well as to handle fluctuating renewables in the power system.

Figure 2-2 Investment spending on electricity grids



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Investment in smart grids must double through to 2030, particularly in emerging markets and developing economies (EMDEs), to achieve the Net Zero emissions by 2050 (NZE) scenario. Several countries, mainly, major economies have announced substantial additional funding to automate, digitalise and modernise their electricity grids.

Many of the big economies have announced large investment plans to improve the operation of their electricity grids through modernising and digitalising by incorporating smart grid technologies.

Below we provide a brief overview of selected countries and regions that are making significant progress into deploying smart grid technologies into their electricity grids. In addition to the three jurisdictions that are reviewed later in the report; the USA, the EU and Australia; we briefly overview two other ISGAN member countries Japan and Canada. While we could not find detailed public information on China it is important to mention that China is investing USD 442 billion over the period of 2021-2025 to modernise and expand its electricity grids. This section has relied on information in IEA's smart grids report (Drtil, Pastore, & Evangelopoulou, 2023).

2.1.1 The United States

In the 21st century, the electricity grid in the US is undergoing the process of evolution on multiple fronts, starting from grid hardware, where the controls are shifting to digital capabilities for measurement, sensing, local intelligence, and distributed control. Grid communications are evolving into a two-way system for wide area networks and field area networks reaching out to the customers, and finally the grid software (GIS, OMS, DMS, EMS) is evolving where the distributive software is being expanded to cover field devices and systems with centralised software capabilities being significantly enhanced.

Technology is at the centre of putting the smart in “smart grid”. In recent years, the availability of new smart grid technologies in the United States has risen, ranging from distribution automation devices and components to advanced computer and control systems. The following table provides an outlook of the devices and systems used in the automation of distribution utility operations.

Table 2-1 Distribution Automation (DA) Technologies and Systems

DA Technologies and Systems		DA Applications			
		Reliability and Outage Management (FLISR)[l]	Voltage and Reactive Power Management (VVO)[m]	Equipment Health Condition Monitoring	DER Integration
Devices	Remote Fault Indicators	✓	✓		
	Smart Relays	✓			
	Automated Feeder Switches (or Reclosers)	✓	✓		
	Automated Capacitors		✓		✓
	Automated Voltage Regulators		✓		✓
	Automated Feeder Monitors	✓	✓	✓	✓
	Transformer Monitors			✓	
Systems Integration	Communications and Backhaul Systems	✓	✓	✓	✓
	Supervisory Control and Data Acquisition Systems	✓	✓		
	Distribution Management System/Advanced Distribution Management System	✓	✓	✓	✓
	Integration with Advanced Metering Infrastructure/Smart Meters	✓	✓	✓	✓
	Outage Management Systems, Geographic Information System, Customer Information System, Workforce Management Integration	✓			

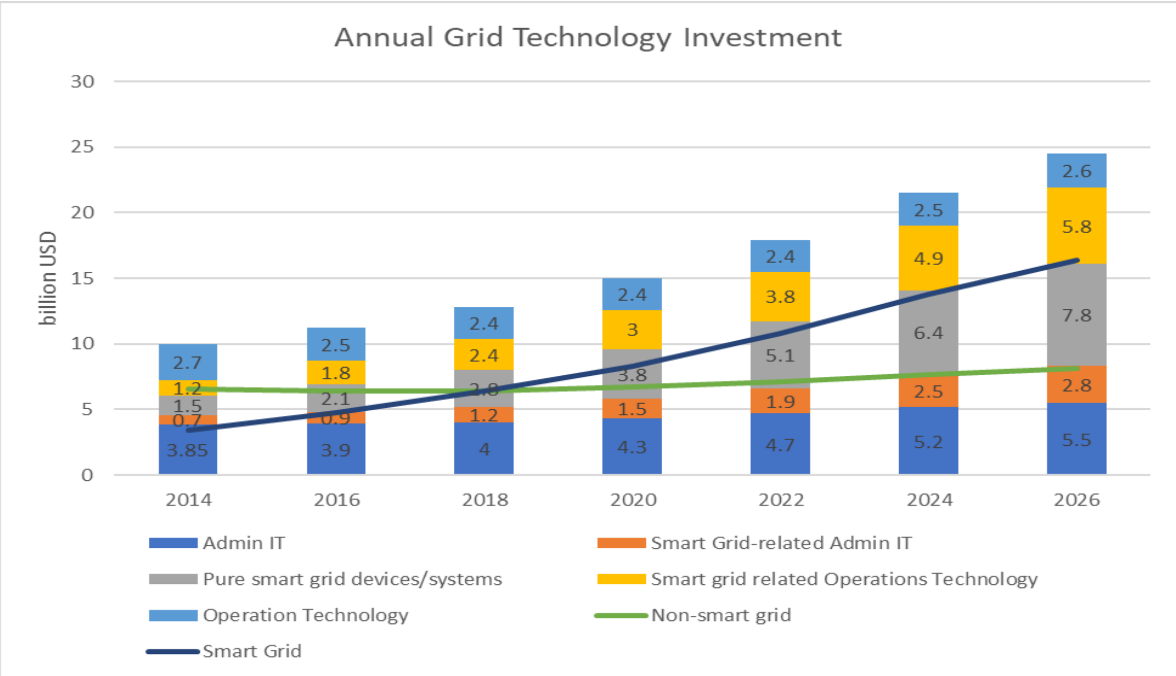
Note: FLISR - Fault Location, Isolation, and service restoration
Source: United States Department of Energy. (2022, January). 2020 Smart Grid System Report.

Investments in smart grid by utilities include information technology (IT) and operational technology (OT). IT is concerned with the management of information for business systems such as payroll, billing, and other administrative systems. OT is responsible for the administration of physical grid components as well as the operation of control and monitoring systems for energy generation, transmission, and distribution. IT and OT systems are both integrated with smart grid technologies.

U.S. electric utilities spent about USD 15 billion on digital technologies in the year 2020, which includes USD 8.3 billion for investments in smart grids, and projected investments of up to USD 26 billion by 2026, which is expected to include USD 16.4 billion in smart grid investments (United States Department of Energy, 2022).

Figure 2-3 depicts previous and forecast growth in capital spending on digital technologies over a 12-year period from 2014 to 2026. The investment is broken into components including investment into smart grid devices and related IT and OT systems. The chart shows that investments in the non-smart grid related technologies have not and are not expected to change noticeably in future while investments in the smart-grid related technologies in both IT and OT have grown significantly in the past decade and are forecasted to continue the trend into 2026.

Figure 2-3 Annual Grid Technology Investment (2014 to 2026)



Source: United States Department of Energy. (2022, January). 2020 Smart Grid System Report.

Table 2-2 Investments in Smart-Grid Related Technologies

Smart grid related admin IT	Meter data management (MDM), billing, and customer information systems (CIS).
Pure smart grid devices/systems	Distribution Automation (DA) technologies, Advanced metering infrastructure (AMI), T&D monitoring and control devices, renewable interties/inverters.

Smart grid related technology	Control systems including advanced management systems (ADMS), distribution automation (DA) control, and substation automation protection and control.

Source: United States Department of Energy. (2022, January). 2020 Smart Grid System Report.

2.1.2 The European Union (EU)

The EU action plan on digitalising the energy system integrate the Fit for 55 and REPowerEU objectives for renewables and energy efficiency. The plan includes an expected investment of USD 633 billion (EUR 584 billion) in improving the European electricity grid by 2030 (The European Commission, 2022). (Drtil, Pastore, & Evangelopoulou, 2023) estimate USD 184 billion (EUR 170 billion) of that amount would be for integration of smart grid technologies such as smart meters, automated grid management, digital technologies for metering and improving field operations. The EU action plan emphasises how new technologies will enhance the effective use of energy resources, make it easier for renewable energy sources to be integrated into the grid, and reduce prices for EU consumers and energy corporations.

Figure 2-4 is an overview of investment in the EU by project category. The category 'Other' is primarily related to R&D on legislative, institutional, and social conditions to promote the energy transition including in the areas of market design, and business models required to incentivise the provision of flexibility services. 'Smart city' projects are demonstration projects for prototyping, testing, demonstrating, piloting, large-scale product validation, and market replication (Vasiljevska, 2021).

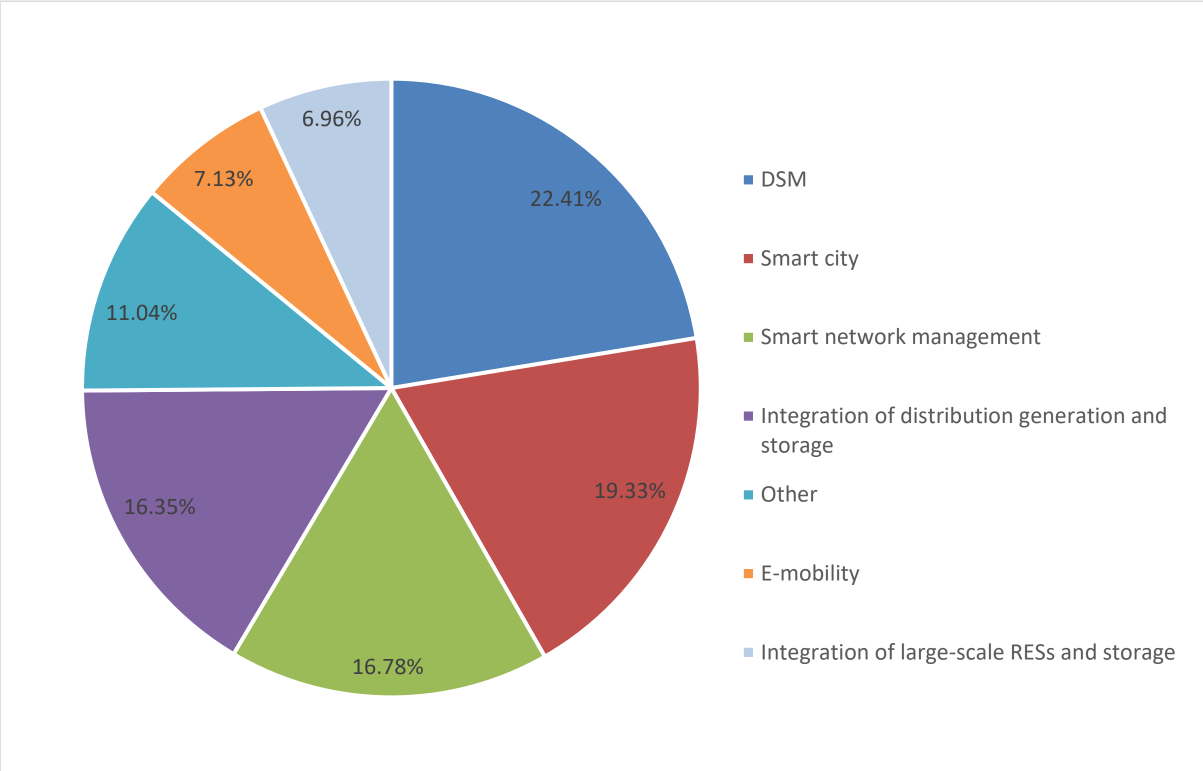
Figure 2-4 Investment and Number of Projects in each Category

	Smart network management	DSM	Integration of distributed generation and storage	Integration of large-scale RESs and storage	Smart city	E-mobility	Other
Demonstration projects: 285	42	135	44	7	23	19	15
Total demonstration investment: EUR 2.62 billion	EUR 413.51 million	EUR 633.43 million	EUR 410.90 million	EUR 196.33 million	EUR 571.60 million	EUR 190.97 million	EUR 201.92 million
Demonstration EU contribution: EUR 1.96 billion	EUR 297.31 million	EUR 461.80 million	EUR 313.73 million	EUR 133.11 million	EUR 449.43 million	EUR 140.36 million	EUR 162.89 million
R&D projects: 122	23	27	27	13	0	8	24
Total R&D investment: EUR 460.41 million	EUR 127.67 million	EUR 78.27 million	EUR 75.21 million	EUR 36.75 million	0	EUR 37.76 million	EUR 104.75 million
R&D EU contribution: EUR 365.96 million	EUR 92.80 million	EUR 59.12 million	EUR 66.32 million	EUR 28.64 million	0	EUR 25.30 million	EUR 93.78 million

Source: Vasiljevska, J., Gangale F., Covrig L., Mengolini, A., Smart Grids and Beyond: An EU research and innovation perspective, EUR 30786 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-36194-7, doi:10.2760/705655, JRC125980.

Figure 2-5 shows the percentage of EU funds allocated to each primary project domain. Four of the seven categories; 'DSM' (22.41%), 'Smart city' (19.33%), 'Smart network management' (16.78%), and integration of distributed generation and storage (16.35%); receive just under 75% of the funding. Of the remaining three project categories, 'Other' receives a significant share of the remainder of the EU funding. This suggests an increased focus on issues such as cybersecurity, standardisation, and development of big energy data platforms aspects of the energy transition (Vasiljevska, 2021).

Figure 2-5 Percentage of EU Funding by Project Category



Source: Vasiljevska, J., Gangale F., Covrig L., Mengolini, A., Smart Grids and Beyond: An EU research and innovation perspective, EUR 30786 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-36194-7, doi:10.2760/705655, JRC125980.

2.1.3 Australia

Australia is advancing various regulatory and technical initiatives to better integrate Distributed Energy Resources (DER) to provide energy and ancillary services. The focus is on analytical, visualising, customer engagement technologies, and smart meters.

The Energy Security Board (ESB) was established in August 2017 by the nation's energy ministers to coordinate implementation of recommendations from the Independent Review into the Future Security of the National Electricity Market. The ESB followed an extensive consultation process and developed a reform plan for the transition of the energy system. The Post-2025 reforms contained recommendations that were approved by the energy ministers (Energy Security Board, n.d.). The four main areas of reform are:

1. Integration of consumer energy resources and flexible demand

2. Transmission and access
3. Essential system services and scheduling and ahead mechanisms
4. Resource adequacy through the transition

An important area within the integration of consumer energy resources is encouraging the participation of DER in a two-way market and incentivising them to provide services that enhance system security and reliability. The ESB's vision is to implement this through unlocking benefits of change for the consumer. The four recommendation areas to accomplish this are depicted in Figure 2-6. They involve:

- A detailed integration plan to resolve technical and market blocks to integration.
- Developing new ways for consumers with DER to be rewarded for providing system services.
- Adopting a tool to assess risks to consumers and put in place adequate protections.
- Removing barriers for consumers to access competitive services from providers including providing data adequate to make informed decisions.

Figure 2-6 Recommendations for Unlocking Benefits for Consumers

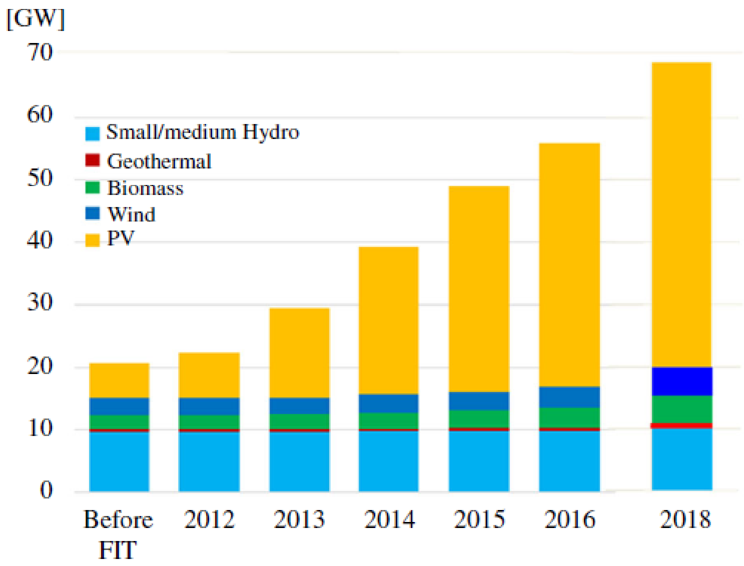
Source: ESB, Post 2025 Electricity Market Design. Available at https://esb-post2025-market-design.aemc.gov.au/

The ESB has been restructured for the delivery phase of the Post-2025 reforms, and comprises the heads of the AEMC (as Chair), AER and AEMO. More detail is provided in Section 5.

2.1.4 Japan

Energy security, economic efficiency, environmental sustainability, and safety are thee guiding principles of Japan's energy policy. Japan has recently diversified its energy mix, increased the efficiency of fossil fuel use, lowered energy demand, and increased integration of renewable energy sources. Japan's FIT policy for renewable energy was implemented in early July 2012 with widespread popular support in order to expedite the deployment of renewable energy. The program employs an incentive system to foster a virtuous cycle of investment, innovation, and cost-cutting measures.

Figure 2-7 Installed Capacity of RESs in Japan



Source: A. Yokoyama, "Toward Deregulated, Smart and Resilient Power Systems with Massive Integration of Renewable Energy in Japan," Wiley Online Library, 2022.

The need for smart grids in Japan is driven by the following trends (Jensterle & Venjakob, 2019):

- Ageing infrastructure.
- Falling prices and rising variable renewable energy sources participation in power networks, along with decentralised energy generation
- Power market liberalisation, along with new market mechanisms and the entry of new players in the generation and retail segments, as well as the necessity to keep power costs at acceptable levels.
- Transportation electrification (both vehicle-to-grid (V2G) and vehicle-to-home (V2H)) and, to a lesser extent, and also electrification in the heating sector.
- Battery storage system market preparedness and deployment, and to a lesser extent P2X technology deployment.
- Hydrogen and fuel cell technologies deployment in the mid to long term.
- Increased commitment to decarbonising the energy system, with a reduced role for nuclear power.

Many programmes, initiatives, and platforms have been formed to promote smart grids and the integration of renewable energy. Many of them are supported by Japanese ministries and national organisations. Status of smart technologies deployment in Japan's electricity grid as of 2018 is shown in the table below.

Table 2-3 Smart Technologies in Japan's Power Grid

S.No.	Technology	Status
1	Smart Communities	Four pilot smart communities (Kansai Science city, Kitakyushu City, Toyota City and Yokohama City) established that are based on smart grid technologies used to optimise energy management, reliably integrate RE sources, and achieve peak demand shift.
2	Smart Metering	Japan has 80 million smart meters in operation (NikkeiAsia, 2023).
4	Grid-connected battery energy storage	Japan is regarded as a global pioneer in utility-scale battery energy storage systems, including businesses such as Panasonic and Toshiba. Batteries are identified as a crucial technology for accomplishing energy policy goals as well as an industrial policy priority in the 5th Strategic Energy Plan.
5	Expansion of EV charging infrastructure	Japan is a global leader in EV charging infrastructure. In terms of publicly available fast chargers, Japan was second only to China in 2018, with approximately 7,600. In 2018, there were approximately 22,000 publicly available slow chargers.
6	Demand Response	In 2017, METI launched the "Negawatt" market. The first auction for demand response (DR) netted approximately 1GW of capacity from industrial and commercial electricity consumers. Demand Side Management (DSM), which aggregates households' demand reduction potentials, has been tested in experimental projects but has not yet been commercialised.
7	Virtual Power Plants	Virtual power plants (VPPs) have been established as pilot and demonstration projects in Japan, but they have yet to reach commercial deployment due to a lack of economic sustainability.

Source: M. Jensterle and M. Venjakob, "Smart power grids and integration of renewables in Japan," adelphi consult GmbH, Berlin, 2019.

In the year 2022, USD 155 billion funding programme was announced towards investing in smart power grids (Drtil, Pastore, & Evangelopoulou, 2023).

2.1.5 Canada

USD 100 million is being invested over a five-year period through the "Green Infrastructure Smart Grid Program". This program focuses on crucial infrastructure to promote the objectives of the Pan Canadian Framework on clean growth and climate change. The program focuses on thedevelopment of utility-led projects which will reduce the greenhouse gas emissions, better utilise the existing electricity assets and promote innovation and jobs for demonstration and deployment of smart grid technologies and integrated systems.

Throughout the program, recipients report on the deployment and grid implications of their projects up to five years after investment. This data is used by Natural Resources Canada (NRCan) to analyse grid impacts and program lessons in order to drive future program and policy development.

The projects funded by this program are listed in Table 2-4, funded by this program. The 21 projects consist of three main project types: Eight deployment projects, seven demonstration projects, and six hybrid projects. By system category there are ten projects in 'Distributed Energy Resource Management Systems' (DERMS), seven in 'Grid monitoring and automation', four in 'micro-grid', two in 'storage' and one in the non-technology category of 'New markets & rate options' (NRO). The categories are not mutually exclusive and some projects are classified across more than one category.

Table 2-4 List of Projects Funded by the Smart Grid Program

S.No.	Recipient	Project Title	Project Type	System category
1	Yukon Energy	Residential Demand Response Program (RDRP)	Demonstration	DERMS
2	EPCOR	EPCOR Smart Grid System (ESGS)	Deployment	DERMS, Microgrid, Distributed energy storage
3	EQUS REA	Canada's 1st Member-Owned Rural Smart Grid Project	Deployment	DERMS
4	ENMAX Power	Integrating Distributed Generation into Secondary Networks in Large Urban Centres	Demonstration	Grid monitoring and automation
5	FortisAlberta Inc.	FortisAlberta Waterton Energy Storage Project	Demonstration	Microgrid-connected
6	City of Lethbridge	Conservation Voltage Reduction (CVR) Deployment in Lethbridge Electricity Utility (LEU) Distribution Network	Demonstration	Grid monitoring and automation
7	SaskPower	SaskPower Distribution Modernization Program	Deployment	Grid monitoring and automation
8	SSM PUC	Sault Smart Grid	Deployment	Grid monitoring and automation
9	Entegrus Powerlines Inc.	Conservation Voltage Reduction	Deployment	Grid monitoring and automation

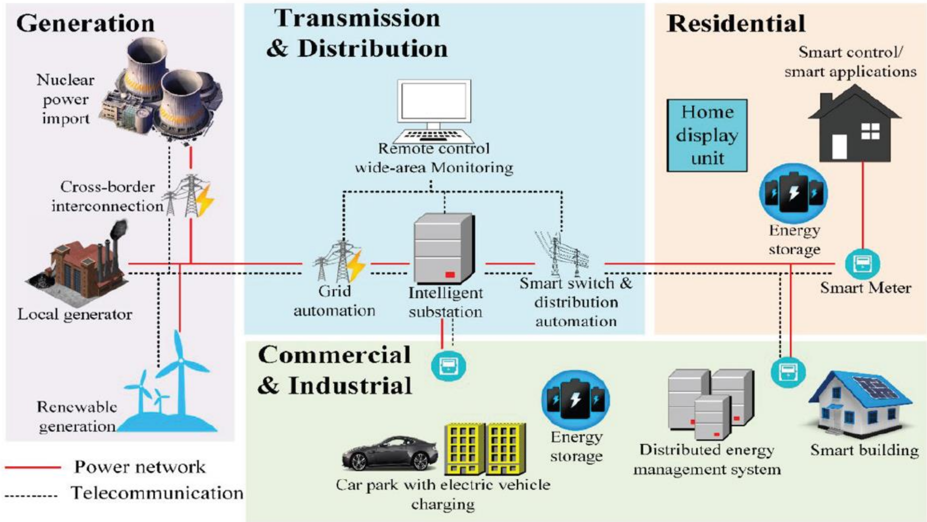
10	Bracebridge	Smart, Proactive, Enabled, Energy Distribution; Intelligent, Efficiently, Responsive (SPEEDIER) Project	Hybrid	DERMS
11	London Hydro	West 5 Smart Grid Project	Hybrid	DERMS
12	Alectra Utilities	Power.House Hybrid: Minimizing GHGs and Maximizing Grid Benefits	Demonstration	DERMS
13	Alectra Utilities	GridExchange	Demonstration	DERMS
14	Independent Electricity System Operator (IESO)	York Region Non-Wires Alternatives Demonstration Project	Demonstration	New markets & rate options (NRO)
15	Lakefront Utilities	Digital Utility Platform	Deployment	Grid monitoring and automation
16	Hydro-Quebec	Smart Grid Deployment of Off-Grid Networks	Deployment	Microgrid off-grid, grid monitoring, automation and storage off-grid
17	Hydro-Quebec	Lac-Megantic Microgrid	Hybrid	Microgrid-connected
18	Saint John Energy	Integrated Dispatchable Resource Network for Local Electric Distribution Utility	Hybrid	DERMS
19	New Brunswick Power	Collaborative Grid Innovation for Atlantic Smart Energy Communities	Hybrid	DERMS
20	Nova Scotia Power	Collaborative Grid Innovation for Atlantic Smart Energy Communities	Hybrid	DERMS
21	PEI Energy	Slemon Park Microgrid Project	Deployment	Microgrid, DERMS

Source: Government of Canada, "Green Infrastructure Smart Grid Program," 2018. [Online]. Available: https://natural-resources.canada.ca/climate-change/green-infrastructure-programs/smart-grids/19793#timelines.

2.2 SG Technology Description and Main Applications

Smart technologies can be deployed in various components and systems of a power grid. Below is a list of the key areas along with a brief description of SG functionality.

Figure 2-8 General Architecture of Smart Grid



Source: J. P. Chaves, P. Bhagwat, S. Kundu, S. R. Kumar and T. Gomez, "Smart Grid Replication: Handbook for India," Florence School of Regulation, 2022.

- Supervisory Control and Data Acquisition (SCADA) and Energy Management Systems (EMSs):

  SCADA and EMSs help monitor and control the power flow in real time. Extra high voltage (EHV) transmission networks, load dispatch centres and control centres have SCADA and EMS to make them smart by integrating real time communication systems and automation into system operations. This is achieved by the SCADA functions namely, data acquisition and data storage from remote terminal units, quality check of collected data, chronological data storage and retrieval for the ease of reconstruction and replay of historical events.

  EMS is a collection of computer-aided tools that electricity grid operators use to monitor, regulate, and optimise the performance of generation assets and transmission systems. The main functions of EMS include network analysis and contingency analysis in real time, monitoring of spinning, operating and regulating reserves, load forecasting, transaction scheduling, and study of power flow, power factor, and grid security.

- Advanced Distribution Management Systems (ADMS)/Substation Automation Systems (SAS):

  In DAS, individual devices connected to the grid will be allowed to sense the operating conditions of the grid around them. The devices employ automatic control techniques to adjust their behaviour to improve the overall power flow and optimise performance of power distribution networks. This improves energy and cost efficiency compared to non-SG applications. In non-SG applications the power systems are analysed manually and, when a fault occurs, intervention is affected by either remotely controlling the devices or dispatching a technician to attend to the fault.

  SAS uses digital relays and communication systems to monitor, control and collect data from substations. The aim is to reduce the duration of interruptions due to equipment failure, natural catastrophes, and outages at substations.

- Wide Area Monitoring System (WAMS):

  WAMS is a warning technology to help prevent system overloading, instability, and cascade tripping resulting in blackouts. WAMS applications require latency in the range of 100ms to 5s. Phasor Measurement Units (PMUs) make it possible for quick, efficient, and accurate measurements from grid equipment. Large volumes of data from the PMUs are captured in milliseconds, time stamped and handled by a fast communication infrastructure.

- Static VAr Compensators (SVC):

  The Australian Market Operator (AEMO) defines SVC as a network device specifically providing the ability to generate and absorb reactive power rapidly in response to voltage fluctuations or voltage instability caused by a disturbance or disruption on the network (Australian Market Operator (AEMO), 2020). Similar definitions are used in other sources for example in (Eremia, Liu, & Edris, 2016)

  According to Institute of Electrical and Electronics Engineers (IEEE) and International Council of Large Electric Systems (CIGRE), “a static VAr compensator is a static VAr generator whose output is varied to exchange reactive currents so as to maintain or control specific parameters of the electric power system, typically bus voltages” (Eremia, Liu, & Edris, 2016).

  SVCs play a crucial role in smart grids by providing reactive power compensation to regulate the voltages and stabilise the power grid. These are particularly useful in mitigating the challenges caused by the integration of renewable energy resources into the power grid (Proctor, A Reactive Solution to Renewables' Growth on the Grid, 2021).

- Distribution Transformer (DT) Monitoring Systems:

  Hundreds of DTs experience overloading and phase imbalances which are potentially damaging. DT monitoring systems can redistribute loads to eliminate phase imbalances in the DT. DT monitoring can help identify DTs that need to be replaced with higher capacity ones to mitigate overloading.

- Outage Management Systems (OMSS):

  OMSS helps identify and resolve outages and reports historical outage information. Geographical Information System (GIS) based OMS result in faster resolutions of power outages. Customer complaint response times can be vastly reduced by using OMSS which enables quick identification of probable faulty locations.

- Demand Response (DR):

  DR typically involves the reduction/shifting of energy consumption from peak hours to off-peak hours by curtailing load at the customer premises. SG applications involve Remote control over the equipment and appliances through communication systems.

- Vehicle-Grid Integration:

  Millions of EVs connected to the grid can be aggregated as Virtual Power Plants (VPPs) to support the grid during power imbalances. Vehicle to Grid (V2G) operations can be implemented with minimal impact on battery life of the EVs by constraining the depth of discharge of the EV battery within specified limits.

- Distributed Energy Resources (DERS) Integration:

  Roof top photo voltaic (RTPV) systems, micro wind turbines and energy storage batteries are typical examples of DERs. More broadly this includes EV, BESS and demand response integration in electricity transmission and distribution systems.

- Advanced Analytics (AA) and Artificial Intelligence (AI):

  SGs equipped with sensors and smart equipment capture operational data in digital format. The big data collected can be used to provide insights into asset performance and customer electricity consumption resulting in efficient network planning and capital expenditure for utilities. AA and AI help utilities improve operational efficiency by acting beforehand thus improving the grid.

- Blockchain:

  Blockchain is a distributed ledger technology built on shared network infrastructure and public key encryption to provide secure transactions through smart contracts. Blockchain-based technologies can be applied at utilities in energy credit management, scaling up of distributed energy resources, asset optimisation, peer to peer (P2P) transactions, etc (Chaves, Bhagwat, Kundu, Kumar, & Gomez, 2022).

- Dynamic Line Rating (DLR):

  DLR is an automated software-based system that uses real time and historical weather and electrical load data to calculate thermal power equipment ratings for overhead lines, underground cables, transformers, and substation terminal equipment. DLR allows for higher loading and improved reliability. Using DLR, electricity utilities can make informed decisions about circuit load limits, increase capacity under relevant weather and load conditions which results in reduced risk of failure under unfavourable conditions (Douglas, Larry, Edris, & Bascom, 2000).

- Geographic Information Systems (GIS):

  GIS maps all the electrical assets with indexes on all customers. This enables the electricity utility to plan and manage its operations accordingly. A GIS system can be unified with other automation systems such as OMSS to increase asset optimisation and shorten response time to fix faults through improved outage detection and faster network restoration (Chaves, Bhagwat, Kundu, Kumar, & Gomez, 2022).

- Metering Data Acquisition System (MDAS):

  MDAS is used for reading meters, consumption monitoring, energy analysis, and billing. This helps electricity utilities achieve energy management goals. MDAS utilises inbuilt metering protocol drivers such as Device Language Message Specification (DLMS), or other communication protocols such as Modbus and Mbus. These protocols aim to transfer meter data securely over the internet (Kalkitech, 2023).

- Advanced Metering Infrastructure (AMI) / Smart Meters:

  A smart meter is a device that can measure the timing and quantity of electricity consumed using a two-way digital communication system. The information is read and stored in intervals, that can be specified, and reported to the retailer daily remotely (NSW Government, n.d.).

A typical AMI structure consists of smart meters, data concentrator unit (DCU), gateway, router access points, a head end system (HES) and a meter data management system (MDMS) with bidirectional communication system over a wide area network (WAN), a neighbourhood network (NAN), and a home area network (HAN) (Chaves, Bhagwat, Kundu, Kumar, & Gomez, 2022).

2.3 Electricity Generation

Many nations that have minimal access to hydro, biofuel, or geothermal energy are focusing on wind and solar technology to provide more sustainable electricity supplies. Wind generation and solar PV technology are rapidly changing, and a continual decrease in costs, combined with a range of government subsidies and incentives, has resulted in increased acceptance during the previous 20 years. Wind and solar PV technologies differ from historically dominant power production methods in various ways, including variability, inverter-based resources, and decentralised nature.

Inverter-based resources (IBR) are devices that connect to the grid using a power electronic device known as an inverter. IBR is used in solar PV systems, high voltage direct current (HVDC) converters, and most modern wind turbines. The inverters digitally synthesise an output to fit the alternating current (AC) waveform of the power supply. These devices work differently than traditional generating systems in coal, gas, and hydro facilities, which use a spinning electro-mechanical generator to connect to the grid (AEMO, 2019).

2.3.1 Smart Inverters.

Integrating high levels of variable renewable energy into electric power systems comes with challenges in maintaining transient and dynamic stability, frequency regulation, and volt/VAR regulation. Previously, inverters merely fed solar power into the grid. Inverters of the future must instead cooperate dynamically with the grid to improve its resilience, reliability, safety, and security. As distributed energy resources come online, smart inverters are a more advanced type of power electronics that can make autonomous decisions to maintain the grid stable and reliable. Instead of simply delivering power into the grid, smart inverters may communicate with it in both directions. According to IREC's "Primer on Adopting the New IEEE 1547 TM-2018 Standard for Distributed Energy Resources," smart inverters may execute specialised grid-supportive activities relating to voltage, frequency, communications, and controls thanks to improved software (Misbrener, 2019).

Australia is a forerunner in the management of high-volume solar penetration on distribution systems. There is 19.5 GW of transmission connected capacity as of May 2023, which includes wind turbines, battery energy storage devices, and solar photovoltaic (PV) power of hundreds of MW for a single installation. Concurrently, renewable energy zones are being built to provide thousands of MW in small areas. Furthermore, due to the expansion of solar rooftop PV installations in the distribution system over the last decade, the NEM today has around 19 GW of distributed PV. These renewable energy sources are all power electronically interfaced, often known as inverter-based resources (IBR) (CSIRO & AEMO, 2023).

The CSIRO (Commonwealth Scientific and Industrial Research Organisation) Research Roadmap investigation of advanced inverter applications covers a wide range of features of the new inverter technologies, from designing control systems to developing tools to facilitate better integration of these technologies. The Global Power System Transformation(G-PST) project aims to improve understanding of grid-forming inverter (GFMI) stability limits and their impact on network stability during faults, as well as the ability of GFMI to support GFLI (grid-following inverter) technology in multi-IBR systems and what control system changes may be possible to improve IBR stability (CSIRO & AEMO, 2023).

The accomplishments of the CSIRO G-PST research programme completed in 2022/23 Stage (CSIRO & AEMO, 2023) include:

- A technical white paper describing the functional requirements for GFMI.
- Adaptive Power Reference Control (APRC) has been developed to increase the transient stability of parallel GFMI-GFLI systems.
- The creation of a modified q-prioritised current limiter for IBR that will improve stability through reducing adverse interactions between internal IBR control loops.
- The creation of an inverter active power freezing function that improves transient stability by preventing power angle development, which could otherwise result in IBR instability.

Furthermore, the Stage 2 study has laid the groundwork for various other IBR control functions that will improve transient stability, which includes, management of negative sequence current reserves of GFMI, and improvements in control systems for multi-IBR system interaction (CSIRO & AEMO, 2023).

However, Australia is not alone in seeking to manage the supply of customer-generated power using the capabilities of smart inverters. Similar issues have surfaced in the United States, with Hawaii's separate island grids housing the greatest per-capita rooftop solar numbers in the country. Certain circuits may have voltage and power flow disturbances because of this. State regulators and utilities have adopted new solar restrictions that restrict power export while also utilising smart inverter capabilities for more active management (Deign, 2021).

California, the state with the most rooftop solar in terms of volume, is also experimenting with how smart inverters may balance local grids through autonomous or utility-linked control settings. State regulators and utilities are in the process of enacting rules that will allow additional solar to be interconnected if it can control its output to prevent overloading circuits during peak production periods. Another solar-heavy state, Arizona, is exploring both utility-controlled and autonomous solar inverter controls to address the same issues. Flexible exports will be the latest in a slew of approaches introduced by SA Power Networks to deal with rooftop solar growth in its distribution region along with smart inverters (Deign, 2021).

2.3.2 Advanced Forecasting

Forecasts of intermittent generation are crucial to ensuring the security of the electricity system and the efficiency of the market. AEMO and ARENA initiated a Participant Forecasting programme in early 2018 to illustrate the potential benefits of wind and solar generator self-forecasting to power system operation. Self-forecasting is expected to provide system-wide benefits by reducing generation forecast error and giving existing semi-scheduled generators more autonomy (AEMO, 2022).

Australian Energy Market Operator (AEMO) operates two forecasting systems, Australian Solar Energy Forecasting System (ASEFS) and Australian Wind Energy Forecasting System (AWEFS).

ASEFS is intended to generate solar generation estimates for big solar power plants and small-scale distributed photovoltaic (PV) systems over timescales ranging from 5 minutes to 7 days. ASEFS is delivered in two different phases, with phase 1 providing forecasts for significant solar farms with registered capacity greater than 30 MW since its operation commencement on 30 May 2014, and phase 2 is involved in generating forecasts for small scale distributed PV systems starting from 30 March 2016 (AEMO, 2022).

ASEFS phase 1 (ASEFS1) forecasts solar generation using a combination of statistical and numerical weather prediction models. The inputs to this system include real time SCADA measurements from the solar power station, weather prediction data from multiple data providers, standing data from the solar power station, additional data such as inverter under maintenance and upper limit of solar farm, and imagery from Himawari-8 satellite. ASEFS phase 2 employs a mix of statistical and physical methodologies, as well as numerical weather prediction models. This system uses various input data similar to phase 1 including numerical weather prediction data from multiple weather data providers, output measurements from selected household rooftop PV systems, aggregate KW capacity by installed postcode for small-scale solar systems as recorded by the clean energy regulator, and imagery from Himawari-8 satellite (AEMO, 2022).

AWEFS was designed in response to the increasing influence of intermittent generation on NEM forecasting operations. AWEFS generates forecasts using the input data which includes, real time SCADA measurements of the wind farms, weather data, standing data, availability information, turbine maintenance data and upper MW limit data from the wind farm (AEMO, 2022).

The National Centre for Atmospheric Research (NCAR) has developed an innovative solar energy forecasting system for New York, which has the potential to help the state meet its renewable energy targets while saving ratepayers millions of dollars. NYSolarCast, an open-source system, uses weather forecasts, observations of atmospheric conditions, and machine learning algorithms to create accurate hours- and day-ahead predictions of solar irradiance and power output. These projections, which are delivered every 15 minutes over a three-kilometre grid covering the whole state of New York, can be used to estimate solar power generation for both large solar farms and rooftop solar panels (Hosansky, 2023).

2.4 The Transmission System

In the United States, 72 balancing authorities have the responsibility for balancing the supply and demand by controlling the generation and transmission of electricity to meet real-time energy demands. To control the power flow within the constraints such as thermals, voltage, etc. and to get alarms for line faults and equipment malfunctions, these entities use energy management services (EMS). Through the supervisory control and data acquisition (SCADA) systems, EMS systems receive data from the field devices, such as grid equipment, line sensors, meters and circuit breakers. The usage of phasor measurement units (PMUs), a sophisticated sensor that has gained popularity in the market since 2009, is still somewhat restricted. Other specialised systems, such dynamic line rating (DLR), manage physical line limits by combining sensors, forecasts, communications, and computing technologies. Modern EMS systems have started incorporating PMU and DLR (United States Department of Energy, 2022).

In Japan, Tokyo Electric Power Company (TEPCO) created a system in partnership with Tecnos Data Science Engineering, Inc. (TDSE) that uses artificial intelligence to automatically identify transmission line faults from video footage taken by helicopters flying over transmission lines in mountainous regions where maintenance workers have limited access. By using this method, it is possible to use video footage captured by drones for transmission line inspection work to automatically identify issues (Jeong, et al., 2021).

In Australia, a transmission network operator called Transgrid developed the Victoria-New South Wales Interconnector (VNI) improvement project by using smart valves developed by a company called Smart Wires, which will boost transfer capacity into NSW from Victoria by 170 MW during periods of heavy demand and is operational as of November 2022. The SmartValve's manufacturer, Smart Wires, claims that the single-phase, modular-SSSC (Static Synchronous Series Compensator) used in smart grid technology injects a leading or lagging voltage in quadrature with the line current. As a result, it may conduct dynamic services and raise or decrease power flows on a circuit (Latief, Transgrid uses smart grid tech in interconnector, 2022).

In contrast to the distribution and consumer systems, which are now developing quickly, transmission systems continue to be relatively mature and established. However, new transmission observability and control requirements are being driven by the deployment of distributed energy resources (DERs) and modifications to distribution planning and operations. Dynamic line ratings (DLR) and Phasor Measurement Unit (PMU) related smart grid transmission technology is described in the parts that follow (United States Department of Energy, 2022).

2.4.1 Dynamic Line Ratings (DLR)

DLR is a technology that allows the transmission line to have additional ampacity depending on local conditions, such as heating from electrical current flow, solar irradiance, and cooling from wind, cooler ambient air temperature contrary to the static rating assumption (INL, 2021).

Transmission line ratings can be used by planners and operators of transmission systems to control risk and dependability. A line may sag into the ground due to exceeding transmission line ratings, which will result in a breakdown and outage. DLR systems allow operators to adjust line ratings for real-time and forecasted conditions to increase available capacity that would otherwise be unused. This is possible because dynamic ratings are frequently higher than the ratings from traditional methods, which are based on static calculations with worst-case assumptions. Since many ISOs/RTOs and utilities are still in the demonstration and piloting phases of proving its capabilities, advantages, and costs, DLR implementation has only been minimal up to this point.

Despite recent technological developments and the potential advantages DLR may offer, obstacles to its widespread implementation still exist. Obstacles include regulatory and market factors as well as a requirement for system planners and operators to incorporate DLR into current systems in a way that minimises new dangers and exposure of operators to unforeseen risks.

A study conducted by American Electric Power expects that implementing DLR on the 345 kV transmission line between the states of Michigan and Illinois at a cost of USD 500,000 is expected to achieve net savings of more than USD 4 million per year through reducing congestion by five percent. This is far lower than the investment of USD 22M to USD 176M for a traditional transmission system upgrade to alleviate congestion, refer to (United States Department of Energy, 2022).

According to the European Network of Transmission System Operators for Electricity (ENTSO-E), current fields of research for improving DLRs are mid-term and long-term forecast adequacy, integration into long term forecast process to fulfil system stability requirements, accuracy of derived values, enhanced combination with weather forecasts. In the year 2015, ENTSO-E's transmission system operators had DLR operations in different extensions. Performance of the best practices include a maximum capacity increase of +40% and +100% compared to static line ratings. Over 90% of the time, ampacity improvements of 10–15% can be anticipated in Europe. The outcomes, however, are very case-specific and reliant on the approach used for impact evaluation (ENTSO-E, 2020).

Best practice applications of DLRs in some of the countries that are EU members include:

- **Belgium/France (2008-2020)**

  27 lines, including all HVAC connecting lines, have DLR systems installed, and both real-time and projected DLR data are used in market capacity allocation and intraday and day-ahead operation planning processes. The system's latest development and validation by surveyor measurements of sag showed that in some situations, up to 200% of its rated capacity was available (ENTSO-E, 2020).

- **Fuendetodos - Maria Line, Spain**

  The research for BEST PATHS is concentrated on repowering current power lines and improving technological understanding and conductor technology application through various improvements. By creating a prototype DLR system based on inexpensive sensors that enables higher temperature operations of present line technologies, DEMO 4 has addressed the following objective. The installation of the DLR sensors on a transmission line in Spain is a component of the BEST PATHS project (ENTSO-E, 2020).

- **Germany (2015)**

  On several massively loaded OHL, DLR is employed. Most of the German TSO dispatching centres that exchange the ratings online have the system incorporated (ENTSO-E, 2020).

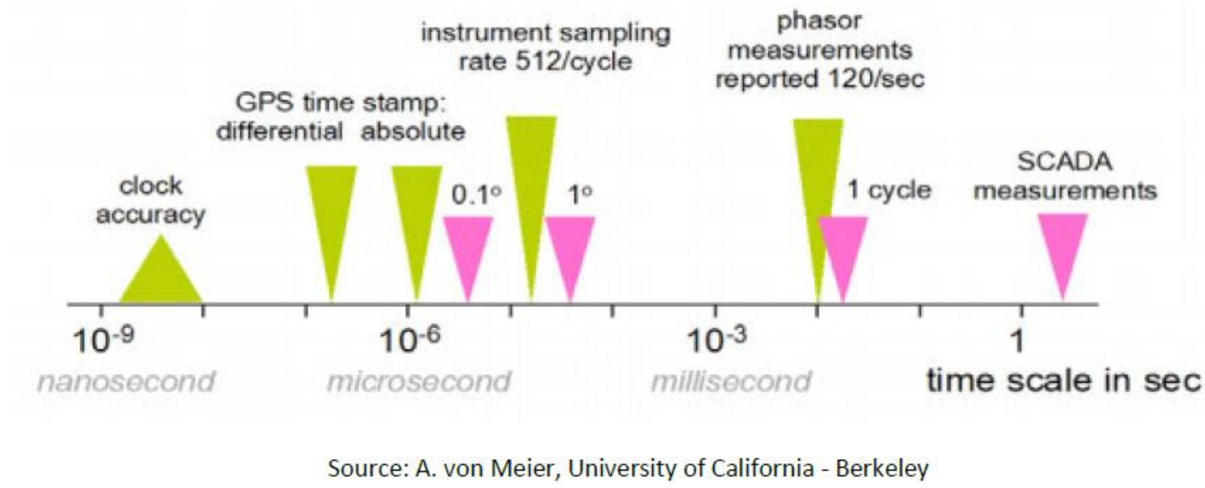
- **Slovenia (2013-2017)**

  The DLR system consists of 29 lines, including 6 400 kV, 4 220 kV, and 17 110 kV lines. The system is integrated into daily use and is completely operational. The mitigation of N and N-1 overloaded operational scenarios and estimations of transmission capacity for up to two days in advance are the key applications that support real-time operation and operation planning. Inverse DLR algorithms for icing prevention and alarms for adverse weather conditions are also included in the system (ENTSO-E, 2020).

2.4.2 Phasor Measurement Units (PMU)

A PMU calculates synchrophasors which are phasors each with a corresponding UTC reference timestamp. A phasor represents the magnitude and phase of voltage and current waves as a complex number. PMUs are often deployed at substations. They use analog-to-digital converters to collect samples of voltage and current to capture phase, frequency and amplitude of these wave forms, assumed to be sinusoidal. A synchrophasor system is made up of time-synchronised PMUs. PMUs are capable of reporting data at a much higher frequency (millisecond) than SCADA (typically four to six seconds). Figure 2-9 shows the relative time scales of measurement and sampling including for PMU and SCADA.

Figure 2-9 Relative Time Scales of Measurements and Sampling



Source: 2020 Smart Grid System Report, January 2022. USA DOE.

The high frequency data of a PMU system can be utilised in real-time to determine the overall health of a power system. This information enables system operators to make well-informed decisions concerning power system control. The data can also be saved for subsequent analysis. Understanding the source of a power outage is a common use case for such preserved data (Carlon, Brancaccio, Rhodes, Volpert, & Jones, 2020).

The Australian Renewable Energy Agency (ARENA) has sponsored a project NOJA Power, Australia's electricity utilities, and universities to assess the advantages of using PMU data. The PMU, integrated into Power Recloser Controllers, were installed at 100 sites across Australia. The early results of PMU technology applications in networks are encouraging. The advantages of integrating renewable energy safely and consistently are obvious. Wide-area stability protection schemes, which offer an intriguing possibility for more study and applications, require PMU data as well (NOJA Power, 2022).

The goal of the North American SynchroPhasor Initiative (NASPI) is to increase power system reliability and visibility by promoting the usage and capabilities of synchrophasor technology. By 2017, over 2,500 PMUs were installed in North America, of which, 1380 PMUs were installed with the support of The American Recovery and Reinvestment Act (ARRA) synchrophasor project. The prospects for utilising PMU technology face a number of technical and institutional difficulties. PMUs have low initial capital expenditures but substantial operating and maintenance costs to operate field equipment, communication networks, and databases. With a single PMU generating about two million data points each day, the proliferation of PMUs presents a significant data burden for system operators. (United States Department of Energy, 2022). Industry standards such as IEEE C37.118.2-2011 address some aspects of this issue. Furthermore, the potential of utilising synchrophasor data for real-time operations has cybersecurity challenges, the most notable being the NERC CIP standards. The high bandwidth, high frequency, and sheer volume of PMU data necessitate requirements for implementing analytics, visualisations, and information storage and retrieval systems, all of which are now under development (United States Department of Energy, 2022).

PMUs have limitations. The guide published by the USA DOE to assist users in selecting and using measurement systems effectively to suit their applications (Follum, et al., 2021) refers to key limitations of PMUs in certain cases. They fit the collected data to a sinusoidal model which can result in unreliable measurements when the actual source data is non-sinusoidal. Point-on-Wave (POW) and continuous POW applications could be more suited in such circumstances. PMUs can also find it difficult to detect stability issues when IBR penetration is high. This limitation is mainly due to the use of generic IBR models instead of user-defined models. The interaction between IBRs and other electronic components of the control system raises the need for electromagnetic transient (EMT) modelling of IBRs in some cases. The resultant non-sinusoidal waveforms of EMT makes PMUs unsuitable for such cases.

2.4.3 Static VAR Compensators

The global Static VAR compensator is on the verge of exceeding the USD 815 million milestone by 2023, demonstrating a spectacular CAGR of 6.5% through 2033, eventually reaching a worth of USD 1526 million. Sales of Static VAR compensators, which are generally used to regulate voltage changes, are driving the market. SVCs regulate voltage in transmission lines and the quality of power supply in major industrial sectors, the railway industry to replace existing grids, and planned solar and wind power plants. China's position as a market leader in the static VAR compensator market is being bolstered by a number of variables that are contributing to the country's projected market size of USD 392.0 million by 2033, representing a 7.9% increase from 2023 to 2033. Furthermore, China's robust power infrastructure construction and rising use of renewable energy sources drive demand for SVCs, assuring stable grid stability and efficient power management. The United States has a well-established and modern power infrastructure, and efficient power management and grid stability are in high demand. This necessitates the use of SVCs to adjust voltage, improve power factor correction, and handle power quality issues. The country is at the forefront of renewable energy adoption and grid modernisation, efforts that are predicted to promote the market in the country, assisting in the market size of USD 236.3 million by 2033. Furthermore, the incorporation of renewable energy sources such as solar and wind power necessitates the use of modern power electronics solutions such as SVCs to preserve grid stability and optimise power transmission and distribution. The favourable regulatory environment and government initiatives in the United States are important factors driving the Static VAR Compensators market. Furthermore, rules that promote clean energy and energy efficiency incentivise utilities and industry to invest in SVC technology. According to Future Market Insights (FMI), the United Kingdom Static VAR Compensator is expected to grow at a 4.9% annual rate from 2023 to 2033, generating around US$ 38.8 million in revenue by 2033. With an emphasis on voltage control and reactive power management, the market offers numerous chances for manufacturers and suppliers to develop their presence and meet the region's expanding demand (Kaitwade, 2023).

SVCs were installed at the Para and South East substations in 1989 as part of South Australia's interconnection with the eastern state. In 2016, ElectraNet, an electrical transmission company in South Australia, made significant upgrades to existing SVC systems that have minimal SCADA controls and fault investigation capabilities. These upgrades included replacement of control and protection systems and installation of 50 Mvar 275 kV reactor at Para substation to control excessive voltage levels that are expected to occur during periods of low demand, high wind generation, and base load generator outage. The modern digital systems installed will reduce analysis response times following a trip (ElectraNet, 2016).

2.5 The Distribution System

In the past, distribution system planners and operators had limited visibility and control over distribution systems, but this has changed in recent decades as intelligent field devices, communications, and back-end software systems have proliferated. System operators have begun using a variety of sensors and field equipment to assess grid status and take appropriate action. Now, the control actions are increasingly being performed by automated, closed-loop systems. For example, an ADMS can employ distribution SCADA (D-SCADA) to collect voltage and current information from sensors and protective device controls in order to automatically manage voltage or restore power after an outage.

According to the U.S. Energy Information Administration (EIA), in 2019, nearly USD 51 billion was invested by the U.S. distribution utilities (approx. 3000) for improving the distribution grid, of which the distribution grid capital investment for investor-owned utilities reached USD 39 billion. From the historic growth trend, it is expected that these investments are likely to continue growing.

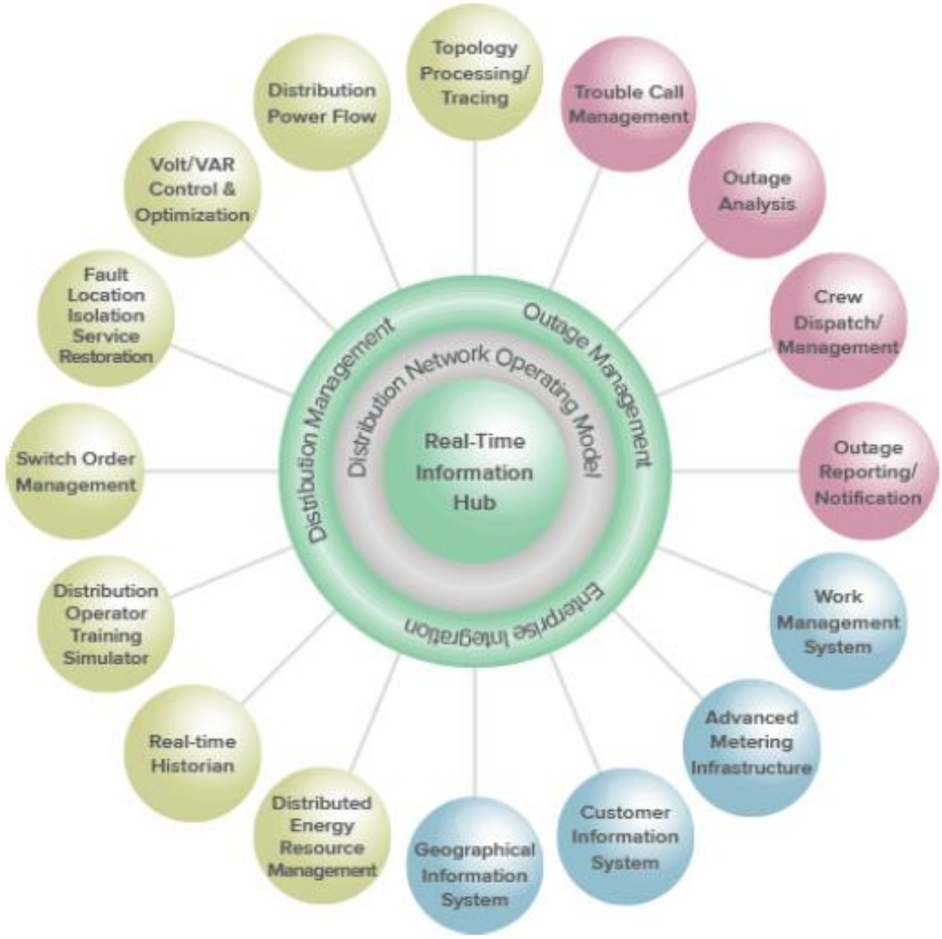
Across the United States, distribution system owners are embarking on a lengthy process of extending the cyber layer from distribution substations (the interface with transmission) to the grid edge where customers are served. The sections that follow describe technologies and applications that are part of the present distribution system transition (United States Department of Energy, 2022).

2.5.1 Advanced Distribution Management Systems

ADMS creates an integrated view of the distribution operations by interacting with other operational systems like GIS, OMS, and CIS. ADMS can gather, organise, display, and analyse real-time distribution system information across several platforms and supports grid operations. These systems enable operators to manage distribution system operations to improve system efficiency, reliability, and avoid overloads. ADMS provides features such as a granular historical power flow data, precise and well-organised network model to help the distribution planners.

In the United States, the ADMS midrange market is anticipated to be worth over USD 80 million in 2020 and is expected to rise to more than USD 200 million by 2026. When considering ADMS deployment, utilities must overcome several technical issues. The primary concern is the availability and robustness of the network model and integrity of system data. Successful implementation of ADMS requires the integration of other systems such as GIS, quality assurance systems, and the ability to execute power flow solutions and fault location analysis using systems such as Fault Location, Isolation, and Service Restoration (FLISR). In addition to technical and integration challenges ADMS requires significant investment utilities and must have a compelling business case with clear identifiable benefits. Refer to (United States Department of Energy, 2022).

Figure 2-10 ILLUSTRATIVE ADMS INTEGRATION OF DISPARATE SYSTEMS, FUNCTIONS, AND DATA



Source: 2020 Smart Grid System Report, January 2020. US Department of Energy, DC.

Ausgrid, largest electricity distributor in Australia, proposed to invest $59.9 million in Advanced Distribution Management System for FY 2020-2024. This investment is at the heart of a plan to update Australia's dated control system and revamp the network management environment to better serve the customers' needs and benefit from technological advancement. The traditional Distribution Network Management System (DNMS) was proposed to be replaced with the ADMS. The ADMS will also make it possible to integrate and rationalise a number of outdated ancillary systems that support operations, planning, and design. The scope also addressed the need to onshore all Ausgrid data during implementation and introduced a staggered implementation method to reduce implementation risk. Three phases are planned for the delivery of the ADMS implementation project: phase one involves replacing the DNMS, phase two involves replacing the Outage Management System (OMS) and satellite systems, and phase three involves aligning to the vendor's baseline product and delivering ADMS Advanced Applications. In December 2018 the ADMS installation began after Ausgrid Board clearance (Ausgrid, 2019).

The DSO of "KEPCO (Korea Electric Power Corporation)" has been working on developing ADMS (Advanced Distribution Management System) for four years, starting in 2017. The first project took place at the Chung-buk branch over a 23-day period commencing on July 6, 2021. This field test location was chosen due to the variety of power infrastructure it already had in place, including its 11 distribution substations (154 kV), 131 distribution lines (22.9 kV), and 1,890 breakers and switchgears. In addition, 441 DERs (Distributed Energy Resources) have been connected, with a total installed capacity of 66 MW, primarily from solar power. The ADMS server system demonstrated its suitability for HQ level application throughout the event. As a result, 15 integrated large-scale server systems used for ADMS might replace the 190 distributed server systems currently utilised for DAS. KEPCO estimates that by doing this, it will save about $60 million over the next 20 years, which it will use to build and maintain a new system (KEPRI, 2022).

Germany's market was the leader in the Europe Advanced Distribution Management System Market by Country in 2021, and it is anticipated to hold this position through 2028, resulting in a market value of $404.1 million. From 2022 to 2028, the UK market is projected to expand at a CAGR of 18.7%. Additionally, a CAGR of 20.7% is anticipated for the France market from 2022 to 2028 (KBV Research, 2022).

2.5.2 Fault Location, Isolation, and Service Restoration (FLISR)

FLISR is a software application and set of field devices that automate distribution operations to enable the detection and fast response (in seconds) to restore power to customers in response to grid events, such as storm-induced outages. FLISR systems include line sensors, automatic switches or reclosers, communication networks, and a control system. FLISR can be implemented within centralised systems (such as ADMS) or in distribute control environments. FLISR is best suited to grid architectures characterised by distribution grids that tie into each other (typically urban environments) to allow the execution of power rerouting options. FLISR deployments on a large scale can assist utilities in improving grid performance as evaluated by standardised parameters connected with outage average duration and frequency. According to a 2016 DOE report containing results from 62 Smart Grid Investment Grant projects implementing distribution automation technologies, five utilities reporting on reliability improvement over one year found that distribution automation reduced the number of interrupted customers by 55% and the number of customer minutes interrupted by 53%. Refer to (United States Department of Energy, 2022)

In Australia, distribution service providers have started incorporating FLISR technology. Over 130,000 consumers in south-east Melbourne and the Mornington Peninsula have had their power automatically restored 90 times since the FLISR technology, created by United Energy, first went into operation in 2017. FLISR's effectiveness was recently demonstrated during a fault in the Donvale region, which initially had 3,200 customers affected but was quickly reduced to less than 270 consumers. United Energy has also started making advances after the success of initial implementation in 2017 by increasing the capability of FLISR to respond to more complex faults (United Energy, 2023).

Beginning in March 2022, Jemena will use cutting-edge network restoration technologies throughout its energy distribution network in Melbourne's north-west. The Fault Location, Isolation and Service Restoration (FLISR) system is now operational across Jemena's high voltage network and is currently transmitting real-time information back to the Jemena control room after significant trialling over the course of more than a year. This programme is the initial step in creating a "self-healing" network and is a component of Jemena's Advanced Distribution Management System (ADMS) (Jemena, 2022).

In the European Union, the distribution grid's resilience is a growing concern for distribution system operators (DSOs) due to variables such as climate change and the associated faults produced by harsh weather conditions, which cause service disruption to consumers. Loss of service has a negative impact on the DSO's key performance indicators (KPI), such as customer minutes lost (CML) and customer interruptions (CI) and can result in financial penalties imposed by the regulator. In 2021, A software-driven Fault Location, Isolation, and Service Restoration (FLISR) solution that combines modern software and communication technologies with the DSO's existing infrastructure to aid fault detection and resolution, with the goal of reducing CMLs and CIs and reducing financial penalties, was tested in a region of south-east Ireland with a higher rate of service loss than more inland areas, providing an excellent environment to assess the technology's performance. It was discovered that the solution generated outputs that might potentially lead to the resolution of fault events faster than the DSO's current systems. Based on the results obtained from running the FLISR solution on an active grid, it has been demonstrated that combining modern software technologies with existing grid infrastructure benefits both the DSO in terms of grid management and operations and the customer in terms of site quality (Ryan, Power, Hayes, & Davy, 2021).

2.5.3 Substation Automation Systems (SAS)

In SAS, automation is done for monitoring, controlling and collecting data from substations which will reduce the duration of interruptions caused due to equipment failures, natural catastrophes, and outages at substations. This is accomplished by using digital relays and communication systems that are to be operated remotely by the electricity utility.

IEC 61590 is an international standard for communication in substations. It is a modern communication standard that allows advanced applications to access and interpret data from substations. This standard specifies digital communications protocols as well as models for application functional information in protective relays and other intelligent electronic devices used in power distribution systems. IEC 61850's key features are (i) data models that share standardised information in automatically configured functional groups, and (ii) the use of protocols that run over Ethernet local and wide-area networks. An engineer will select IEDs (with HMI and remote servers), perform function-level design integration with software tools and standard archives, install IEDs and connect fibres, download integration files and application settings, commission-test whole functions, respond to failure alarms in service, and turn detailed data into information for the entire organisation using an IEC 61850 standardised design (Clermont, et al., 2020).

According to Future Market Insights, the global substation automation market will be worth USD 29.12 billion this year, rising to USD 55.59 billion by 2032, driven by rising demand for electric and hybrid vehicles, as well as increased use of digital technology to improve grid efficiency. According to Smart Energy International, Europe will spend USD 23.9 billion over the next decade to automate or monitor secondary substations. Utilities in France, Italy, and Spain are likely to make the largest investments in equipment and services to enable substation automation (Latief, Substation automation market to boom to $55.6bn by 2032, 2023).

Substation automation has an optimistic outlook in Europe, as grid operators strive to modernise infrastructure for increased reliability and efficiency. For more than a decade, transmission system operators (TSO) and distribution system operators (DSO) have universally recognised substation automation as a vital instrument for improving the performance and stability of the European power grid. Substation automation has provided various benefits to European grid operators, the most notable of which is the capacity to boost power system resilience. In comparison to centralised substation automation, distributed architecture substation automation has emerged as the dominating technology. This adaptable and dependable approach to substation automation is ideal for the demands of current power networks. France and Germany lead the regional market for substation automation deployment, accounting for over one-quarter of global market share. While the transmission and distribution sectors continue to be important application areas for substation automation, automation technologies are also being used more frequently in the generation sector (Tariq, 2023).

The global market for substation automation appears to be highly competitive. Market leaders are spending in R&D to continuously reinvent their products and are progressively seeking market expansion through various strategic mergers and acquisitions, innovation, and a cost-effective product range (Mordor Intelligence LLP, 2019).

2.5.4 Distributed Energy Resource Management System

A distributed energy resource management system (DERMS) is a software application that provides an operator with real-time visibility into the state of distributed energy resources (DERs) and the controls required to integrate and optimise DERs in support of grid operational objectives. One of the primary DERMS functions is to maintain DER aggregations, forecast their capability, and connect with other DER aggregators.

In response to the increased emphasis on DERMS as a result of expanding DER penetration, the industry has produced technical standard, IEEE P2030.11, that defines DERMS functional standards to better facilitate grid services from microgrids and DER. Furthermore, IEEE 2030.5 standardises DER communications with DERMS, whilst IEEE 2030.7 (the Standard for the Specification of Microgrid Controllers) aids in the standardisation of microgrid operational communications. These standards, when combined, begin to establish end-to-end interoperability for microgrids and groups of DER.

Although 23 utility-led DER aggregation activities were initiated in the United States by late 2018, DERMS is still in its early phases of adoption, with many utilities actively studying or evaluating the variety of potential commercial alternatives. The DERMS market is expected to be worth between USD 69 million and USD 85 million in 2020, rising to between USD 110 million and USD 160 million by 2024.

Many early pilots and demonstrations focus on a subset of feasible DERMS functionalities (for example, transactive energy for behind-the-meter DER). Southern California Edison, for example, uses a DERMS to control electric vehicles (EVs), batteries, and solar PV in response to real-time market price signals. The project will put to the test the idea of expanding the bulk electric system's long-standing feature of security-constrained economic dispatch to the distribution system level. The three-year initiative, which is partially funded by a DOE grant, aims to develop an interoperable, distributed control system. Similarly, Arizona Public Service is integrating a DERMS with a portfolio of customer and utility DER devices to cut peak demand and shift load (United States Department of Energy, 2022).

In 2019 in Western Australia, Australia’s first distributed energy resources management system (DERMS) was introduced to manage distributed energy resources (DERs) spanning approximately 1 million square miles, with an emphasis on efficiency and dependability by a company called Horizon

Power. Horizon Power will benefit from PSiXE's Active Control Technology (ACT) system, which will enable continuous, high-resolution view into the operations of solar panels, batteries, and generators. The ACT system, which is part of PSiXE's platform, is meant to automatically respond to transmission grid conditions to balance any intermittency. To enrich, analyse, and respond to grid data from various power resources, the PXiSE ACT platform runs on a normal Windows platform with embedded OSIsoft software and synchro-phasor data. It provides constant higher-resolution visibility and uses artificial intelligence to balance the electrical grid's mix of renewable energy, storage, and traditional generation (Proctor, DERMS Technology Part of Australia's Push for Renewables, 2019).

2.6 Customer Systems

The third significant area of investment in grid modernisation is made up of electricity consumers and aggregators who use EMS in residences, commercial buildings, and manufacturing facilities. These resources will gradually be co-ordinately incorporated into the larger electric system. By 2018, there had been a large increase in the amount invested in these systems, and EV sales had also climbed. Customers from the commercial, industrial, and residential sectors are engaging with the electric grid more frequently. While historically utilities primarily considered customers as energy consumers, the increasing use of DERs and smart grid technology has given consumers active control over both energy generation and consumption (United States Department of Energy, 2022).

2.6.1 Advanced Metering Infrastructure

AMI deployment is often classified into one of two waves. As part of the initial wave, utilities primarily implemented AMI to support consumer billing, enhanced rate implementation, and some specific utility operational use cases, largely fuelled by ARRA financing. However, the second wave of AMI implementation, which is currently under progress, includes a shift to greater edge computing and interoperability with home networks. This second wave enables utilities to improve advanced outage management and voltage management skills, support a developing planning and operations capacity of load disaggregation, and automate procedures such as service orders and consumer alerts.

In the United States, as of 2022, about 119 million smart meters have been installed by electricity utilities, which is about 72% of total meter installations.

Table 2-5 Smart meter installations

Residential	Commercial	Industrial	Transportation	Total
104,237,855 (73%)	13,908,481 (69%)	542,726 (68%)	1,879 (55%)	118,722,741 (72%)

Source: Frequently Asked Questions (FAQs) - U.S. Energy Information Administration. (2022). Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA). Retrieved September 21, 2023, from https://www.eia.gov/tools/faqs/faq.php?id=108&t=1

Of the total AMI installations, residential smart meters contributed to 88% installations (U.S. Energy Information Administration, 2022).

In the United States, the Advanced Metering Infrastructure cost assumptions are as follows.

Table 2-6 Advanced Metering Infrastructure cost assumptions

Residential Meter	Cost (USD, 2016)	Cost (USD, 2022 adjusted)
Meter + AMI	\$40-\$80/unit	\$48.8-\$97.6/unit
Meter + AMI + Disconnect	\$70-\$130/meter	\$85.4-\$158.5/meter
Meter + AMI + Disconnect + HAN	\$80-\$140/meter	\$97.6-\$170.7/meter
Commercial and Industrial Meter		
Meter + communications	\$120-\$150/meter	\$146.3-\$182.9/meter
Installation Cost		
Residential	\$7-\$10/meter	\$8.5-\$12.2/meter
Commercial and Industrial	\$20-\$65/meter	\$24.4-\$79.3/meter
AMI network and blackhaul equipment	\$3-\$11/endpoint	\$3.7-\$13.4/endpoint
Head and software and integration	\$4-\$10/endpoint	\$4.9-\$12.2/endpoint
System initiation and management	\$2-\$4/endpoint	\$2.4-\$4.9/endpoint
Ongoing maintenance	\$3 - \$11/year/endpoint	\$3.7-\$13.4/year/endpoint

Source: Asian Development Bank. (2016). Outlook for Increased Adoption of Smart Grid Technologies in ADB Energy Sector Operations.

Regardless of whether the deployments are first or second wave, utilities face additional issues with AMI adoption. Regulatory commissioners in several states, for example, have rejected utility AMI proposals in recent years due to concerns about the investment's cost-effectiveness and a lack of measures to clearly quantify the investment's performance. Separately, because AMI introduces potentially hundreds of thousands or millions of entry points to acquire customer data, the question of how to strengthen cybersecurity to prevent attackers from targeting data, networks, or physical devices is a constant focus (United States Department of Energy, 2022).

According to a study from March 2020 (Directorate-General for Energy, 2020) , the deployment of the smart meters in the European Union is as follows,

- By 2024, the EU will have installed up to 225 million smart meters for electricity and 51 million for gas, representing a potential investment of about EUR billion.
- By 2024, 77% of consumers will have smart meters for electricity and 44% of the consumers will have smart meters for gas.
- The average cost of installing a smart meter in the EU is between 180 and 200 euros.
- Based on data from pilot projects, smart meters often result in energy savings of at least 2% and as much as 10%, as well as savings of €230 for gas and €270 for electricity per metering point (divided among users, suppliers, distribution system operators, etc.)

The Australian Energy Market Commission (AEMC) targets to install smart meters in all the homes and small businesses that are a part of the National Energy Market (NEM) by 2030 (Singh, 2023). They are planning to achieve this through,

- A framework that helps create smart meter installation programs for retailers through plans developed by Distributed Network Service Providers (DNSP).

- Streamlining the smart meter installation process, familiarising the customers with the benefits from smart meter data and services to create a more positive customer experience through supporting recommendations (Singh, 2023).

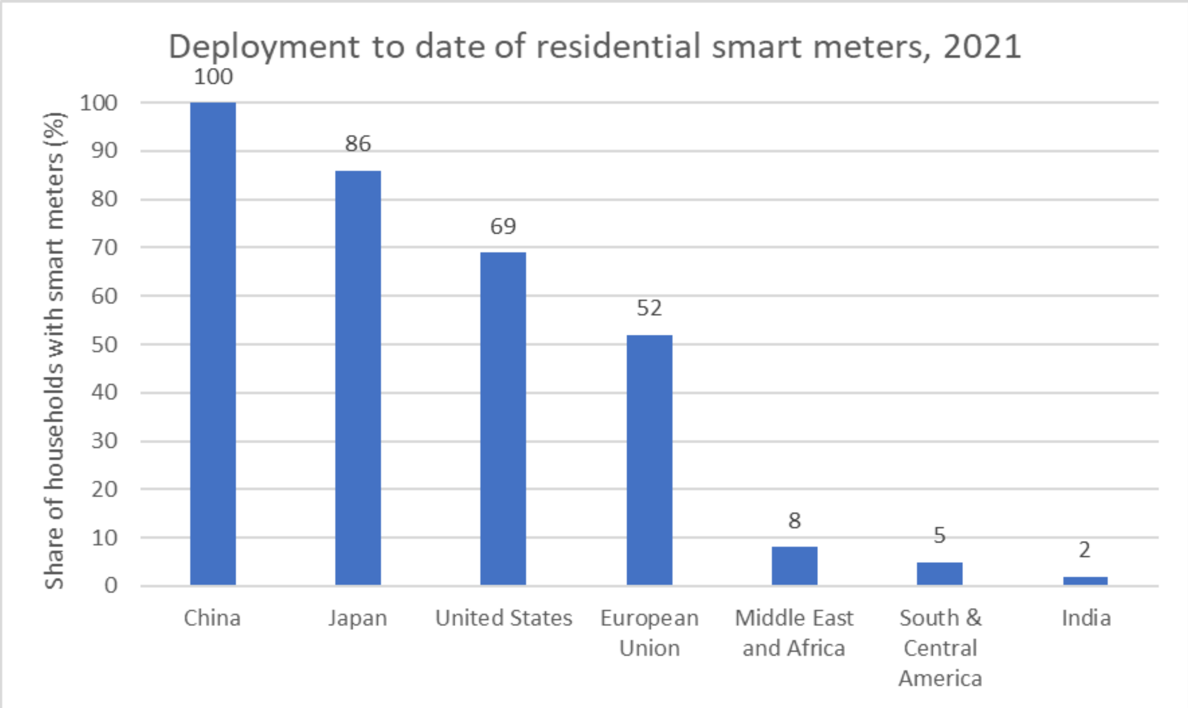
Key recommendations and feedback regarding the state of smart metering in Australian Energy System by AEMC (Singh, 2023) include,

- By 2030, universal uptake of smart meters in NEM jurisdictions. DNSPs to develop an annual schedule to retire the legacy accumulation and manually read meters. During this five-year acceleration period, retailers are responsible for installing smart meters across these sites.
- AEMC has identified and developed measures to provide support to the customers in transitioning to smart meters by protecting them from unexpected cost increases and providing them with clear information and rights under the framework.
- AEMC has identified opportunities to improve efficiencies in the current metering framework by improving transparency and information availability to customers, reducing the regulatory burden on retailers and DNSPs, and reducing delays in meter replacements.
- So that consumers and the industry can get more value out of this investment, AEMC has established steps to improve access to a wider range of data and services offered by smart meters. AEMC advocates for enhanced consumer real-time data access as well as DNSP access to power quality data from smart meters.

International Smart Grid Action Network (ISGAN) conducted a multinational prioritised assessment of smart grid technologies in the years 2014 (Australia, Canada, China, Finland, Germany, India, Ireland, Italy, Japan, Korea, Mexico, the Netherlands, Russia, Singapore, South Africa, Spain, Sweden, Switzerland, and United States) and 2020 (Australia, Austria, Belgium, Canada, France, Germany, India, Ireland, Italy, Japan, Korea, Malaysia, the Netherlands, Spain, Sweden, Thailand, the United Kingdom, and Vietnam) with the purpose of analyses of common motivating drivers and driver-technology pairs at the national level across all nations participating in the survey. According to the results of this survey, 'Advanced Metering Structure (AMI)' is chosen as the top technology in both 2014 and 2020, indicating that AMI is not only expected to be fully propagated in the upcoming years but has also been progressively deployed in many nations. It demonstrates that the AMI is the fundamental technology for smart grids and the key foundation for some prospective revenue models (An & Bae, 2021).

Figure 2-11 shows the percentage of households with smart meters installed in countries across the world as of 2021. Even though the deployment of residential smart meters has improved in recent years, reaching 100% in some economies such as China, the share remains quite low in many nations (Drtil, Pastore, & Evangelopoulou, 2023).

Figure 2-11 Smart meter deployment in households across the world



Source: Drtil, M., Pastore, A., & Evangelopoulou, S. (2023, July 11). Smart grids - IEA. International Energy Agency. Retrieved September 21, 2023, from https://www.iea.org/energy-system/electricity/smart-grids#tracking

2.6.2 Electric Vehicles and Charging Infrastructure

EVs are an emerging technology, with estimates for overall EV adoption in the United States by 2030 ranging from roughly 1.5 million to 6 million. Accessibility to charging stations is a crucial factor in enabling further EV deployment and in the United States, there are more than 3,000 private charging stations with over 13,000 outlets and approximately 26,000 public charging stations with more than 82,000 outlets as of June 2020.

This anticipated increase in EVs, which will include the electrification of commercial and industrial vehicles as well as bus fleets, will present both opportunities and challenges for the grid. One difficulty is that more EVs charging at once could lead to spikes in electricity demand, which might make certain parts of the grid unstable if overall demand exceeds the system's capacity (United States Department of Energy, 2022).

Projects being funded by the Australian Renewable Energy Agency (ARENA) evaluate various strategies for maximising the use of EVs. ActewAGL Retail (ACT) is one project that shows how an EV fleet can perform functions that grid-scale batteries and virtual power plants can. The EVs utilised in the study can send electricity back to the grid in addition to charging from mains power or rooftop solar. With the assistance of AusNet Services, Evoenergy, TasNetworks, United Energy, and Jemena (Victoria), a different study is investigating the use of hardware-based smart charging to dynamically manage residential electric vehicles (Australian Energy Regulator, 2022).

The EU Commission has established aggressive CO2 targets for the transportation sector. The EU's "Fit for 55 Package," released in July 2021, outlined aims to cut emissions by at least 55% by 2030 (relative to 1990 levels) and become the world's first climate-neutral continent by 2050. All sectors of the economy, including transportation, are expected to contribute to reaching these reductions. Transport is one of the few industries where glasshouse gas (GHG) emissions have been increasing since 1990, accounting for over 20% of total EU GHG emissions.

The EU has expedited its transition to e-mobility during the last couple of years. With approximately 20% EV sales in 2021, Europe has moved ahead of China and the United States in terms of electrification. Over the next decade, Europe has the opportunity to establish a world-leading ecosystem for zero-emission mobility. If all industry stakeholders collaborate successfully along the lines of this masterplan, Europe can serve as a role model for an integrated zero mobility transition, enabling healthy business models along the value chain, creating new jobs, and increasing the transport sector's GDP contribution. The diversity of Europe's mobility footprint is both a challenge and an opportunity (ACEA - European Automobile Manufacturers' Association, 2022).

2.6.3 Grid-Interactive Efficient Buildings and Connected Communities

A growing number of consumers can connect their homes, businesses, and other buildings into grid operations as a flexible resource thanks to the developing technical capabilities known as "grid-interactive efficient buildings" (GEB). According to U.S. Department of energy, GEB is defined as "an energy-efficient building that combines smart end-use technology and/or other onsite DERs to provide demand flexibility while continuously and seamlessly co-optimising for energy cost, grid services, and occupant demands and preferences is known as a grid-interactive efficient building (GEB)."

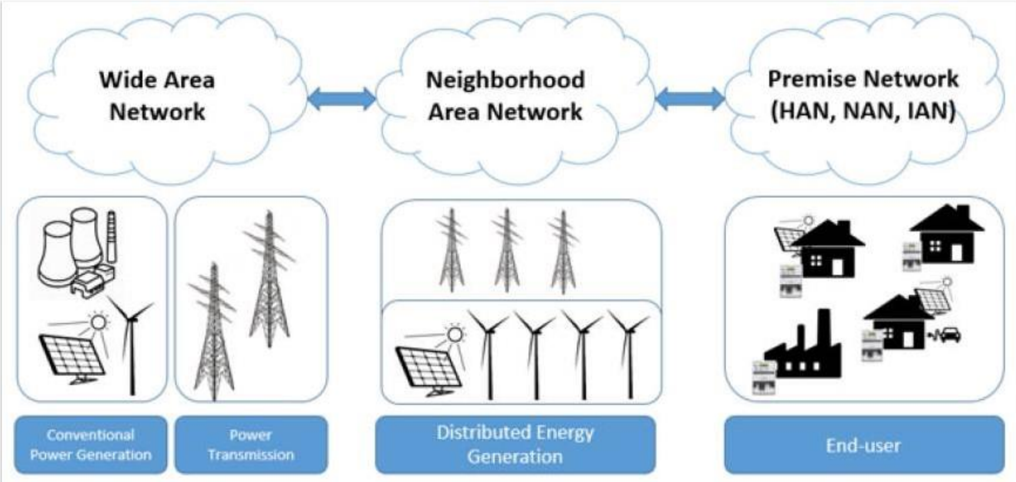
Portland General Electric's (PGE) Smart Grid Test Bed is actively investigating how the utility can target three neighbourhoods to use energy from new technologies, programmes, and products while allowing customers to maintain control over their comfort and supplying clean, reliable, and affordable energy. This is one effort to test the capabilities of GEBs. PGE aims to boost dependability and service quality by combining customer initiatives (such as rebates for using batteries during peak hours and incentives for their adoption) with modifications to current feeders and substations (U.S. Department of Energy, n.d.).

On 22 June 2023, The Green Building Council of Australia (GBCA) launched its first report on grid-interactive buildings, emphasising their importance in attaining a zero-carbon future. As the Australian Government plans to expand renewable energy in the power grid from 36% to 82% by 2030, in accordance with the Paris commitments, it is critical to guarantee that buildings are ready for a zero-carbon environment. Currently buildings consume roughly 50% of Australia's electricity, but account for 77% of system capacity during peak periods. By moving a fraction of building energy usage for a few hours each day, five days a week, Australia may reduce glasshouse gas emissions by 0.6%, the equivalent of 180,000 homes. This reduction can be achieved without reducing energy use and would result in a $1.7 billion cost reduction in supplying electricity to Australian buildings each year (Green Building Council Australia, 2023).

2.7 Communication Technologies

Smart grids rely heavily on information flow and communication between various entities in various networks. Communication is one of the smart grid's enabling technologies. The amount of data coming to and from the utility increases as the number of sensors increases. The smart grid's communication infrastructure can be based on three types of networks: home area networks (HAN), neighbourhood area networks (NAN), and wide area networks (WAN).

Figure 2-12 Communication Networks in Smart Grid



Source: Abrahamsen, F. E., Ai, Y., & Cheffena, M. (2021, December 3). Communication Technologies for Smart Grid: A Comprehensive Survey. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8659758/#sec3-sensors-21-08087

2.7.1.1 Wide Area Networks

A WAN serves as the communication network's backbone in the power grid. It connects smaller distributed networks to utility firms' control centres, such as transmission substations, control systems, and protection equipment, such as Supervisory Control and Data Acquisition (SCADA), Remote Terminal Unit (RTU), and Phasor Measurement Unit (PMU). To ensure stability, this communication demands a great degree of distance coverage as well as speed. PLC, fibre optic communication, cellular, and WiMAX are all suitable communication technologies for this application. Satellite communication can be used as a backup or in remote regions.

2.7.1.2 Neighbourhood Area /Field Area Networks

Neighbourhood Area Networks (NAN) and Field Area Networks (FAN) are distribution domain networks that allow information to flow between WAN and a Premise Area Network (HAN, BAN, IAN). The NAN connects neighbourhood premises networks via smart meters at the end-user. The NAN enables services such as monitoring and regulating individual end-user electricity delivery, demand response, and distribution automation. In NAN/FAN, both wired and wireless communication technologies are used, and the different communication technologies should be complementary. As distributed energy generation is deployed, it is linked to the NAN/FAN. In these networks, communication technologies like ZigBee, Wi-Fi, Ethernet, and PLC are commonly employed.

2.7.1.3 Premise Area Networks

Depending on the environment, the Premise Area Network is divided into three sections: HAN (Home Area Network), BAN (Building Area Network), and IAN (Industrial Area Network). These are wired or wireless networks that are located on the end-user's premises. The HAN's objective is to enable communication between devices such as smart meters and home automation, appliances, Home Energy Management Systems (HEMS), solar panels, and electric cars. These applications do not require extensive coverage, high speed, or data rates, and can be managed using low-power, low-cost technologies such as Power Line Communication (PLC), Wi-Fi, or ZigBee (Abrahamsen & Cheffena, 2021).

3 The United States of America (USA)

The USA is the first of the three jurisdictions reviewed in this report. The selected jurisdictions have considerable technical and regulatory experience in implementing smart grid. This allows analysis of successes and challenges faced in implementation and drawing lessons that can benefit Viet Nam's circumstances.

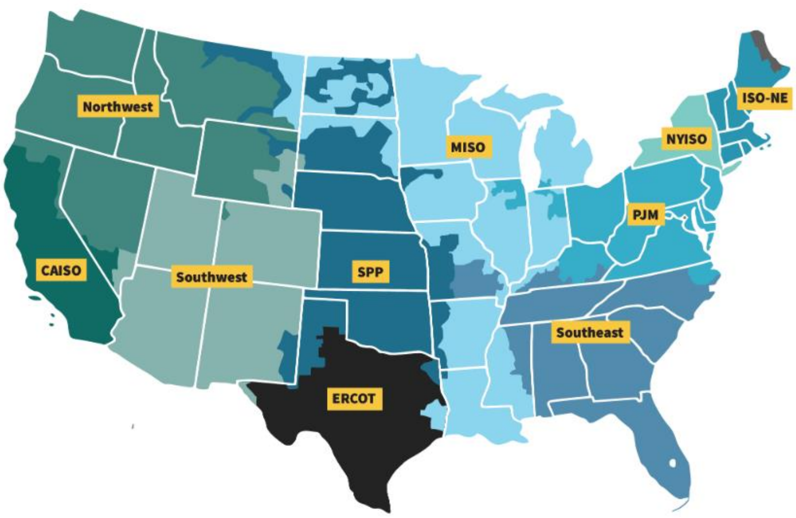
3.1 Structure of the USA market

The USA electric grid is a complex network comprising more than 200,000 miles of high-voltage transmission lines and approximately 5.5 million miles of local distribution lines. It operates under various regulatory jurisdictions, including Federal, State, Tribal, and local authorities. The U.S. grid is segmented into three primary regions that operate autonomously, though there are occasions of power exchange between them:

- The Eastern Interconnection, serving states located to the east of the Rocky Mountains.
- The Western Interconnection, covering states from the Pacific Ocean to those bordering the Rocky Mountains.
- The Texas Interconnected system.

The USA energy market is often characterised as a hybrid system, involving states with a mix of vertically integrated markets, unregulated markets, and partially regulated markets. The regulatory and operational framework includes 77 balancing authorities, seven independent system operators/regional transmission organisations (ISOs/RTOs), four federal power marketing organisations, and over 2,786 distribution utilities regulated by various entities [the Federal Energy Regulatory Committee (FERC), state public utility commissions, and local boards]. The jurisdiction of the organisations extends to specific segments of the grid, which they operate in adherence to federal reliability standards (Federal Energy Regulatory Commission, 2022).

Figure 3-1 Regional Transmission Organisations in the USA



Source: Federal Energy Regulatory Commission website https://ferc.gov/power-sales-and-markets/rtos-and-isos accessed on 2 November 2023.

3.2 Technologies

A varied spectrum of smart grid technologies in the United States is directed towards enhancing the efficiency, reliability, and sustainability of the electrical grid. The levels of implementation can differ among utilities and regions.

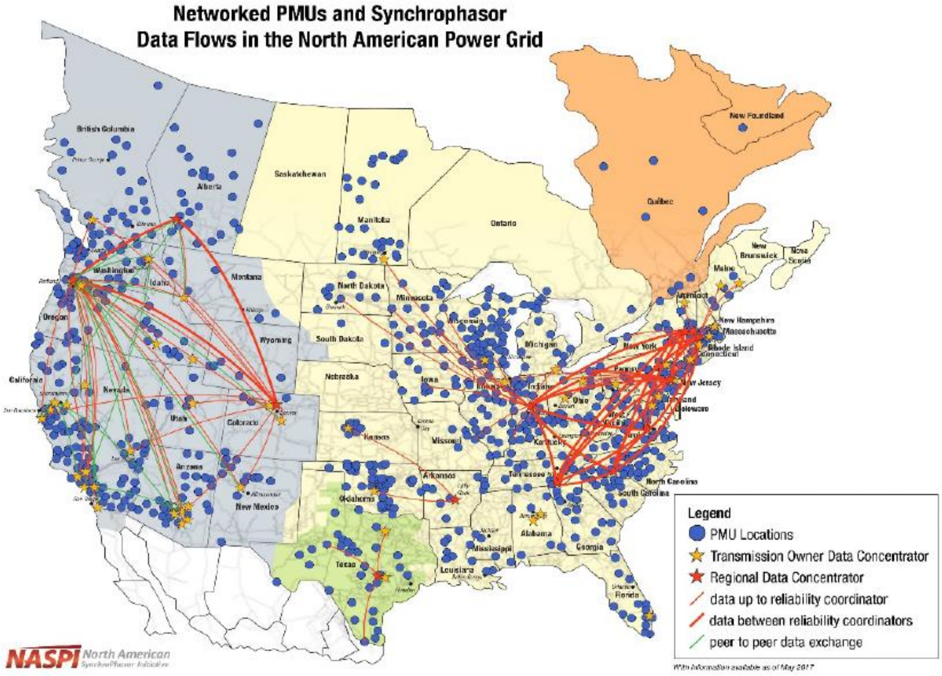
In the USA, implemented technologies span the key domains of Communications Infrastructure, Supply, Transmission, Distribution, Dynamic Line Rating (DLR), Power Flow Controllers, Advanced Distribution Management Systems, Grid Automation, Demand-Side Management, and Grid Modernisation Equipment. Some of the technologies implemented in these areas are:[1]

- Advanced Metering Infrastructure (AMI):
- Fiber Optic Networks
- Wireless Technologies
- Power Line Communication (PLC)
- Sensor Networks
- Phasor Measurement Units (PMUs) and Phasor Data Concentrators (PDC). The American Recovery and Reinvestment Act (ARRA) of 2009 supported the installation of 1,380 PMUs which contributed to than 2,500 PMUs by 2017, refer to Figure 3-2 which depicts the geographic spread of PMU installations in the USA. A USA DOE guide (Follum, et al., 2021) refers to the following key points on PMUs:
  - PMU deployments have increased significantly due to their capabilities and significant funding support by ARRA).
  - The IEEE standard for PMUs suggests 15 samples per cycle (900 samples per second) in one of the examples it gives.
  - Reporting rate is typically 30 or 60 synchrophasors per second in a 60 Hz system
  - PMU's high reporting rate and time synchronisation enable various applications.
  - Technical limitations of PMUs are highlighted at the end of Section 2.4.2 of our report.
- DLR implementation in the USA lags other advanced systems in the deployment of DLRs according to a 2019 DOE congressional report. The lag is not due to technical issues. Utilities and technology providers have addressed the issues from first generation DLRs such as inferior quality of data, complexity of installation, and limitations of indirect measurement methods and are working on further improving the data quality, installation and communications, and actionable line ratings. Slow implementation of DLR is due to regulatory and market factors. The regulatory environment does not incentivise transmission owners to maximise power delivery or reduce congestion. DLRs could reduce wholesale power prices thus affecting the profitability of existing generation assets(U.S. DOE, 2019).

[1] The major technologies are elaborated upon in Section 2 of this report.

- The ADMS market is estimated to grow to over $200 million in 2026 from around $80 million in 2020. The major challenges faced by ADMS include the availability and accuracy of network model data, integration of different operational systems, and trade-offs between sensor deployment and model improvements. In the case of Arizona's Public Service, its successful implementation of ADMS required integrating its GIS, the developing a detailed network model and implementing quality assurance tools to ensure data integrity (United States Department of Energy, 2022).
- FLISR can help improve fault response performance. The 2019 Pacific Gas & Electric Co. (PG&E) Smart Grid Annual Report (Pacific Gas and Electric Company, 2019) boasts FLISR deployment to about 30% of circuits at a cost of USD 194 million. The benefit, since the start of the program, is estimated at USD 828.8 million due to a reduction of an estimated 391 million customer outage minutes. PGE's 2020 Smart Grid Annual Report states that FLISR has enabled the following statistics for Customers Experiencing Sustained Outages (CESO), avoided outage minutes, and Customer Minutes of Interruption (CMI), respectively (Pacific Gas and Electric Company, 2020) :
  - Avoided Customer Sustained outages over reporting period: 824,258 (CESO)
  - Actual recorded outage minutes over reporting period: 719,792,704
  - 5-year average recorded outage minutes: 147,390,767 (CMI)
  - 5-year average avoided outage minutes: 78,079,958 (CMI)
- Dynamic Transformer Ratings aims to unlock additional capacity in existing transformers to alleviate congestion issues within the power grid.

Figure 3-2 PMU installations by 2017 in the USA



Source: 2020 Smart Grid System Report, January 2022. USA DOE.

3.3 Initiatives and Implementation Approach

3.3.1 Investment Trends

We highlight below significant investments in the modernisation and digitalisation of the electric grid in the United States. American electric utilities have been investing heavily in transmission and distribution equipment, systems, and services. In 2016, these investments exceeded $70 billion, with a growing portion allocated to grid modernisation and smart grid development (United States Department of Energy, 2022).

3.3.2 Smart Grid Investments

The smart grid investments include both Information Technology (IT) and Operational Technology (OT). IT involves managing information for business systems, while OT focuses on managing physical grid devices and control systems. In 2020, total capital spending on digital technologies (IT and OT) reached approximately $15 billion, and it is projected to increase to over $24.5 billion by 2026. A substantial portion of this spending is dedicated to smart grid technologies, amounting to $8.3 billion in 2020 and projected to reach $16.4 billion by 2026.

3.3.3 Distribution Grid Capital Investments

Capital investments in the distribution grid have been steadily increasing, reaching nearly $39 billion in 2019 for Investor-Owned Utilities (IOUs). When including all U.S. distribution utilities (approximately 3,000), this investment figure rises to nearly $51 billion.

3.3.4 Investments in Interoperability

Interoperability investments have the potential to provide value to a broad range of stakeholders, enhance system resilience, and facilitate the integration of clean energy resources, ultimately contributing to sustainability and cost savings in the energy sector. Interoperability achieves these benefits by providing the ability for devices and systems to share data that is understood by all without the need for operator intervention. This provides a holistic view of the system and facilitates coordination in an efficient manner

3.3.5 AMI Deployment Investments

The Electric Power Research Institute (EPRI) estimated the total cost of AMI deployments for 165 million existing customers from 2010 to 2030 to range from $15 billion to $42 billion. Some utilities, like Pacific Gas & Electric, have reported that the benefits of smart meter deployments, including automatic meter reading and demand response, exceed the deployment costs. However, some state authorities do not impose AMI costs on certain customers, such as low-income and elderly individuals, who may not benefit significantly from these deployments due to limited flexibility in electricity usage (Asian Development Bank, Smart Grid Task Force, 2016).

3.3.6 The Grid Modernisation Initiative (GMI)

Grid Modernisation Laboratory Consortium (GMLC), and Advanced Research Projects Agency-Energy (ARPA-E) are significant initiatives under the DOE focused on transforming the nation's power grid to align with the requirements of the 21st century and beyond. GMI collaborates with partners from both the public and private sectors to pioneer the concepts, tools, and technologies essential for the grid of the future.

3.3.7 Investments by DOE projects at National Laboratories

The DOE has announced a substantial investment of up to $39 million for projects conducted at its National Laboratories, with the aim of advancing the modernisation of the electricity grid and addressing emerging challenges and harnessing innovative technologies (Office of Cybersecurity, Energy Security, and Emergency Response, 2023). Below is a selection of projects, a summary of which is given in Appendix 8.2.

- Medium Voltage Resource Integration Technologies (MERIT), led by Oak Ridge National Laboratory (ORNL).
- Assessment and Coordination of Electric Vehicle Supply Equipment (EVSE) Cybersecurity Standards, led by Sandia National Laboratories.
- Assessment and Coordination of DER Cyber Security Standards, led by NREL.
- Assessment of Communication Architectures for Energy Systems (ACAES), led by Pacific Northwest National Laboratory (PNNL).
- Grid Research, Integration, and Deployment for Quantum (GRID-Q), led by ORNL.
- Advancing Equity in Grid Planning and Operations, led by Lawrence Berkeley National Lab (LBNL) and PNNL.
- Enhanced Modelling to Ensure Equitable Power System Operations and Planning, led by Argonne National Laboratory (ANL) and NREL.
- Aligning Climate Analysis for Power Systems (ALCAPS) and Climate Resilient Equitable Resource Planning (CRERP), led by NREL.
- Critical Analysis of Severe Climate Events (CASCDE), led by ANL.
- Projects like Pecan Street in Austin, Texas, serve as examples to integrate community-based technologies with the electric grid to advance innovation.

3.3.8 Integration of SG deployment

The integration of smart grid technologies into the electricity sector across the USA proceeds along several technical fronts. Key areas are reported in (United States Department of Energy, 2022) and are summarised below.

- **Integrated Distribution Plans (IDPs)** are comprehensive strategies developed by utilities to accommodate the integration of DERs while ensuring the reliability of the grid. Five states have mandated that utilities submit IDPs, and 21 states are actively considering regulatory proceedings to require them. IDPs are essential for addressing the challenges posed by high levels of DER adoption, including monitoring, control, and adequate system conditions.
- **Time-varying rates** and other alternatives that provide a price signal have been adopted or are actively being considered by many states as an alternative to net energy metering. The

aim is to align compensation to the value provided by DER to incentivise DERs to behave in ways that provide higher system value.

- **Non-wires alternatives (NWA)** are innovative solutions that combine smart grid technologies and DERs to achieve specific grid objectives without the need for traditional utility infrastructure investments. New York and California are leaders in NWA deployments, with numerous projects in progress. These alternatives can defer or avoid costly infrastructure upgrades.

3.3.9 Integrated Planning

Integrated planning is a crucial aspect of modernising the electric grid, and varies across the United States, largely due to state-level policies and incentives. Key points to highlight are the necessity of selecting a holistic strategy before embarking on specific technological solutions and reaching out to stakeholders to secure alignment and the broadest adoption.

- **Stages of Grid Evolution:** The stage of evolution in a distribution grid is primarily influenced by the integration of DERs and new ownership models. Utilities are at different stages of operational sophistication, ranging from Stage 1 (traditional) to Stage 2 (addressing bidirectional power flow and voltage/thermal management) to Stage 3 (observing and controlling DERs under various grid configurations and ownership models, coordinating with DER owners/operators). Advancement through these stages requires grid modernisation strategies.
- **Holistic Planning vs. Technology-Centric Approaches:** Some state legislators and regulators tend to target specific technologies, such as energy storage, without first developing holistic grid modernisation strategies based on clear policy objectives. A more comprehensive approach is necessary, taking into account foundational capabilities and priorities related to critical infrastructure protection and grid resilience.
- **Integrated Planning Process:** An integrated planning process within the broader framework of grid modernisation highlights the importance of coupling integrated resource, integrated distribution, and transmission planning processes, which is still evolving due to the recent emergence of DERs and the need for whole-system planning. Challenges include technological advancements, institutional acceptance, and stakeholder involvement in resilience planning.
- **DOE Planning Framework:** The U.S. DOE has collaborated with state regulators and utilities to develop a consistent planning framework for grid modernisation. This framework encompasses several key steps, including formulating clear objectives, conducting functional and structural analyses, developing a strategic planning roadmap, and creating implementation plans. The goal is to guide investments in smart grid technologies and align them with planning objectives.
- **Importance of Strategy Before Technology Selection:** One of the key takeaways is the importance of formulating a holistic grid modernisation strategy before selecting specific technologies. Regulators and utilities should focus on defining clear objectives, functional requirements, and architectural principles to ensure a well-rounded approach to modernising the grid.

- **Need for Outreach:** While some regulators and utilities have begun adopting these integrated planning concepts, there is a need for more outreach and education to encourage broader adoption and alignment with grid modernisation goals.

For more detail refer to (United States Department of Energy, 2022).

3.3.10 SG Related Projects

Grid modernisation efforts in 2020 included several key technologies and approaches:

3.3.10.1 Energy Storage

Twenty states were involved in energy storage regulatory proceedings or bills. Energy storage technologies, including batteries, play a critical role in grid stability and renewable energy integration.

3.3.10.2 Smart Grid Technologies

Sixteen states were engaged in general smart grid regulatory proceedings. Smart grid technologies encompass systems like Advanced Distribution Management Systems (ADMS), SCADA, and distribution automation, which improve grid operations.

- PMUs have seen significant adoption, with over 2,500 units installed by 2017, facilitated mainly by initiatives like the American Recovery and Reinvestment Act (ARRA) synchrophasor project.
- The ADMS market was estimated to be around $80 million in 2020 and is expected to grow to over $200 million by 2026.

3.3.10.3 Distributed Energy Resource Management System (DERMS)

DERMS is a software application that enhances real-time visibility and control of DERs to integrate and optimise them for grid operations. It manages aggregations of DERs, forecasts their capability, and communicates with other DER aggregators. Utilities are exploring DERMS functions such as transactive energy and demand response. The DERMS market is estimated to be between $69 million to $85 million in 2020, with expected growth.

- An example of using DERMS is the implementation by Southern California Edison to provide control EVs, BESS and solar PV to respond to real-time price signals.
- Another example is the implementation by Arizona Public Service to reduce peak demand by managing a portfolio of customer and utility DER.
- Standards like IEEE P2030.11 and IEEE 2030.5 are being developed to facilitate DERMS and DER communications, enhancing interoperability.

3.3.10.4 Smart Meter Adoption in the USA

Regulatory proceedings or bills related to AMI were under consideration in 12 states. AMI enables real-time data collection and communication between utilities and customers based on information provided by the U.S. Energy Information Administration (EIA). In 2021, the United States had approximately 119 million advanced metering infrastructure (AMI) installations, accounting for approximately 72% of the total electric meter installations. Residential customers accounted for most AMI installations in 2021, followed by the commercial and industrial sectors. AMI provide more granular data on electricity usage and enable better communication between utilities and customers. AMI installations are broken down by main sector as follows:

- Residential: There were about 104,237,855 AMI installations in the residential sector, representing approximately 73% of total residential electric meter installations.
- Commercial: The commercial sector had approximately 13,908,481 AMI installations, accounting for about 69% of total commercial electric meter installations.
- Industrial: In the industrial sector, there were around 574,726 AMI installations, constituting approximately 68% of total industrial electric meter installations.
- Transportation: The transportation sector had approximately 1,879 AMI installations, making up about 55% of total transportation electric meter installations.

The Edison Institute for Electric Innovation's 2023 report on smart meters in the USA sheds light on the significant growth and importance of this technology in the electric power industry. Here are the key findings and projections:

Current State of Smart Meter Adoption (2021)

- As of 2021, there were 114 million smart meters installed in the USA, representing a penetration rate of 73%.
- Smart meters enable two-way communication between electric companies and their customers, enhancing grid resiliency and offering new services.
- One of the valuable benefits is the ability to introduce expanded pricing programs and demand flexibility for residential customers.

AMI Projections for 2025

- Looking ahead to 2025, the Institute anticipates further growth, with a projection of 135 million smart meters installed.
- This would bring the penetration rate to nearly 85%, underlining the enduring relevance of smart meters in the electric power sector.

Regional Differences in AMI Penetration

- While overall penetration is high, there are significant variations among states.
- In 2021, 11 states had a smart meter penetration of 15-50%, while five states—Hawaii, Massachusetts, New Jersey, New Mexico, and Utah—had less than 15% penetration.

Additional Insights on AMI are provided in (Jones, 2023)

- Berg Insight's 2022 North America update corroborates these trends, reporting a smart meter installed base of 116.2 million in 2021.

- Their projections show that smart meter penetration is expected to reach 93% by 2027, with an estimated 148-149 million smart meters.
- This growth is driven by large utility projects and second-wave rollouts for early adopters.
- Major players in the North American smart meter market include Itron, Landis+Gyr, Aclara, Honeywell, and Sensus.
- Notably, 58 investor-owned electric companies have fully deployed smart meters across their service areas. These electric companies are leveraging smart meter data to enhance grid operations, improve resilience, and integrate DER.

3.3.11 Grid Modernisation Projects

The modernisation of the electric grid in the USA is a complex and evolving process. It involves a coordinated effort among states, regulators, utilities, and federal agencies. It encompasses not only the deployment of smart grid technologies and DERs but also the development of resilience strategies and the advancement of various technologies and tools to support grid modernisation. Research and development play a crucial role in ensuring the successful transition to a more advanced and resilient grid infrastructure. Key points regarding grid modernisation activities, resilience planning, and the need for research and development are given below.

- **State-Level Grid Modernisation:** Thirty-eight states and the District of Columbia have embarked on grid modernisation activities that involve the deployment of SG technology and DERs. Additionally, several states have mandated integrated distribution plans (IDPs), reflecting a growing trend towards holistic planning.
- **Consistent Practices:** The U.S. Department of Energy (DOE) has collaborated with state regulators and utilities to establish consistent practices for determining grid modernisation strategies. These practices involve examining functional and structural requirements over time to inform technology implementation roadmaps. The goal is to ensure that technology investments align with broader objectives.
- **Resilience Planning:** Beyond traditional reliability and asset management practices, there is a need for a whole-systems approach to resilience planning. This approach considers vulnerabilities related to interdependencies between the electric grid and other infrastructures, protection of critical functions, and novel grid configurations like microgrids. Stakeholder involvement, including government and private sector entities, is crucial for developing resilience strategies.
- **Integration of New Technologies:** Utilities are cautious as they transition from legacy to more advanced grid infrastructures. Research and development, combined with technology demonstrations, are essential for a smooth transition. Key areas of focus include improving power electronics devices, enhancing energy storage technologies, developing advanced sensors, standardising data formats, advancing communication networks, testing grid architectures, improving modelling and simulation tools, and enhancing cybersecurity measures.
- **Infrastructure Investment and Jobs Act:** The Infrastructure Investment and Jobs Act, signed into law in 2021, provides support for testing and demonstrating new technologies and

advancing grid modernisation efforts. This legislation aims to accelerate the deployment of advanced grid solutions.

3.4 Policies and Regulations

The reliability of the bulk power system, including large generators and the transmission network, is primarily overseen by the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation (NERC), which establish and enforce mandatory reliability standards. Professional organisations like IEEE, IEC, and CIGRE also issue technical standards.

3.4.1 The Energy Independence and Security Act of 2007 (EISA)

EISA provided legislative backing for U.S. Department of Energy DOE's smart grid activities. EISA established the Smart Grid Advisory Committee and Federal Smart Grid Task Force within DOE, reinforcing its leadership in national grid modernisation endeavours.

3.4.2 The American Recovery and Reinvestment Act (ARRA)

ARRA, introduced in 2009, played a pivotal role in catalysing the adoption of smart grid technologies throughout the United States. It allocated significant funding alongside private investments awarding funding to 341 projects under eight programs, summarised in Table 3-1. The largest program, the Smart Grid Investment Grant (SGIG), saw joint investment between the DOE and the electricity industry of approximately USD 9.5 billion (approximately USD 3.5 billion funded by the program) in 99 cost-shared projects involving more than 200 participating electric utilities, refer to (U.S. Department of Energy, n.d.). These smart grid systems contributed to enhanced grid efficiency, decreased power outage frequency and duration, facilitated precise control over operational parameters like voltage, and encouraged increased customer engagement through advanced metering infrastructure (United States Department of Energy, 2022).

Table 3-1 Summary of ARRA Programs

PROGRAMS	TOTAL OBLIGATIONS	AWARD RECIPIENTS
Smart Grid Investment Grant	$3,482,831,000	99
Smart Grid Regional and Energy Storage Demonstration Projects	$684,829,000	32
Workforce Development Program	$100,000,000	52
Interconnection Transmission Planning	$80,000,000	6
State Assistance for Recovery Act Related Electricity Policies	$48,619,000	49
Enhancing State Energy Assurance	$43,500,000	50
Enhancing Local Government Energy Assurance	$8,024,000	43
Interoperability Standards and Framework	$12,000,000	1
Program Direction supports administration and management of funds	$27,812,000	--

Source: Adapted from (U.S. Department of Energy, n.d.)

3.4.3 Other State and Federal Policies

We highlight below other state and federal policies and initiatives driving the advancement of smart grid deployment and the integration of distributed energy resources (DERs) into the power grid, refer to (United States Department of Energy, 2022):

- **Renewable Portfolio Standards (RPS):** Both state and federal policies play a pivotal role in providing incentives for the adoption and integration of renewable energy sources and Distributed Energy Resources (DERs). Many states, for instance, have implemented Renewable Portfolio Standards (RPS) to encourage renewable power generation. RPS policies mandate that utilities produce a specific portion of their electricity from renewable sources, with the intention of fostering the adoption of clean energy.

- **Alternatives to Net Energy Metering:** Net Energy Metering traditionally enables customers with solar panels or other Distributed Energy Resources (DERs) to receive credits for the surplus energy they contribute to the grid. In some states, alternative compensation mechanisms to NEM, such as time-based tariffs, that better reflect the value delivered by DERs are being adopted to incentivise behaviour helpful to system needs.

- **Clean Peak Energy Standard:** The Clean Peak Energy Standard, as implemented in Massachusetts, centres on the reduction of carbon emissions during peak demand hours. This policy promotes the incorporation of clean energy sources, such as solar and wind, capable of supplying power when it is most in demand, thereby diminishing the dependence on fossil fuels during high-demand periods.

- **Time-of-Use (TOU) Rates:** Time-varying rates, commonly referred to as Time-of-Use (TOU) rates, incentivise customers to shift their electricity consumption to off-peak hours when electricity costs are lower. This approach offers benefits to customers by reducing their bills and also aids utilities in more effectively managing peak demand.

- **Non-Wires Alternatives (NWAs):** NWAs involve using DERs and microgrids as alternatives to traditional grid infrastructure upgrades, such as building new transmission lines or substations. By utilising NWAs, utilities can defer or avoid expensive infrastructure investments while enhancing grid reliability and resilience.

- **Rate Designs and Utility Programs**

  - **Definition:** PBR is a regulatory approach that incentivises utilities to achieve specific performance goals and outcomes rather than relying solely on traditional cost-of-service regulation.

  - **High Rates of Reliability:** PBR structures may reward utilities for achieving high rates of reliability and for using non-traditional generation resources to meet capacity needs.

- **Performance-Based Ratemaking (PBR)**

  - **Performance Metrics:** Under PBR, utilities are evaluated based on specific performance metrics, which may include reliability indicators like SAIDI and SAIFI, as well as environmental and customer satisfaction metrics. Utilities that exceed performance targets may receive financial incentives.

- **Innovation Incentives:** PBR structures encourage utilities to innovate and adopt new technologies that improve grid operations and customer service. Utilities have a financial incentive to explore advanced solutions like grid modernisation and DER integration.

- **Federal Energy Regulatory Commission (FERC) Actions**

  - **Energy Storage Participation:** FERC's Order 841 mandates that ISOs/RTOs create market rules allowing energy storage resources to participate in wholesale electricity markets. This includes energy storage technologies like batteries, which can provide rapid responses to grid events.

- **DER Aggregation Rules:** Order 2222 requires ISOs/RTOs to develop rules enabling the aggregation of distributed energy resources (DERs) in wholesale markets. DER aggregations can consist of a mix of resources, including solar, wind, batteries, and demand response.

3.4.4 Technical Standards

An important aspect of regulation is to specify and enforce the implementation of technical standards. Technical standards are essential for ensuring the interoperability, performance, and security of smart grid technologies. These standards cover a wide range of aspects from DER integration and communication protocols to cybersecurity and the integration of electric vehicles and smart city technologies. Certification programs have been introduced where compliance with standards has been shown to be poor. Collaboration among stakeholders and ongoing efforts by organisations like The National Institute of Standards and Technology (NIST) are crucial for advancing smart grid standards to meet the evolving needs of the grid. Key relevant technical standards for smart grids and a short description of each are given in Appendix 8.3.

3.5 Summary

Integrated planning is crucial to grid modernisation. It recognises that holistic planning covering technology, operational, data, regulatory and funding aspects is needed. Legislators and regulators that have focused on technology aspects only have been less successful. A unified planning framework across all levels of government, involving utilities and customers is key to success of SG.

Regulation is an important area for the success of SG implementation. Regulations requiring high levels of DER to be integrated into grids have been, or are in the process of being, implemented. Another area of regulation is considering options for the design of rates that provide the right price signal to consumers to incentivise consumers to behave in ways that provide higher system value. DER and storage are required to be considered as an alternative to network augmentation. Funding has been accomplished through several laws including EISA, ARRA and RPS.

ARRA supported the rollout of PMUs across the USA funded by a combination of government and private investment.

DLR lags other advanced jurisdictions due to regulatory and market factors. Despite having addressed technical and data limitations.

The success of ADMS required resolving challenges of network models and integration with other systems, such as GIS.

FLISR has reduced the duration of customer loss of power through interruption and outages. The reduction resulted in significant benefits to customers.

AMI deployment investment is reported to have been economically justified through reduced meter reading costs and facilitating higher demand response.

Utilities made significant SG related investments in transmission and distribution grids.

Interoperability is recognised as an important area with potential to produce benefits. Standards covering devices, protocols and systems are critical to successful integration of SG technologies.

The programs have linked research and development programs to the general SG development plans and encouraged collaboration among research institutions as well as involving stakeholders in research and development.

4 The EU & UK

4.1 Structure of the EU Electricity Market

The European Commission (EC) is leading the completion of the EU's internal market transition which requires the removal of barriers, adoption of common standards and environmental and safety regulations. The EU electricity market is a capacity market. The fifth Energy Package 'Fit For 55' was released in 2021 and aims at aligning the EU's energy target with the climate ambitions that were set for 2030 and 2050. EC directives must be passed by national parliaments into law to take effect in individual states. The EU Agency for the Cooperation of Energy Regulators (ACER) has been operating since March 2011. ACER's role as a coordinator of the action of national regulators was strengthened in June 2019 particularly in cross-border issues that would lead to problems or inconsistencies for the internal market, see (Regulation (EU) 2019/942). In such instances ACER has been given more responsibility in developing and submitting the final proposal for a network code to the EC and in influencing the regional electricity market (bidding zone) review process set out in Regulation (EU) 2019/943.

510 GW of new renewable energy is expected to be installed in the EU27+UK with 70% of that to be connected to distribution grids. Four countries Germany, Spain, France and Italy account for more than half of the addition. The distribution grid is ageing with over 65% of power lines aged 20 to 40 years and a further 25%-35% aged more than 40 years, refer to (Eurelectric, E.DSO et al., 2021).

4.2 Technologies

For the advancement of smart grid systems within the EU sector, the following have been employed with some of the more major technologies employed discussed in further detail in Section 2 of this report.

- WAM
- PMUs
- Phasor Data Concentrator (PDC)
- Distribution Automation (DA)

  The EU initiated its distribution automation project in 2012, with a focus on modernising distribution systems for improved efficiency and reliability. Notably, as of 2019, no smart substations had been completed within the EU.

- AMI

  Efforts to deploy smart meters in the European Union have been substantial, aiming for an 80% coverage target for all EU customers by the year 2020. 51% of EU households and SMEs have smart electricity meters installations.

- Customer technology and Smart Home Adoption

  The European Union has also seen progress in the adoption of smart home technologies, with an estimated 12.5% of households integrating smart home technologies as of 2020. The Smart Metering Benchmarking Report estimates that 51% of EU-28 households and SMEs have smart electricity meters installations, (European Commission D.-G. f., 2020).

- Additionally, Information and Communication Technologies (ICT), Distributed Generation (DG), and Energy Storage Systems (ESS) play crucial roles in the smart grid landscape.

The Innovation and Networks Executive Agency (INEA) manages components of the energy and transport research funded by the EU's Horizon 2020 programme. INEA manages 32 SG projects with EUR 337 million invested since 2014. The projects address both energy and ancillary services and have wide participation of stakeholders from 379 organisations from 31 countries.

4.3 Initiatives and Implementation Approach

This section discusses the key initiatives that support SG deployment in the EU.

4.3.1 SG projects in Europe

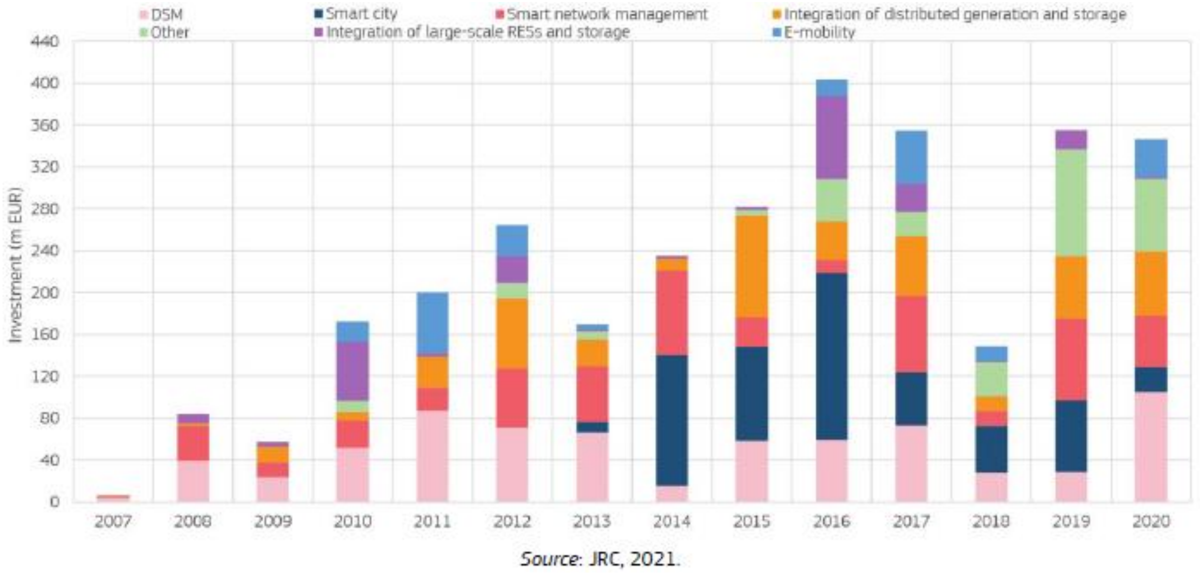
SG is one of the three focus areas of the Trans-European Networks for Energy (TEN-E) regulation. TEN-E's three main aims are: (1) to support the integration of renewable energy, (2) complete the European energy market and (3) allow consumers better control over their energy consumption. It introduced the Projects of Common Interest (PCI) which are infrastructure projects that have significant impact on the EU electricity and gas systems and contribute to the achievement of EU energy policy and climate objectives. ACER participates in the identification of PCI projects and monitors each project's implementation and publishes annual reports on its website, to access these reports go to (ACER - PCI Monitoring, n.d.). Beginning in 2013, the EC lists PCI projects every two years. The fifth PCI list in April 2022 had 98 projects including 72 electricity transmission, storage and SG projects. The balance of the projects was 20 in gas and 6 CO2 network projects, refer to (ACER TEN-E, n.d.). The Smart Grid Regional Group evaluates SG projects that apply to be included in the PCI list. The decision-making members comprise members from EU countries, the EC, representatives of national regulatory authorities, TSOs and DSOs. SG PCI project evaluation reports are published on (EC - SG PCI Selection, n.d.).

The revised TEN-E regulation, was published on 3 June 2022, with declared aims to:

- conform the infrastructure development to reflect the climate mitigation's targets,
- promote the integration of renewables and of clean energy technologies into the energy system,
- continue to connect isolated regions,
- strengthen existing cross-border interconnections and
- promote cooperation with partner countries.

Investment in SG projects by project category over the period 2007 to 2020 is shown in Figure 4-1. The chart shows that DSM (pink bar) is an enduring component of investment mainly in the EUR 40 to 80 million range per year. Investment in 'Smart city' (dark blue bar) started small in 2013, picked up in 2014 to 2016 before reducing again as of 2017. Investment levels in 'Smart network management' (fuchsia bar) vary from year to year.

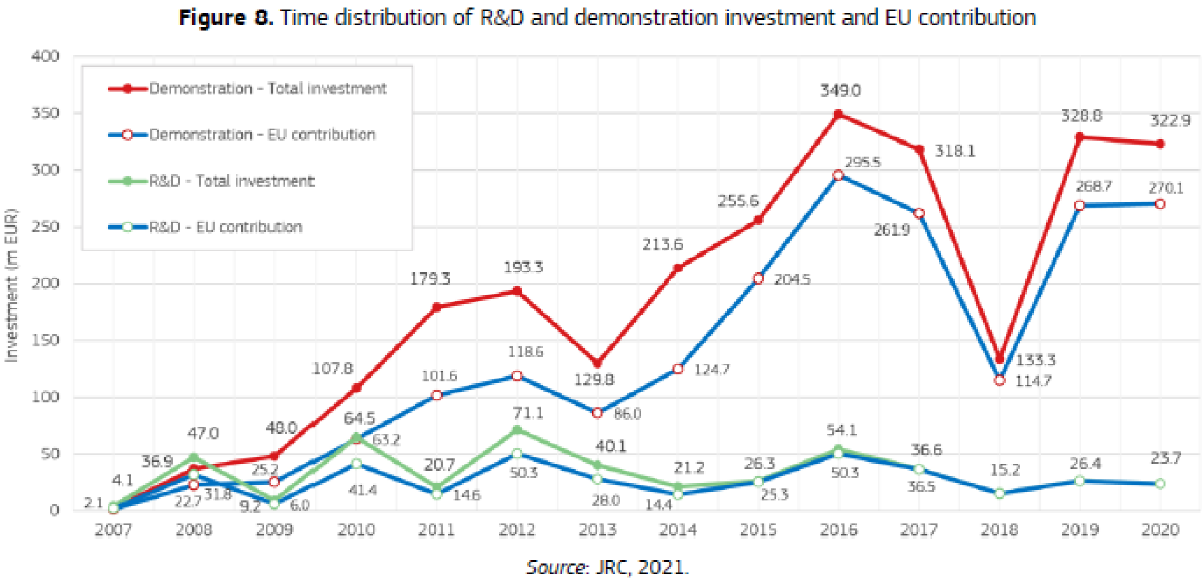
Figure 4-1 Investment by Project Category 2007 - 2020



Source: Vasiljevska, J., Gangale F., Covrig L., Mengolini, A., Smart Grids and Beyond: An EU research and innovation perspective, EUR 30786 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-36194-7, doi:10.2760/705655, JRC125980.

Figure 4-2 shows total investment and the EU contribution for R&D and demonstration projects over the same period 2007 to 2020. The figure shows that total investment has risen from below EUR 10 million in 2007 to over EUR 300 million in 2020. Over the same period the EU contribution has stayed at around the same level in raw Euro terms, but as total investment has grown the EU contribution has fallen in percentage terms.

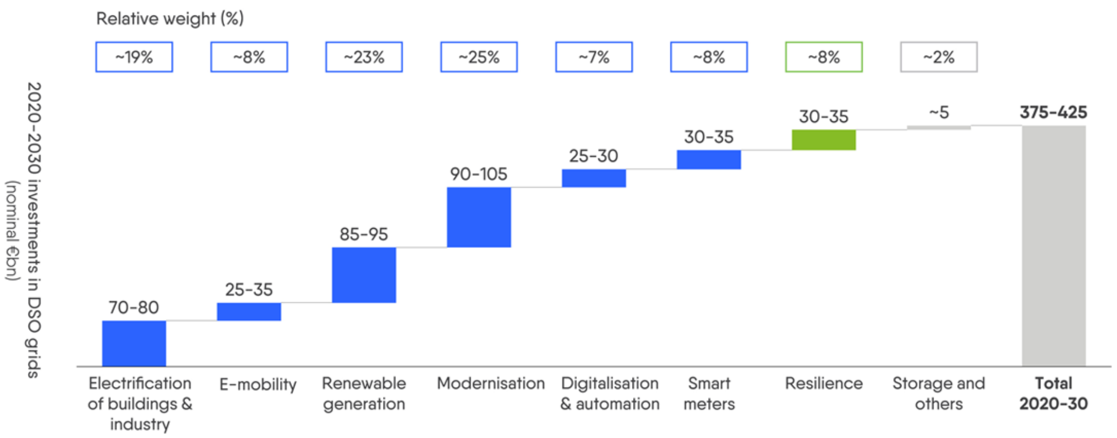
Figure 4-2 Investment and EU Contribution in R&D and Demonstration Projects 2007-2020



Source: Ibid, see Figure 4-1

The EC estimates investment in the electricity grid between 2020 and 2030 to be approximately EUR 584 billion. Most of the investment will be in the distribution grid with a substantial part to be in digitalisation. The Eurelectric study estimates between EUR 375 to 425 billion of investment is needed over the period 2020-2030 as shown in Figure 4-3. Average investment in distribution grids is expected to rise from an average of 23 billion Euro over 2015 to 2019 to an average of 34-39 billion Euro in the period 2020-2030, a 50% to 70% increase. Demand flexibility measures could reduce investment needs, but uncertainties exist around degree of adoption and regulation that is passed.

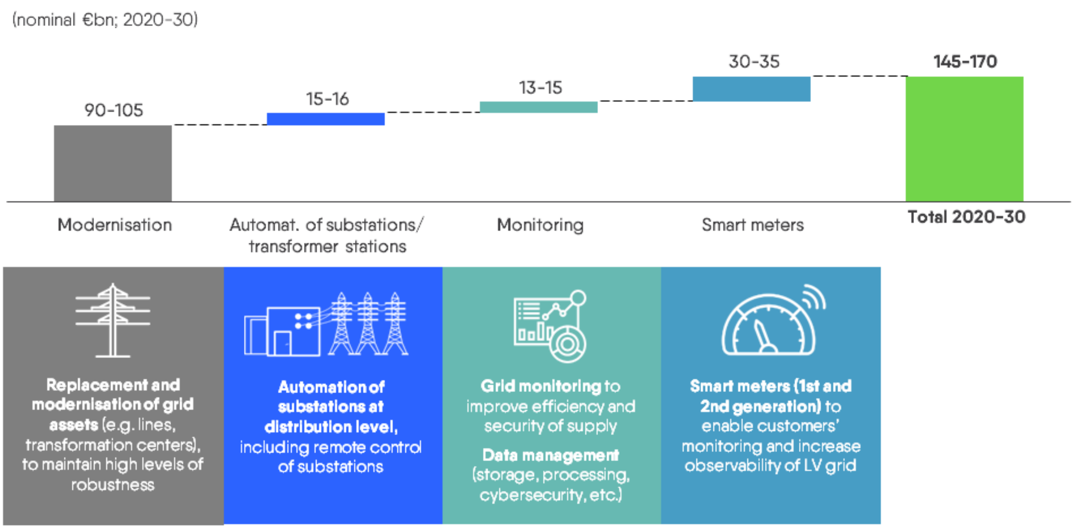
Figure 4-3 Estimated Investment by Major Component 2020 - 2030 (EU 27 + UK)



Source: Connecting the dots: Distribution grid investment to power the energy transition - Eurelectric – Powering People. Available at https://www.eurelectric.org/connecting-the-dots

The share of digitalisation of total grid investment is estimated to be EUR 170 billion with grid modernisation as the largest block, refer to Figure 4-4.

Figure 4-4 Digitalisation Investment by Major Component 2020 – 2030 (EU 27 + UK)



Source: Connecting the dots: Distribution grid investment to power the energy transition - Eurelectric – Powering People. Available at https://www.eurelectric.org/connecting-the-dots

4.3.2 'Smart Energy Expert Group' (SEEG)[2]

The EC re-established the SEEG, gave it greater responsibilities and expanded it to involve all Member States and additional relevant stakeholders.

4.3.3 'Data for Energy' (D4E)

D4E, a working group within the SEEG, focuses on the main priority areas to be addressed and develop a description of the relevant actors, processes and data flows for each specific business and operational arrangement. D4E will build upon the work of:

- the Smart Grids Task Force,
- Network code on demand side flexibility,
- work related to the Commission proposal for a Regulation on the deployment of alternative fuels infrastructure,
- the outcome of the Sustainable Transport Forum, the activity and products of the Expert group on European financial data space,
- the Energy Efficiency Financial Institutions Group (EEFIG), and
- cooperate closely with the European Group on the European financial data space.

In advising the EC, D4E will factor in the activities that support enhanced data exchanges, including:

- Adoption by the EC of an implementing act on interoperability requirements, and procedures for access to metering and consumption data;
- Preparing implementing acts on interoperability requirements, and procedures for access to data required for demand response and customer switching (as provided for by the Electricity Directive, Article 24);
- Promoting a code of conduct for energy-smart appliances to enable interoperability and boost their participation in demand response schemes.

4.3.4 ERIGrid 2.0

The European Research Infrastructure supporting Smart Grid and Smart Energy Systems Research, Technology Development, Validation and Roll Out – Second Edition is an initiative between 13 European countries that aims at connecting European research infrastructure. Currently it connects 20 research partners, 21 smart energy laboratories and eight virtual facilities. It promotes digitalisation and develops simulation, ICT and automation & controls for power and energy systems and builds on the results from the ERIGrid-1 project (EriGrid 2.0 Project, n.d.).

Researchers and developers can access simulation software and apply for free access to labs such as the Smart Grid Interoperability Laboratory in Petten, NL (SGIL). SGIL is a JRC facility for testing interoperability of SG systems. The lab aims at assessing implementation of technology against proposed standards, use cases and processes in conjunction with applicable reference architectures.

[2] The SEEG succeeds the Smart Grids Task Force (SGTF).

The goal is to contribute to policy making and industrial innovation of the electricity grid (SMART GRID INTEROPERABILITY LAB IN PETTEN, n.d.).

In 2012, the European Network of Transmission System Operators for Electricity (ENTSO-E) initiated a significant project, creating the inaugural Research and Development (R&D) Roadmap spanning from 2013 to 2022. This roadmap played a pivotal role in coordinating research and innovation efforts among European Transmission System Operators (TSOs) by addressing the dynamic landscape of the European electrical power system, encompassing technological trends, operational necessities, market dynamics, and external stakeholder insights. The ENTSO-E R&D Roadmap functions as a high-level, long-term planning tool to ensure the security of the European electrical power system, capitalising on technological advancements, addressing TSOs' operational needs, and considering market evolution. It also identifies infrastructure gaps, forming the basis for R&D priority determination. The existing 2020–2030 RDI Roadmap employs a use-case approach to address challenges that must be resolved by 2030.

The annual ENTSO-E R&D Implementation Plan is instrumental in translating R&D priorities into actionable strategies, focusing on select prioritised topics each year. It bridges the gap between innovation concepts and practical realisation, utilising identified priorities, feedback from external stakeholders during consultation phases, and insights from the Agency for the Cooperation of Energy Regulators (ACER). Since 2016, the Implementation Plan has been published annually, summarising R & D activities over a three-year timeframe, in accordance with the Roadmap's directives.

R&D priorities also inform the EC's energy research agenda and funding schemes, including the Horizon 2020 Energy Challenge. These priorities combine TSOs' vision (the "bottom-up" approach) with topics from EC calls that adopt a comprehensive energy system-integrated perspective (the "top-down" approach). The Implementation Plan harmonises these two perspectives. Once specific topics and projects are defined, they become individual projects aimed at achieving R&D objectives. These projects are executed by ad hoc consortia, pooling resources from multiple TSOs and other partners. Progress and realisation of R&D projects are closely monitored throughout their lifecycle and post-completion.

Additionally, the EU's shift towards sustainable energy systems is closely intertwined with the adoption of smart grid technologies. Although the pace of advancement differs among member states, the incorporation of smart energy solutions and the exploration of demand-side management and response initiatives are expected to influence the future of the European energy sector. Additionally, these developments provide valuable lessons for emerging economies which are aiming to improve their electricity systems by integrating smart grid and renewable energy solutions, drawing inspiration from the achievements witnessed in the European Union and the United States.

4.3.5 Digital Twin

The European Network of Transmission System Operators for Electricity (ENTSO-E) and the EU DSO Entity signed in Dec 2022 a Declaration of Intent to develop jointly a digital twin of the EU-wide electricity grid.[3] The twin is a sophisticated virtual model of the European electricity grid.

It will ensure the development of innovative solutions and coordination of investment in five areas:

- Observability and controllability;
- Efficient infrastructure and network planning;
- Operations and simulations for a more resilient grid;
- Active system management and forecasting to support flexibility and demand response;
- Data exchange between TSOs and DSOs.

4.3.6 The Universal Smart Energy Framework (USEF)

A group of seven stakeholders established the USEF foundation and developed the USEF framework.[4] The framework creates a common standard for building smart energy products and services through making flexible energy as a tradeable commodity. USEF main features are that it implements the EC electricity market directive; accelerates smart energy transition by adopting a common standard, enhancing integration and scalability, and sharing learning; reduces costs of connection, optimise energy cost; and connects smart energy products and projects through a standardised open IT architecture without locking in the project to a vendor.

4.3.7 ACER Guideline on Demand Response

The EC is considering the framework guideline submitted by ACER on 20 Dec 2022 as mandated. When passed by the EC, ENTSO-E and the EU DSO Entity will be asked by the Commission to draft the proposal for the new binding EU rules within 12 months. The guideline addresses the following areas:

- Requirements for European-wide market access.
- Principles for prequalifying that remove barriers including for consumers with PV panels, EV and batteries.
- Principles for the coordination of market-based procurement of congestion management, voltage control and balancing services with wholesale markets for other services across the distribution and transmission grids.
- Requirements for market-based procurement for electricity congestion management and voltage control products.

  More details can be obtained from (ACER, 2022).

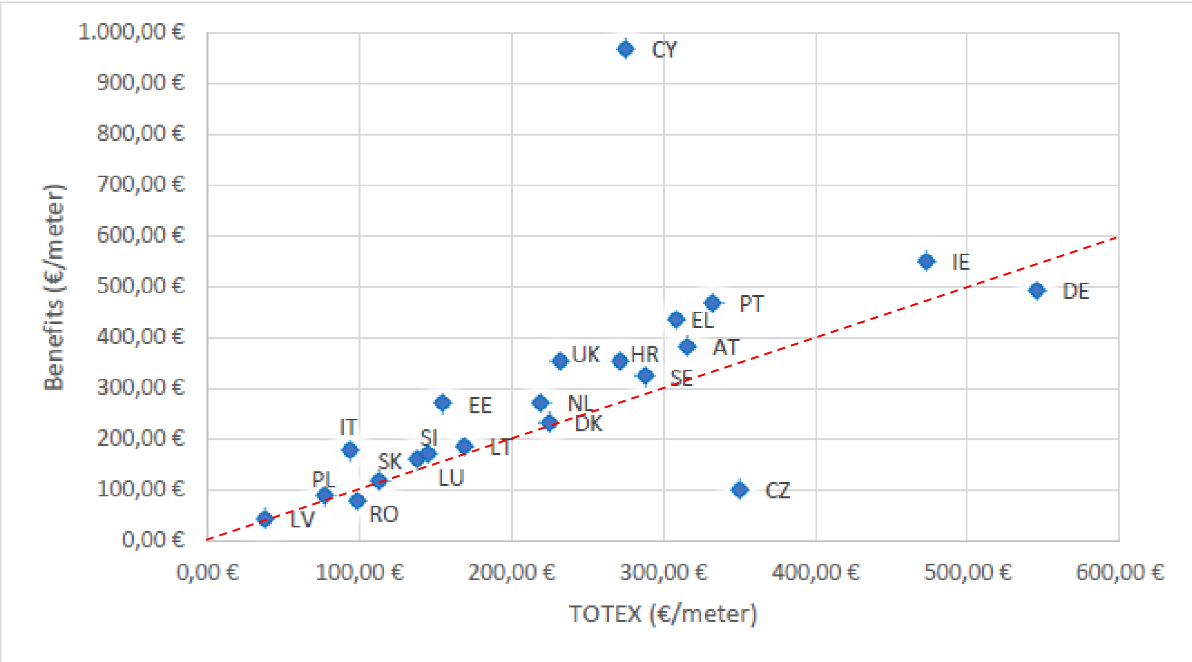
[3] See declaration on https://www.entsoe.eu/news/2022/12/20/entso-e-and-dso-entity-signed-today-the-declaration-of-intent-for-developing-a-digital-twin-of-the-european-electricity-grid/

[4] The founding members of USEF are ABB, Alliander, DNV, Essent, IBM, ICT Group and Stedin. The foundation is no longer active.

4.3.8 Smart Meters

Smart meters are an important element in SG deployment. The JRC analysis of Cost Benefit Analysis (CBA) in 2014 showed a positive outcome in most countries: Austria, Denmark, Estonia, France, Greece, Ireland, Luxemburg, Malta, Netherlands, Poland, Romania, Spain, and the UK. However, the CBA was negative or inconclusive in seven countries: Belgium, the Czech Republic, Germany, Latvia, Lithuania, Portugal, and Slovakia. Bulgaria and Hungary did not complete or did not communicate the outcome of their CBA. CBA in a follow up December 2019 report by Tractebel, published by the EC in 2020) (Tractebel, 2020) showed the CBA to be positive in most countries. Figure 4-5 shows a chart reproduced from the Tractebel report. The red-coloured dotted straight line with 45-degree slope is superimposed by IES. Countries that lie above the line have benefits higher than costs and vice versa. The report suggests that the reasons for the difference in CBA outcomes relate to differences in the cost and benefits that were included by individual countries in the CBA. Some countries had undertaken investments to digitalise the distribution network or did not attribute these costs to the smart meter roll out because they were funded under different programs. Countries that had regulations (such as dynamic pricing) that allowed consumers to use the information from smart meters to control their consumption patterns and reduce their bills included these benefits in the CBA.

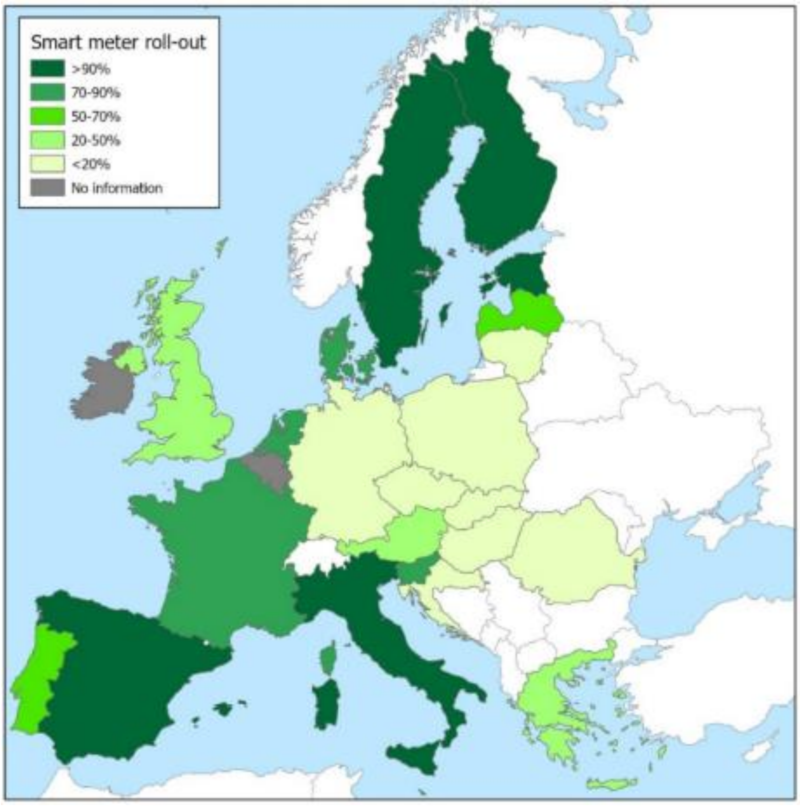
Figure 4-5 Normalised Costs vs. Benefits per Metering Point



Source: Tractebel December 2019, Benchmarking smart metering deployment in the EU-28 - Final Report. European Commission 2020. [The red-coloured dotted straight line with 45-degree slope is superimposed by IES. Countries that lie above the line have benefits higher than costs and vice versa].

Deployment rates of smart meters vary among EU countries as depicted in Figure 4-6. Estonia, Finland, Italy, Malta, Sweden and Spain report very high roll-out percentages between 93.1% and 100%. A December 2019 report by Tractebel, published by the EC in 2020) (Tractebel, 2020) concluded that progress in rolling out smart meters was slower than planned and predicted 43% penetration to be achieved in 2020 instead of 72%.

Figure 4-6 Smart Meter Roll-outs in the EU + UK



Source: (Vitiello, Andreadou, Ardelean, & Fulli, 2022) based on data from Benchmarking Smart Metering Deployment in the EU-28, Final Report. March 2020. Available online: https://op.europa.eu/en/publication-detail/-/publication/b397ef73-698f-11ea-b735-01aa75ed71a1/language-en

Various types of smart meters and communication protocols have been deployed across European countries including wireless cellular technology. This gives rise to concerns over interoperability issues. The variation in types of smart meters and communication protocols will make data exchange between smart meters and systems more complicated raising the level of challenge for interoperability and obtaining a holistic view of the system and utilising the data.

In their 2022 report on Smart Metering Roll-Out in Europe, Vitiello et. al. (Vitiello, Andreadou, Ardelean, & Fulli, 2022) grouped SG projects that have a smart metering component into the following main application categories:

- Smart metering applications—projects that deal with the smart meters implementation or development of different smart meter features for advanced services;
- Demand Response (DR) applications—projects that deal mainly with the facilitation of DR and are based on smart meter usage;

- Smart cities/smart home/smart building development—projects that deal with one of these topics either focusing on the consumer part (consumer involvement) or the network part (management of a smart city district or building);
- Grid monitoring applications—projects that deal with grid management/grid monitoring issues and smart meter usage can facilitate this goal;
- Data management issues—projects that deal with techniques related to data traffic management, like the increased traffic of data created by the implementation of smart meters;
- Other applications—we have identified projects that deal with EV charging issues and cyber security issues.

The referenced paper provides a list of projects under each of these categories along with a short description.

4.4 Policies and Regulations

SG development is integrated within the energy, climate change, cybersecurity and digitalisation framework of EU policy.

4.4.1 Digitalising the Energy System – EU Action Plan

SG is an important plank in 'Digitalising the Energy System – EU Action Plan' dated 18 October 2022, (European Commission, 2022). The digitalising action plan builds on the data exchange provisions of the proposals in the Fit-for-55 package[5] and links to other acts that deal with communication, cybersecurity and privacy aspects. The acts are summarised below:

- The European Data Strategy (COM(2020) 66 final) created the Common European data spaces in nine sectors, including energy.
- The proposed Data Act (COM(68) final) lays down the rules for use and access of data generated in the EU, including in the electricity sector.
- The Data Governance Act (COM(2020) 767 final) strengthens data sharing mechanisms.
- The data sharing framework he is estimated to facilitate participation of more than 580 GW of flexible energy resources by 2050, estimated to address 90% of flexibility needs of the EU grid, (European Commission D.-G. f., 2022). The work is to be implemented following completion of preparatory work in 2024. Complex legal, operational and technical requirements will be developed to ensure the smooth exchange of data subject to strong governance.

4.4.2 Funding Support

The EC provides financial support for SG through a number of programmes and initiatives.

[5] Fit-for-55 set an intermediate target to reduce emissions by 55% from 1990 levels by 2030.

- The Commission supports ENTSO-E and the EU DSO Entity in developing the digital twin of the EU grid as well as concrete investments by system operators through various means including Horizon Europe, (European Commission, 2022).
- At EU level, the EC intends to include in the Horizon Europe[6] work programme for 2023-2024 a flagship initiative to support digitalisation of the energy system, which addresses the key priorities of the digitalisation action plan.
- The EC has called on Member States to increase their research and innovation (R&I) support for the testing and piloting of digital technologies in the energy sector and promote cooperation between digital and energy stakeholders through the national R&I programmes.
- The Digital Europe Programme supports operators of critical infrastructures (including energy). The programme and Member States, aim at increasing capacity building, innovation and investments.

4.4.3 CBA Methodology

ENTSO-E has developed Costs-Benefits Analysis Guidelines for the EC that take into account social, economic and environmental facets including the potential for reducing emissions, stability, flexibility, capital and operating costs, mitigation of loss of power over long-distance transmission and integration of renewable energy into existing systems. The main points can be summarised as:

- The socioeconomic benefits from the reduction of overall generation cost due to the change in generation mix.
- The evolution of Greenhouse gas and other polluting gases from generation and network losses. The gases are carbon dioxide (CO2), nitrogen oxide (NOx), ammonia (NH3), sulphur dioxide (SO2), particulate matter (PM5 and PM10) and non-methane volatile organic compounds (NMVOC) emissions resulting from the new exchange and the evolution of losses or redispatch.
- The evolution of the volume and cost of electric losses on the grid taking into account the change of power flow due to the new infrastructure.
- The improvement in adequacy due to a new project by reducing the loss of load expectation and decreasing the need for generation capacity.
- The improvement to the capability of the power system to provide balancing energy and services in the context of high penetration levels of VRE generation (seen as non-dispatchable).
- The change in reserve power plants requirement for redispatch.

More details on the CBA methodology can be found on ENSTO-E's website, at https://tyndp.entsoe.eu/explore/what-is-the-cost-benefit-analysis-framework

[6] Horizon Europe was adopted by the European Parliament. It is the EU's key funding programme for research and innovation with a budget of EUR 95.5 billion over the 2021-2027 period. It incorporates six clusters and allocates approximately EUR 15 billion for the 'Digital, Industry & Space' cluster and EUR 15 billion for the 'Climate, Energy & Mobility' cluster.

4.5 Summary

Investment needs in grids is estimated to be between 375 to 425 billion Euro over the period 2020 to 2030. Digitalisation represents between 145 to 170 billion Euro of that amount. Distribution Automation has been slow but is recognised as an important element in SG deployment.

SG is one of three focus areas of the TEN-E regulation. The regulation provides funding support to PCI projects. ACER participates in the identification of PCI projects.

SG is an important element in 'Digitalising the Energy System – EU Action Plan'. It builds on the data-exchange provisions of the Fit-for-55 package and links to other acts that deal with communication, cybersecurity and privacy aspects.

The EU reestablished the SEEG. D4E is a working group within SEEG that focuses on data. D4E will advise the EC on matters such as interoperability, preparing implementation acts and boosting participation in demand response schemes. D4E will build upon previous work including that of the Smart Grids Task Force and work done on the network code relating to DSM.

The EC is considering the framework guideline submitted by ACER on 20 Dec 2022 as mandated. The framework facilitates European-wide market access for consumers with DER. If passed it will be converted to binding legislation within 12 months.

ENSTOE and EU DSO signed a declaration of intent in Dec 2022 to develop the Digital Twin, a sophisticated virtual model of the EU-wide electricity grid. The Digital Twin will assist in the coordination of investment in innovative solutions.

The EC provides financial support to SG programs. For example, it supports the development of the Digital Twin, supports digitalisation through Horizon Europe, provides support to critical infrastructure through the Digital Europe Programme and urges member states to increase their research funding.

ENSTOE has developed CBA methodology guidelines for projects which facilitates standardising CBA of projects.

The EU roll out of smart meters is below target, 43% by 2020 versus a target of 72%. The degree of penetration varies among countries with some at or close to full penetration while others are below 20%. CBA analysis is positive for most of the countries. The variation in types of smart meters and communication protocols will make data exchange between smart meters and systems more complicated raising the level of challenge for interoperability and obtaining a holistic view of the system and utilising the data. The uptake of smart home technologies is slower. It is estimated that 12.5% of households have integrated smart home technologies as of 2020.

R&D investment in DSM is consistently supported in the EU. Other important investment categories are 'Smart city' and 'Smart network management'. Government funding has been maintained at a steady level in terms of raw amount. Government investment represented a large proportion of total investment in the early years of the program but fell, in percentage terms, as private funding increased its share of total investment.

ERIGrid 2.0 supports SG research and enables researchers to access free software and apply for free access to laboratories. ENSTO-E's R&D roadmap for 2013 to 2022 played an important role in coordinating R&D efforts.

A group of seven private stakeholders founded USEF and developed a framework which creates a common standard for building smart energy products and services through making flexible energy as a tradeable commodity.

5 Australia

5.1 Structure of the Australian Electricity Market

The Australian National Electricity Market (ANEM) is a wholesale energy only spot market with five regions[7] connected to it including the island state of Tasmania which is connected to the mainland via an undersea cable. Due to geography, Western Australia and the Northern Territory are not connected to the ANEM. The Australian Market Operator (AEMO) plays the two roles of Market Operator and System Operator charged with maintaining the power system is a reliable and secure state. The Australian Energy Market Commission (AEMC) is the rule making body in the ANEM. The two main laws governing electricity are the National Electricity Law (NEL) and National Energy Retail Law (NERL). The National Electricity Rules (NER), made by the AEMC under the NEL, is the set of rules that governs the operation of the ANEM. The AEMC is also the rule making body for the National Energy Retail Rules (NERR). The NERR are primarily concerned with retail customers (both residential and other small customers). It sets out the rules for the sale and supply of electricity to, including consumer protection measures for, this customer segment. The Australian Energy Regulator (AER) regulates the market as well as the transmission and distribution grids. State governments maintain responsibility for power grids and retail energy prices in their states.

5.2 Technologies

Australia is implementing or evaluating a number of SG technologies. Details of their implementation are incorporated elsewhere in this report, either in the discussion of projects below or earlier, in the section on technologies. The following is a list of SG related technologies implemented in Australia.

- Communication protocols to enhance communication with DER devices or coordination between parts of the power system.
- Smart Inverters to improve the stability of the power system particularly with high penetration of VRE.
- The complete rollout of smart meters is essentially achieved in Victoria, targeted by 2026 in Tasmania and recommended to be targeted by 2030 by the AEMC.
- PMUs are being assessed in a project sponsored by ARENA. Intelligent switchgear has been designed by NOJA Power and trialled in 100 sites in two distribution networks in Australia.
- Implementation of ADMS to replace the current network management system has been identified as a goal for SG implementation by Ausgrid, a major DNSP.
- FLISR implementation within ADMS is being further extended to cover more complex network faults after initial successful trial in 2017 by United Energy, (United Energy, 2023). The AER approved the proposed capex by Ausgrid for AUD 59.9 million in the 2019-2024 regulatory period, refer to Appendix B.5.1 of the AER's final determination for the 2019-2024 regulatory period (Australian Energy Regulator, 2019).
- Research is on-going on many fronts. Australia has a mission to the Global Power System Transformation (GPST) Consortium which brings key actors together to support the rapid

[7] A region in the ANEM is basically the equivalent of a state.

transition to a zero-carbon electricity grid.[8] Australia's mission is led by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). CSIRO with the Australian Energy Market Operator (AEMO) and other research partners have developed a research roadmap to support Australia's transition to a decarbonised power system. Australia's Global Power System Transformation (G-PST) Research Roadmap was launched in 2022 includes work on nine important research areas. The first six areas were established based on research subjects identified in the GPST Consortium research agenda and last three are additional topics of special importance to Australia. The nine research topics are:

1. Advanced inverter applications and requirements for current-limited grid-forming inverters
2. Analytical methods for determination of stable operation of IBRs in a future power system
3. Control Room of the Future
4. Planning
5. The role of inverter-based resources during system restoration
6. Services
7. Power System Architecture
8. Distributed Energy Resources (DERs)
9. Distributed Energy Resource and Stability

More detail on these topics can be found on CSIRO's website, (CSIRO, 2022).

5.3 Initiatives and Implementation

This section discusses the Initiatives related to SG including trends, maturity, implementation approach, funding and CBA where available.

5.3.1 The NEM Reform Program

AEMO established the NEM Reform program to deliver the ESB's Post 2025 reforms and other market reforms in collaboration with the energy market participants. AEMO identified more than 30 foundational and strategic initiatives including Integrating Energy Storage Systems (IESS) project, a SG related initiative that aims to implement the regulatory changes designed to enhance the integration of distributed energy storage systems. More details on these projects are available on AEMO's program webpage, refer to (The Australian Energy Market Operator, n.d.).

A diagrammatic representation of the initiatives identified in the NEM Reform Program is given in Figure 5-1. The 'Integration of CER & Flexible Demand' stream has the most direct link with SG. In addition, individual initiatives in other streams are closely linked to SG. Examples of these initiatives are: 'SCADA Lite' in the AEMO Foundational stream, 'Network Visibility' and 'EV Supply Equipment Standing Data Register' both of the latter are in the Data Strategy stream.

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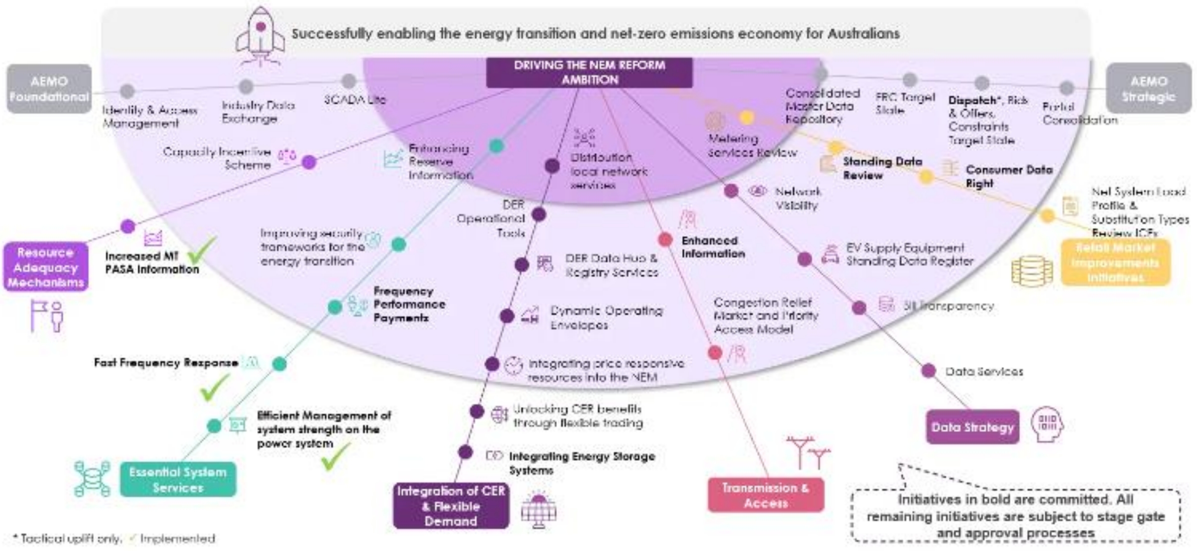
8 More on G-PST can be found on their website https://globalpst.org/#:~:text=The%20Global%20Power%20System%20Transformation%20Consortium%20(G%2DPST)

Figure 5-1 NEM Reform Program Streams and Initiatives



Source: *[AEMO | About the NEM Reform Program]()*

5.3.2 SCADA Lite

This is an initiative under the AEMO Foundational stream of the NEM Reform Program. It will enable NEM non-NSP (Network Service Provider) participants to establish a bi-directional connection to exchange operational information (telemetry and control) with AEMO. The solution will support both physical and cloud-hosted services, hosted by major Australian cloud providers. SCADA Lite will lower barriers for and enhance access to revenue streams for consumer DER and provide greater visibility and operational control of resources, refer to (The Australian Energy Market Operator, n.d.).

The solution will benefit the following types of NEM participants that are currently not able to exchange operational telemetry and control information with AEMO via an NSP:

- Demand Response Service Providers (DRSPs)
- VPPs (Virtual Power Plants)
- SGAs (Small Generation Aggregators)
- Operators of remote grid scale assets (e.g. solar and wind farms)

5.3.3 Distributed Energy Resources (DER) Program

AEMO established the DER Program with a focus on studying and integrating high levels of Distributed Energy Resources (DER) into Australia's energy system and markets. The effective integration of DER enhances power system security and reliability. The DER program comprises the following workstreams, see (The Australian Energy Market Operator, n.d.):

- **Markets and framework:** This workstream advances the design of new two-sided systems and markets. The design is aligned with the Hybrid Model developed by the Open Energy Networks initiative.

- **DER Demonstrations:** This workstream involves the design and execution of small-scale trial such as:
  - DER marketplace demonstrations,
  - demand response mechanisms, and
  - Virtual Power Plant models.

  The demonstrations are aimed at collecting evidence to inform changes to regulatory and operational processes to ensure effective integration of DER devices into the power system and markets.
- **Operations:** This workstream examines the behaviour of DER resources during power system disturbances. It develops tools and models to predict and manage DER performance in the future power system with high DER penetration.
- **Data and visibility:** The program developed a database of DER installations at residential and business sites. The DER Register was launched on 1 March 2020. The specification and other information about DER devices are entered by installers at the time of installation. AEMO is obligated to report on DER installation down to a postcode level while protecting privacy. For more details refer to (The Australian Energy Market Operator, n.d.)
- **Standards and connections:** This workstream revises standards (e.g. AS4777 and AS4755) and guides with an aim to ensure optimal DER technical performance and energy system security and enhance interoperability and cyber security protection.
- **Engagement and collaboration:** AEMO is working with a wide range of stakeholders to deliver the DER workstreams.

5.3.4 Compliance of DER with Technical Settings

To raise performance of small-scale DER inverters, primarily PV and BESS, it has become mandatory as of 18 December 2021 for these inverters to comply with Australian Standard AS/NZS4777.2:2020 which focuses on disturbance ride-through capabilities. The project's web page contains more detail, (The Australian Energy Market Operator, n.d.).

AEMO has published a report that investigated the nature and scale of compliance of DER with technical settings. The work supported the AEMC review into consumer energy resources technical standards.[9]

5.3.5 DER Standards and Connections

This workstream by AEMO supports the uplift of Distributed Energy Resources (DER) and associated device level capabilities with the aim of unlocking the full value of their investment and harnessing the benefits from integrating DER into the two-way electricity grid and markets.

The main activities consist of:

[9] The AEMC's review into consumer energy resources technical standards is discussed in the policies and regulations section below.

- Compliance of DER with Technical Settings (AS/NZS4777.2)
- AS/NZS 4777.2 - Inverter Standard
- AS/NZS 4755.2 - Demand Response Standard
- South Australia Short Duration Undervoltage Disturbance Ride-through Test procedure (completed)

See the project's webpage (The Australian Energy Market Operator, n.d.).

5.3.6 Common Smart Inverter Profile Australia

Australia is moving toward the adoption of the 'Common Smart Inverter Profile Australia' (CSIP-Aus) with the aim of facilitating the deployment of DER. CSIP-Aus was created by the DER Integration API Technical Working Group (DERIAPITWG). CSIP-Aus is set out in a report dated January 2023, (DER Integration API Technical Working Group, 2023). This working group was formed in 2019 by a consortium of Australian energy industry companies from all parts of the supply chain, including several distribution networks, retailers, aggregators, and equipment manufacturers. The panel agreed on using existing standards, including the IEEE 2030.5-2018 specification and CSIP to promote interoperability among DER and DNSPs in Australia. These standards were chosen primarily because they encompass crucial data communications and have widespread adoption in related international jurisdictions (Standards Australia, 2023).

A selection of the DERIAPITWG's guiding principles, shown below, could be of interest when designing an approach to developing standards in Viet Nam. The selected principles focus on creating a minimalist specification; to be as close to international standards as possible; and reduce complexity, development time and cost. The selected principles are:

- Utilise current engineering (e.g., AS/NZS 4777.2) and communications (e.g., IEEE 2030.5) standards and models - The creation of a new, stand-alone standard would impose additional burdens on all parties and would only serve to increase development and maintenance costs. [CSIP 3]
- Assume that future changes will be required - The use of DER will continue to evolve, and utilities and other DER players anticipate the emergence of new use cases in the near future and in the long run. Concentrate on core, common use cases that will generate the most value in the Australian electrical market right away. Attempting to foresee all future use cases will increase the specification's complexity without necessarily adding benefit. The definition must be extensible through future revisions. [CSIP 4]
- Create a minimum specification - A minimalistic interface reduces expenses while improving quality. [CSIP 6]
- Where possible, the CSIP-AUS should be as near to existing implementations (e.g., CSIP) as practicable, and be explicit about where changes or additions have been made.

5.3.7 Virtual Power Plant (VPP) Demonstrations

A VPP is an aggregation of decentralised generation, storage and controllable loads coordinated to deliver services for power system operations and electricity markets. AEMO, ARENA, AEMC, AER, and members of the Distributed Energy Integration Program (DEIP) collaborated to complete this project. The demonstrations were a first step in a broad program of work designed to inform changes to regulatory frameworks and operational processes to better integrate DER into the power system and ANEM. The objectives of this project were to demonstrate the capability of VPP to deliver services in contingency FCAS (through a trial specification) and respond to energy market price signals. After the trial was concluded VPP delivering FCAS have to comply with the Market Ancillary Services Specification (MASS). More details can be found on (The Australian Energy Market Operator, n.d.).

5.3.8 A Bridge between SG and Users

The new smart energy standard, AS 5385:2023, will support Australia's move to a renewable energy future. AS 5385:2023 Smart Energy Profile Application Protocol is an international adoption of IEEE 2030.5-2018, a standard protocol allowing devices and systems connected to an energy distribution network to communicate with one another via the internet. Australian Standard AS 5385:2023 contributes to this through the creation of a standardised communication protocol between the SG and devices and systems at user sites such as rooftop PV, batteries, EV and energy management systems. The protocol can support additional commodities such as water and natural gas as well as providing a mechanism for exchanging error and other messages in a secure manner.

The standard protocol focuses on various architectural and usage models. These include communication within a home area network (HAN), or between the user and external parties such as a service provider, or between a service provider and an aggregator. AS 5385:2023 draws on several existing standards, including IEC 61968 and IEC 61850, and employs a representational state transfer (REST) architecture for network-based applications, utilising commonly used internet protocols including TCP/IP and HTTP, see (Standards Australia, 2023).

5.3.9 Open Energy Networks Project

The open Energy Networks project aims at facilitating the engagement of DER in the power system. It was led by AEMO and involved the following main activities:

- **Initial consultation:** The consultation was carried out in collaboration with ENA to investigate proposed frameworks for integrating DER, including as a more active Distribution System Operator (DSO) and the emergence of relevant markets. The consultation explored three frameworks: The Single Integrated Platform, the Two-Step Tiered, and the Independent DSO frameworks. The consultation opening seminar had 350 registered attendees. Extensive submissions were received. This stage culminated in a report issued in June 2019.
- **International Review:** Focused on market design and system architecture to coordinate DER between AEMO, transmission and distribution network operators, and customers. The options covered expanded roles and responsibilities of stakeholders.
- **Smart Grid Architecture Model (SGAM):** A number of SGAMs were considered and discussed in a series of workshops. A hybrid model was selected in which AEMO operates a central platform for energy and ancillary services, optimises the system taking into account distribution network constraints. DER participate in the market via an aggregator or retailer.

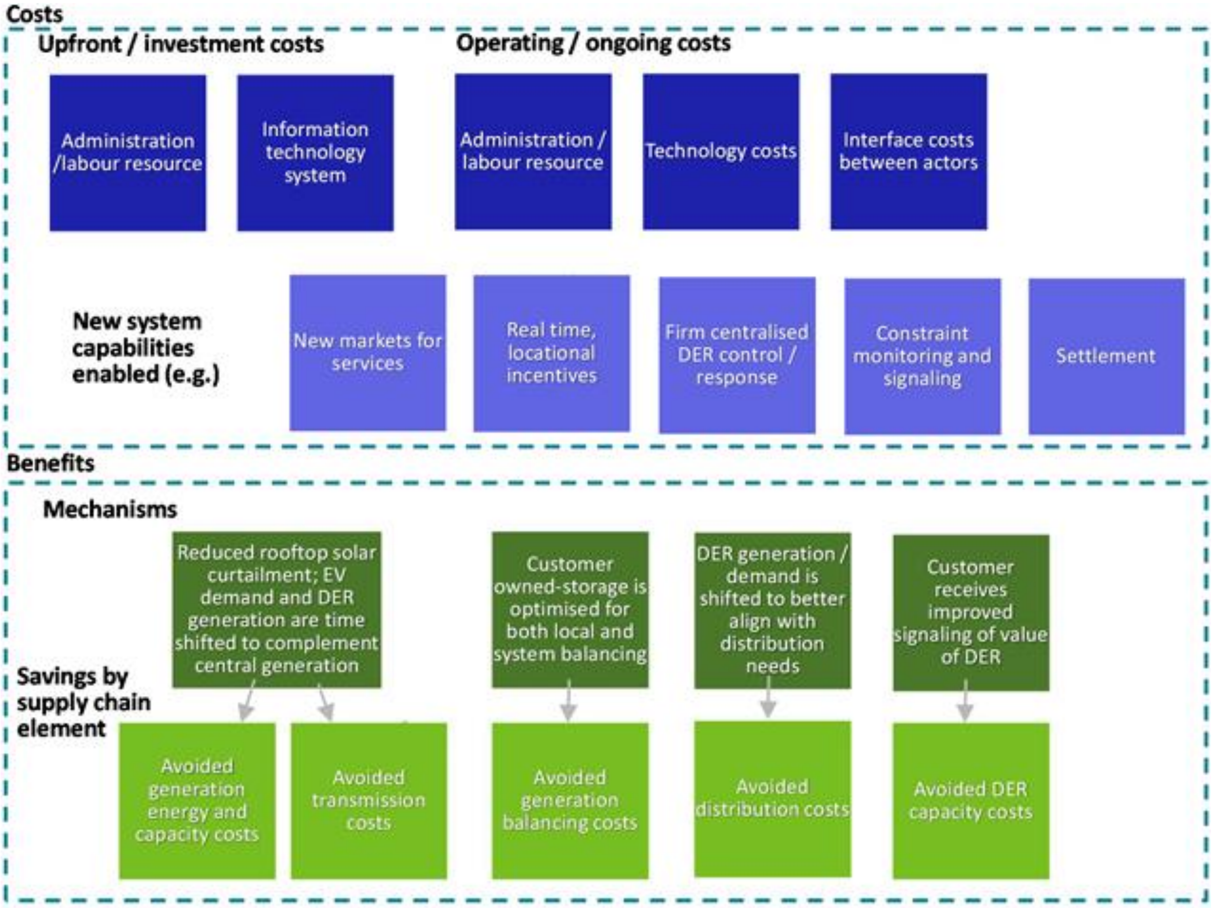
- **Cost-benefit analysis (CBA)**: This activity reviewed approaches to CBA employed internationally or within Australia related to the coordination and optimisation of DER. The report estimated costs, based on existing Australian and international studies, of approximately AUD 600 million by 2030 and AUD 1 billion by 2050. Benefits were much larger and estimated to be AUD 5 billion by 2030 and over AUD 10 billion by 2050. The report also proposed a framework for CBA of DER integration. This activity is summarised in the next section.

  The reports referenced above are available on AEMO's Open Energy Networks Project web page, (AEMO, 2019).

5.3.9.1 Cost-benefit analysis for DER integration

DER integration is a key element of SG. We summarise here the main aspects of the CBA framework proposed in the CBA task undertaken as part of the One Energy Networks project, refer to (Graham, Brinsmead, Spak, & Havas, 2019). The proposed cost-benefit analysis framework shown in Figure 5-2 includes both investment costs involved in setting up the DER integration system for operation and the ongoing operation costs. Two categories of investment costs were included. The first category is information technology systems which encompasses the automation costs of the various functions that comprise the DER integration system. This category includes the costs of information technology systems at the distribution level to monitor and communicate hosting capacity constraints. The second category is the administration or labour costs involved with system setup. Once operational, the system will continue to incur administrative and labour costs to maintain the necessary governance.

Figure 5-2 Proposed cost-benefit analysis framework



Source: Graham, P., Brinsmead, T., Spak, B., & Havas, L. (2019). Review of cost-benefit analysis frameworks and results of DER integration. CSIRO.

The benefits of DER integration for the electricity system are mainly due to reduced rooftop PV curtailment and the shifting of DER demand (such as from EV and PV with BESS) to better align with the capacity limits of the generation, transmission, and distribution sectors. If DER can perform this task reliably, the capacity and costs of these three sectors can be lower than they would otherwise be.

The last benefit in Figure 5-2 is less certain since it pertains to customer decision making regarding DER investment under new incentives. Customers and their representatives (e.g., installers, aggregators) will have a clearer view of the value available in exchange for their services if DER is fully integrated. The study makes the reasonable assumption that properly constructed incentives will encourage DER investment to gravitate to locations where it will be most beneficial to the system and move away from locations where it is not (Graham, Brinsmead, Spak, & Havas, 2019).

5.3.10 Integrating Energy Storage Systems Project (IESS)

IESS is part of the NEM Reform program proposed by the ESB and approved by the Energy ministers. Following the IESS rule change AEMO set up a project to implement it in the ANEM with effect from

2 June 2024. The IESS rule comprises four distinct high-level changes, see (The Australian Energy Market Operator, n.d.)

- **FCAS by aggregated resources:** Aggregators of small generating and storage units can provide ancillary services as of 31 Mar 2023.
- **Aggregated dispatch conformance (ADC):** Allows an aggregated system to conform to dispatch instructions at a connection point in aggregate rather than on an individual unit basis. For a BESS ADC means a BESS is monitored on the net (or aggregate) of its generation and load units. 9 Aug 2023.
- **IESS retail and settlement:** Cost recovery of non-energy services (such as ancillary services…) will be settled on the basis of separate consumed and generated energy amounts as opposed to the current net basis. This will come into effect on 2 June 2024.
- **Registration and bidding:** A new participant category of Integrated Resource Provider (IRP) and bi-directional unit (BDU) bidding, scheduling and participation, with impacts for BDU participants and bidding system vendors/developers. This will come into effect on 3 June 2024.

5.3.11 Intelligent Switchgear

ARENA sponsored a project by NOJA Power which incorporated PMUs into Power Recloser Controllers that have been installed in two distribution networks in Australia. Developme is continuing to implement PMU data in islanding detection and control of DER, accurate state estimation, protection coordination, and fault identification and location detection, (The Australian Renewable Energy Agency, n.d.).

5.3.12 Smart Grid Road Map

Energy Networks Australia (ENA) is the national industry body representing electricity transmission and distribution and gas distribution networks in Australia. ENA developed a roadmap for modernising the grid in four stages over the period to the early 2040s. The streams comprise Data and Visibility, Operating envelopes, Passive and Active DER, Pricing and Access for customer, Networks and Optimisation. The stages and main tasks are summarised below, see (Energy Networks Australia, 2020).

5.3.12.1 Stage 1 (-early 2020s)

Data and Visibility

- Static customer connection data and little to no live data.
- DER register in place.
- Limited to no LV visibility.

Operating envelopes

- Fixed export limits.
- Dynamic operating envelopes (DOEs) being trialled.
- Simple allocation of export capacity.

Passive and Active DER

- Mostly passive PV and poor disturbance performance.
- Minimum DER technical standards under development.

Customer Access and Tariffs

- New residential time-of-use tariffs.
- High priorities on network access and tariff reform.

Networks and Optimisation

- Unmanaged customer DER.
- Rare usage of active DER solutions for solving network constraints.

5.3.12.2 Stage 2 (mid 2020s - late 2020s)

Data and Visibility

- Start of customer DER data transfer to NSMs automatically.
- Automation of data gathering for constrained networks.
- Increased network visibility.

Operating envelopes

- Start of DOEs in constrained networks.
- Near real time and flexible export limits
- Forecast based export capacity allocation.

Passive and Active DER

- Technical standards for DER in place.
- Active emergency PV shedding capabilities in some jurisdictions.

Customer Access and Tariffs

- Regulations for network access arrangements for DER exports.
- Expansion of network tariffs - V2G, EV, and time varying feeds in tariffs.

Networks and Optimisation

- Trials in DER integration and optimising DER across local networks.
- Widespread usage of network batteries.

5.3.12.3 Stage 3 (late 2020s - early 2030s)

Data and Visibility

- Automated near real-time data collection.
- Dynamic calculation of constraints based on infrastructure status of the network.

- Smart meters installed for most customers.

Operating envelopes

- High DER penetrated areas commonly use DOEs.
- Export capacity is allocated based on real time data.

Passive and Active DER

- Refreshed the DER technical standards.
- Improving the DER response capabilities.

Customer Access and Tariffs

- Refinement of network access, DER value, and network service value.
- Gradual transition into network cost reflective tariffs, and incentivising supportive customer behaviour.

Networks and Optimisation

- Maximise levels of networks' inherent hosting capacity.
- Evolution of local DER markets and DER integration platforms.
- Identification and justification of desired Distribution Systems Operator (DSO) / market optimisation end-state.

5.3.12.4 Stage 4 (early 2030s - early 2040s)

Data and Visibility

- Automated real-time data collection.
- Comprehensive network visibility.

Operating envelopes

- Widespread use of DOEs across the whole system optimisation.
- DOEs optimise the network hosting capacity for faire, more equitable access.

Passive and Active DER.

- Active and optimised DER resulting in grid support and value for all the customers.
- Customer Access and Tariffs.
- DSO and market optimisation delivered.
- Whole system optimisation supported by key data exchanges through market operations.

5.3.13 Examples of Miscellaneous Projects

Below are examples of miscellaneous projects related to SG.

5.3.13.1 Project Energy Demand and Generation Exchange (Edge)

Project EDGE is a multi-year project to demonstrate an off-market, proof-of-concept market place for DER to provide both wholesale and local network services within the constraints of the distribution network. The project is a collaboration between AEMO, AusNet Services and Mondo, with financial support from ARENA. The trial is based in the AusNet Services distribution area within Victoria and intended for replication to other regions of the ANEM. The project demonstrates how consumer participation in a DER marketplace could be facilitated through aggregators. The services required are determined by AEMO, or the DNSP (The Australian Energy Market Operator, n.d.).

5.3.13.2 Project Edith

Project Edith is an to demonstrate how the grid can facilitate technology and green energy solutions like VPPs to participate in energy markets while operating within distribution network capacity limits. Edith is exploring the use of tools such as:

- Dynamic operating Envelopes (DOEs) that can allow customers to use more energy or export larger amounts of their rooftop solar at times when there is extra capacity on the network. The University of Melbourne has been commissioned to research this aspect, for details refer to (The Australian Energy Market Operator, n.d.).
- Dynamic network prices (DNPs) for customers who already have a retailer or aggregator managing their battery in a VPP. The price signal varies daily and within the day to provide an incentive for BESS to manage charging and discharging based on network needs, for details refer to (Ausgrid, n.d.).

5.3.13.3 Advanced VPP Grid Integration by SA Power Networks

South Australia Power Networks (SAPN) implemented an advanced VPP grid integration trial. ARENA shared the funding of the project. Tesla and industry representatives participated in the project. Under real-world conditions, the project:

- Developed a design for an API for VPP integration. Consistent with CSIP (discussed earlier), the draft specification was modelled on IEEE 2030.5.
- Developed an algorithm for calculating DOE based on three models for (1) Network at LV feeder level, (2) Solar PV and (3) Load.
- Developed a new hosting capacity estimation engine.
- Demonstrated the capability to raise the export limit to 10kW during unconstrained times. Also demonstrated how raising the export limit facilitates participation in FCAS.

Refer to the 2021 report Advanced VPP Grid Integration Project (SA Power Netwoks (SAPN), 2021) which can be found on the link provided in (SA Power Networks, 2021).

5.3.13.4 Battery Storage and Grid Integration Program

The ANU's new Battery Storage and Grid Integration Program, launched in April 2018, is co-hosted by the Research School of Engineering and the Research School of Chemistry. The program focuses on the development, integration, operation, and optimisation of energy storage in power networks and electricity markets. The devices, optimisation, and control stream, which is particularly relevant to the Smart Grid Cluster, will conduct research and development of distributed optimisation and control capabilities (both hardware and software) to enable the effective and efficient operation of DER (Australian National University, 2022).

5.3.13.5 Consumer energy systems providing cost-effective grid support (CONSORT)

The project started in 2016 and was funded by ARENA. It developed and implemented algorithms to automatically control consumer-owned PV-battery systems to offer network support and customer value on Bruny Island, Tasmania. The deployed system has resulted in a 30% reduction in the use of backup diesel during peak usage periods, see (Australian National University, 2022).

5.3.13.6 Smart Grids Innovation Challenge

CSIRO leads Australia's participation in the International Energy Agency's (IEA) Mission Innovation Challenge for Smart Grids. The Smart Grids Innovation Challenge project aims to improve reliability and interoperability under high VRE penetration. The Smart Grid Innovation Challenge intends to develop and demonstrate the use of smart grid technology and storage in a number of grid applications during the next decade. The total cost of the project is $278k USD ($383k AUD) with a $87k USD ($113k AUD) funding from ARENA (ARENA, 2022).

5.4 Policies and Regulations

Appropriate policy and regulatory reform of technical and market areas is necessary to incentivise investment and participation in the ANEM. Here we discuss key policy and regulatory reforms in the ANEM.

5.4.1 ESB and the Post-2025 Reforms

The Energy Security Board (ESB) was established in August 2017 by the nation's energy ministers to coordinate implementation of recommendations from the Independent Review into the Future Security of the National Electricity Market (commonly referred to as the Finkel Review[10]). The Energy Ministers endorsed a final package of reforms based on the ESB's recommendations for the Post-2025 NEM in October 2021. The ESB has been restructured for the delivery phase of the Post-2025 reforms, and comprises the heads of the AEMC (as Chair), AER and AEMO.

The four reform directions address aspects of electricity generation and dispatch, consumer access to services, and efficient investment, (Energy Security Board, n.d.).

1. Resource adequacy through the transition – critical to ensuring reliable and affordable energy during the transition of the power system to lower emissions and new technologies.
2. Essential system services and scheduling and ahead mechanisms – To build a stronger power system during the transition.
3. Integration of distributed energy resources and flexible demand – unlocking opportunities for households and businesses to manage their resources including

[10] The Finkle review is available at Independent Review into the Future Security of the National Electricity Market | energy.gov.au

through load shifting, installing more efficient appliances and investing in locally based generation or storage.

4. Transmission and access – providing networks to meet future needs including connection of renewables, at the lowest possible cost.

5.4.2 Review of Regulatory Framework for Metering Services

Following the independent review of the regulatory framework for metering, the AEMC released final recommendations, on 30 August 2023, to improve the regulatory framework for metering services and to accelerate the deployment of smart meters to reach a target of 100% of small customers to have a smart meter installed by 2030. Rule changes to enable reaching this target will follow, (AEMC - Smart Meters, 2023). The AEMC sees smart meters will enhance participation of customers in providing services to the power system, mainly through aggregated virtual power plants, and to manage their consumption to take advantage of low wholesale prices. The AEMC's key recommendations are:

- Speeding up smart meter deployments to achieve a target of universal uptake of smart meters by 2030 in ANEM jurisdictions. DNSPs would develop an annual schedule for the roll out. Retailers would be responsible for installing smart meters at these sites.
- Supporting a positive customer experience in the transition to smart meters through the provision of new customer safeguards to protect customers from unexpected cost increases and clearer information and rights under the framework.
- Improving meter installation processes through opportunities to improve efficiencies, transparency and information availability for customers, reduce the regulatory burden on retailers and DNSPs, reduce delays in meter replacements and facilitate better coordination between stakeholders in the industry.
- Unlocking further benefits from smart meter data and services by improving access to a broader range of data and services provided by smart meters. We recommend improved customer access to real-time data, and DNSP access to Power Quality Data from smart meters, (AEMC, 2023).

The CBA conclusion was that an accelerated roll-out of smart meters would be cost effective for the states of Queensland, New South Wales and South Australia. Tasmania was not included as it has a policy of installing smart meters by 2026. Victoria was excluded as it has nearly complete penetration of smart meters.

Figure 5-3 CBA Outcome of Accelerating the Rollout of Smart Meters (AUD 2022)

State	Costs ($m)	Primary non-contingent benefits	Net benefit	Selected additional benefits	Net benefit w/ additional benefits
NSW	$69.2	$212.3	$143.1	$112.8	$255.9
QLD	$30.0	$99.1	$69.1	$127.6	$196.7
SA	$21.6	$46.9	$25.3	$28.5	$53.8

Source: Costs and Benefits of Accelerating the Rollout of Smart Meters. AEMC Review of the Regulatory Framework for Metering Services, September 2022.

5.4.3 Review into Consumer Energy Resources (CER) Technical Standards

The AEMC completed its review of CER technical standards on 21 September 2023. CER includes devices such as rooftop PV, BESS, EVs and actively controlled appliances such pool pumps. The report makes recommendations to improve compliance including immediate steps and, more importantly, recommendations to address the key root causes including closing gaps in the existing regulatory framework under the NEL and the development of a national regulatory framework for CER technical standards. The report can be downloaded from the AEMC website, (Australian Energy Market Commission, 2023).

5.4.4 Wholesale Demand Response (WDR)

WDR was introduced into the NER with effect from 24 October 2021. It introduced a new participant category ‘Demand Response Service Providers’ (DRSP) who can receive payment for dispatched response against a baseline methodology.

5.5 Summary

Various SG related technologies are implemented in Australia. Smart inverters to improve stability of the power system, communication protocols to enhance interoperability and coordination of components of the system, the complete roll out of smart meters is targeted by 2030, or earlier, and completed in some jurisdictions. Capex for FLISR has been approved by the regulator, AER. Projects to assess PMUs, ADMS, and other technologies have been undertaken. Demonstration projects for VPP and DER have been completed and provided valuable information on technical capability and inform work on market mechanisms and regulatory options.

The Australian energy ministers established the ESB in 2017 to coordinate the implementation of the recommendations of a major study into the future security of the Australian NEM. The resulting Post-2025 reform program is now in its delivery phase under a restructured ESB comprising the heads of the AEMC (as Chair), AER and AEMO. WDR was introduces in late 2021 and the rules to better integrate energy storage systems will take effect as of 2 June 2024. AEMO has identified and launched several streams to implement the initiatives identified in the NEM Reform Program including SG related initiatives. An example is SCADA Lite which aims to enhance participation of non-NSP participants by facilitating the establishment of bi-directional connections.

The DER program focuses on integrating high levels of DER with the aim of enhancing system security and reliability. The program incorporates six main workstreams: Markets and framework, DER Demonstrations, Operations, Data and visibility, Standards and connections, and Engagement and collaboration.

VPP demonstrations was a collaboration of AEMO, ARENA, AEMC, AER, and members of the DEIP. It demonstrated the capability of VPP to provided contingency FCAS and respond to market price signals. The project is a stage of a broad program of work designed to inform changes to regulatory frameworks and operational processes to better integrate DER. Other projects followed including Project Edge, Project Edith and Advanced VPP Grid Integration. The projects aim to demonstrate how to facilitate the participation and integration of DER, VPP and storage systems.

The Open Energy Networks Project considered candidate SGAMs and recommended a hybrid model.

Integrating Energy Storage Systems implements the reforms designed to facilitate services by distributed resources and will take effect as of 2 June 2024.

Various projects have developed standards for devices. These include standards for inverters, standards for DER connections, the development of the CSIP-Aus, and the adoption of a standard communication protocol for DER devices.

The AEMC released in August 2023 a review of the regulatory framework for metering services aimed at accelerating the rollout of smart meters to reach 100% by 2030. A review of CER technical standards was completed in September 2023.

Energy Networks Australia developed a roadmap for modernising the grid in four stages over the period to the early 2040s. The streams comprise Data and Visibility, Operating envelopes, Passive and Active DER, Pricing and Access for customer, Networks and Optimisation.

Australia participates in international research efforts such as its mission to the Global Power System Transformation (GPST) Consortium led by the CSIRO.

6 KEY LESSONS FOR VIETNAM

We begin this section by discussing key features of the experience of the reviewed jurisdictions. This will help bring to relief best practices, opportunities for improvement and leads to identifying aspects that Viet Nam can consider in its SG implementation.

The review shows that the presence of appropriate regulation is crucial to encourage participation of resources and incentivising behaviour that is helpful to system performance. All jurisdictions have introduced legislation to award consumers for providing system services. The decision on mechanism and market design to reward these services was made based on information gathered from research and demonstration projects. For example, projects in Australia demonstrated the technical capabilities of VPP and DER to respond to market price signals under different mechanisms. A related aspect is enhancing competition by opening the provision of new services to new players without compelling consumers to source these services from their incumbent retailer. In Australia the introduction of the wholesale demand response mechanism achieved limited participation. Other initiatives are underway to improve participation of DER. Regulation to better integrate energy storage systems will take effect from 2 June 2024 and the AEMC is considering other proposals related to the Post-2025 NEM market design submitted by AEMO to integrate DER into market and operational processes more fully.

The review shows that rolling out devices and technologies without an integrated strategy and common standards is not effective. The roll out of smart meters in the EU is extensive but the lack of common standards and communication protocols placed challenges on ensuring interoperability of these devices with Europe-wide systems. The limitations on automated data exchange limits the ability to have a holistic view of the condition of the system and provide effective price signals to consumers.

Establishing common standards for devices, components, systems, communications, and data exchange is critical. Without this, there will be risks to interoperability which will limit benefiting from the full capabilities of these smart devices and technologies. A related issue is the presence of adequate infrastructure to handle the communications requirements of these devices. For example, PMUs capture extensive amounts of data and need to be supported by a strong data communications network to fully utilise their potential.

All jurisdictions discovered that the success of implementing new technologies and systems depends on proper system integration. The projects showed that system integration requires significant effort and resources. For example, benefiting from FLISR in the USA was more beneficial when integrated with existing GIS systems. Related to this is the presence of accurate models for the the market, power system and system components. Without accurate models there is a risk of reaching wrong decisions both at a strategic level and in operations. Data quality and validity also needs to be assured. Systems need to be in place to ensure that the data received, processed, and fed into models is accurate and valid. Compromising the correctness or validity of data during processing will lead to incorrect decisions.

Funding of projects in all three jurisdictions was through a mix of government and private funding. The EU for example provided a consistent level of funding for projects but as the system matured and penetration of SG related technologies increased, that consistent level represented a smaller percentage of total funding of projects. In a sense, government took higher risk in projects in the early stages which fell as SG technology implementation rose. Projects applied for funding and were selected by an appointed body in accordance with clear established criteria for funding. Projects had to meet performance obligations and milestones and to report on progress during the life of the project. The bodies with responsibility to select and administer the projects also had obligations to report regularly on progress and success of individual projects and the overall program.

CBA methodology guidelines were developed by ENSTO-E to establish a common basis for estimating project benefits and is considered a strength of the EU implementation. This aspect is less developed in the other jurisdictions reviewed in this report.

Regulations on data ownership, privacy legislation and consumer protection regulations are key elements in all three jurisdictions. It was recognised as critical to overcome consumer concerns over privacy and the risk of ending up in worse position resulting from entering into new arrangements.

All jurisdictions had extensive stakeholder engagement in all stages including the development of policy and regulations, mechanism and market design, development of standards, technology selection, project design and execution, data exchange, privacy and consumer protection.

Based on the review of the selected jurisdictions we can draw key success factors that are worthy of consideration in Viet Nam's implementation of SG.

- **Strategy:** The success of SG implementation starts with the careful development of a strategy that defines the target, studies the current state and charts the roadmap of getting to the desired target. Once a holistic strategy is in place, plans can be drawn, and implementation of subsystems and devices can proceed in a staged manner consistent with the strategic objective. Thus, one should resist the temptation of jumping into technical solutions that are devoid of strategic context. Technical challenges are often not purely related to technology but are linked to the availability of robust valid data at the right temporal, geographic and system level of granularity. The development of operational and market models that faithfully represent the assets connected to the system is crucial if this data is to be used effectively. For example, smart meters that record data with great precision are of limited use unless it is communicated consistently and not compromised by the systems that process the data. Valid data cannot be used effectively if the operational models for VRE and other assets have not been developed to reflect and predict the behaviour of the assets under all operating circumstances, particularly during events when the system is under stress.
- **Integration of Systems:** Integration of systems is a key success factor. For example, FLISR is more effective when implemented as part of an ADMS and integrated with a GIS. There is no single solution that is best for all circumstances. From a network topology perspective, FLISR is effective when deployed in a network in that is intermeshed to allow rerouting of paths to resolve outages.
- **Centralised versus Distributed Architecture:** Similarly, the choice of central versus distributed control depends on the situation. Distributed architectures have become more dominant in SAS. Data requirements is also a key consideration. Solutions with heavy data requirements, such as PMU, are not effective if the communication infrastructure cannot support such needs.

- **Interoperability:** Interoperability between devices and systems is key. Thus, careful selection of standards is an important consideration to ensure the different parts of the system can work collaboratively. Managing current or legacy systems is an important part of implementation.
- **Regulatory Reform:** Regulatory aspects are an obvious key area to consider. The reviewed jurisdictions have implemented, and continue to implement, regulatory reforms to fairly value and compensate services provided by participants. Appropriate regulation is crucial in ensuring DER participates broadly in a two-way system and market for services. Some markets, such as markets for demand response or for ancillary services by aggregated small resources, were developed to allow high levels of participation. This was done following trials and demonstrations were carried out that furnished information about the capability of such systems and market design options to accommodate and integrate these resources.
- **Funding and Financing:** Funding and financing mechanisms are important to have in place to adequately propel investment. The reviewed jurisdictions have implemented a combination of government and private funding of projects. Clear criteria for selection strongly linked to policy objectives should be established. Clear responsibility for selecting and administering projects have been key features that should be considered for adoption in Viet Nam. Finally clear performance and reporting obligations should be set.
- **Privacy and ownership of Data:** Privacy and ownership of data are also key issues that have been a common thread in the reviewed jurisdictions. It is important to set the right framework to encourage competition and make it easy for consumers to switch providers.
- **Stakeholder consultation and involvement:** Stakeholder consultation and involvement is a cornerstone of successful implementations. This has been accomplished in international implementations by involving stakeholders in all stages of the process and projects through submissions to consultations, information sessions, participation in trials, demonstrations, research projects and committees.

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8 APPENDIX

8.1 Technology Matrix

The Technology Matrix summarises the technology trends and provides estimated costs and application areas of technologies.

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
Smart Inverters	High penetration of Distribution Energy Resources (DERs) resulting in high usage of smart inverters across the world. Advancements in deployment of smart inverters to continue for efficient operation and integration of DERs into the grid.	$0.22 USD/W ($0.18 USD/W, 2016)		X			X				
Forecasting for intermittent sources	Advanced forecasting systems designed for intermittent renewable energy sources already in use in countries like Australia and USA since the last decade.	$6.48m USD ($7.59m AUD, 2016)		X			X	X			

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
Dynamic Line Ratings (DLR)	Despite recent technological developments and the potential advantages DLR may offer, obstacles such as lack of incentives, impact on wholesale markets, etc. thereby hindering the widespread implementation.	$610k USD ($500k USD, 2017) for "three sections of 22-mile 345kV transmission line"		X					X		
Phasor Measurement Units (PMU)	Across the nations, EMS systems are being incorporated with PMUs as they provide data rates 100 times faster than the traditional SCADA monitoring. As of 2017, in USA, PMU deployment is being carried out across the nation. In 2022, Australia began testing the usage of PMUs by installing them at 100 sites across nation. The initial results were	$41k USD ($50k CAD,2021) - $246k USD ($300k CAD,2021) for transmitters (transmission stations) $20.5k USD ($25k CAD, 2021) - $164k	X	X					X	X	

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
	encouraging showcasing an advantage over traditional SCADA systems.	USD ($200k CAD, 2021) for generators (generation stations)									
Advanced Distribution Management System (ADMS)	Many nations including USA, Australia, Korea, and the EU are investing resources into the deployment of ADMS because of advantages such as increased system efficiency, reliability, and reduced system overloads. Deployment also includes technical and financial challenges requiring a significant initial investment from the utilities.	\$48m USD (\$60m AUD, 2020) – AusGrid ADMS	X	X						X	

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
Fault Location, Isolation, and Service Restoration (FLISR)	Software based FLISR systems are incorporated by the distribution service providers in USA, Australia, and the EU. Since 2021. Deployment of these FLISR systems resulted in reduction of millions of customer outage minutes.	\$0.56 USD (\$0.5 USD,2020)/ avoided customer outage minute.	X	X						X	
Advanced Metering Infrastructure (AMI)/ Smart Meters	Advanced Metering Structure (AMI) is considered as top technology, indicating that AMI is not only likely to be fully propagated in the coming years, but has also been gradually applied in many nations. It indicates that AMI is a vital technology for smart grids and a critical foundation for some potential income streams. Currently China is frontrunner with 100% smart meter	Residential: 1. Meter + AMI - \$48.8-\$97.6/unit 2. Meter + AMI + Disconnect - \$85.4-\$158.5/meter 3. Meter + AMI + Disconnect +		X	X					X	X

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
	deployment followed by Japan, USA, and EU with 86%, 69%, and 52% deployment respectively.	HAN - $97.6-$170.7/meter Commercial and Industrial: 1. Meter + communications - $146.3-$182.9/meter Installation Cost: 1. Residential - $8.5-$12.2/meter 2. Commercial and Industrial - $24.4-$79.3/meter									

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
		Ongoing maintenance: $3.7-$13.4/year/endpoint									
Distributed Energy Resource Management Systems (DERMS)	DERMs is still in early stages of adoption. Pilots and demonstration projects are installed across the world to test the functionality of DERMs and evaluate against potential commercial alternatives.	3% of cost of microgrid		X	X					X	X
Electric Vehicles and Charging Infrastructure	EVs are an emerging technology, with estimates for overall EV adoption in the United States by 2030 ranging from roughly 1.5 million to 6 million.				X						X

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
	Projects being funded by the Australian Renewable Energy Agency (ARENA) evaluate various strategies for maximising the use of EVs. These projects show how an EV fleet can perform functions that grid-scale batteries and virtual power plants can by sending electricity back to the grid in addition to charging from mains power or rooftop solar.										
Grid Interactive Efficient Buildings and Connected Communities	A growing number of consumers can connect their homes, businesses, and other buildings into grid operations as a flexible resource thanks to the developing technical capabilities known as "grid-				X						X

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
	interactive efficient buildings" (GEB). Pilot projects are being tested across the world to actively investigate how the utilities can target neighbourhoods to use new energy technologies, programmes and products. Example of this is the PGE Smart Grid Test Bed in USA. Australia's GBCA launched first report on grid-interactive buildings in 2023 emphasising on the importance of demand response.										
Static VAR Compensators	Increased integration of renewable energy sources necessitates the usage of SVCs to preserve grid stability and	$100 USD/kVAR		X			X		X	X	

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
	optimise power transmission and distribution. Rules that promote clean energy and energy efficiency are incentivising utilities and industry to invest in SVC technology.										
Substation Automation Systems (SAS)	SAS systems are in operation since more than a decade and are considered as a vital instrument for improving the performance and stability of the grid. In comparison to centralised substation automation, distributed architecture substation automation has emerged as the dominating technology. This adaptable and dependable approach to substation automation is ideal	$12k USD – cost of transition from traditional substations to digital substation with automation systems	X	X					X	X	

Technology	Trend	Cost (USD Real 2022)	Communications Infrastructure	Supply & Network	Consumer and End-User	Data Management	Supply	Dispatch	Transmission	Distribution	End-Use / Consumers
	for the demands of current power networks.										

8.2 Brief Description of Projects at U.S. DOE's National Laboratories

Summarised description of projects

- **Medium Voltage Resource Integration Technologies (MERIT)**, led by Oak Ridge National Laboratory (ORNL): This project aims to develop cost-effective and scalable technologies that can integrate various distributed energy resources, such as solar, wind, and fuel cells, into the grid efficiently and reliably. The success criteria include high efficiency, long lifespan, and minimal downtime.
- **Assessment and Coordination of Electric Vehicle Supply Equipment (EVSE) Cybersecurity Standards**, led by Sandia National Laboratories: This project focuses on implementing and harmonising cybersecurity requirements and testing for the electric vehicle charging ecosystem. It aligns with the Biden Administration's National Standards Strategy for Critical and Emerging Technology and aims to establish a standardised set of testing requirements and a "Security Star" EV Charging System Cybersecurity Certification Program.
- **Assessment and Coordination of DER Cyber Security Standards**, led by NREL: This project addresses cybersecurity requirements for DERs and works to harmonise potentially conflicting standards. It also collaborates with the Biden Administration's National Standards Strategy for Critical and Emerging Technology to enhance the security of distributed energy systems.
- **Assessment of Communication Architectures for Energy Systems (ACAES)**, led by Pacific Northwest National Laboratory (PNNL): This project involves analysing and mitigating gaps in technology, standards, and processes for grid communications. It also focuses on identifying cyber-attack scenarios and recommending technology and standards improvements to enhance grid security, particularly in a high DER penetration environment.
- **Grid Research, Integration, and Deployment for Quantum (GRID-Q)**, led by ORNL: This project lays the groundwork for power grid testing facilities with quantum capabilities. It explores the use cases for quantum computing, communication, and sensing in grid operations, with the goal of enhancing grid resilience, reliability, and security.
- **Advancing Equity in Grid Planning and Operations**, led by Lawrence Berkeley National Lab (LBNL) and PNNL: This project supports efforts to incorporate equity considerations in energy planning and operations. It includes convening stakeholders, updating equity databases, conducting research, and providing technical assistance to address grid-equity issues.
- **Enhanced Modelling to Ensure Equitable Power System Operations and Planning**, led by Argonne National Laboratory (ANL) and NREL: This project focuses on identifying and implementing metrics, datasets, and methods to improve energy equity in power system models, enhancing decision-making processes and outcomes.
- **Aligning Climate Analysis for Power Systems (ALCAPS) and Climate Resilient Equitable Resource Planning (CRERP)**, led by NREL: This project integrates climate change analysis into energy sector planning and risk management tools. It examines the impacts of climate change on energy resources, demand, and infrastructure, helping to inform energy planning and resilience efforts.

- **Critical Analysis of Severe Climate Events (CASCDE)**, led by ANL: CASCDE combines expertise from DOE's national labs and private sector partners to improve energy planning for extreme weather events. The project forecasts extreme weather events' impact on power markets and grid operations, facilitating grid infrastructure investments for resilience.
- Projects like Pecan Street in Austin, Texas, serve as examples where various community-based technologies, such as building control systems, electric vehicles, photovoltaic systems, and energy storage, are integrated with the electric grid to advance innovation.

8.3 Technical Standards for SG and Cybersecurity Guidelines and Standards

Key relevant technical standards for smart grids and a short description of each are shown below. The list has been complied based on references (Electric Power Research Institute, 2021), (Gopstein, Nguyen, O'Fallon, Wollman, & Hasting, 2021) and (Song, Nguyen, & Gopstein, 2019).

- **IEEE 1547 Family of Standards:** IEEE 1547 is a set of standards that addresses the integration of distributed energy resources (DERs) into the grid. It defines requirements related to interconnection performance, operation, testing, safety, and maintenance of DERs. These standards have been pivotal in enabling the integration of renewable energy sources and DERs into the grid.
- **IEEE 2030 Family of Standards:** The IEEE Standard 2030-2011 serves as a guide for smart grid interoperability, covering energy technology, information technology, and their interaction with the electric power system. It provides best practices and alternative approaches for achieving smart grid interoperability.
- **IEC Family of Standards:** The International Electrotechnical Commission (IEC) has developed over 100 standards relevant to smart grids. These standards cover various aspects of smart grid technology, including service-oriented architecture, common information models, power utility automation, security, data exchange, and more.
- **Equipment Standards**: There are industry standards, such as IEC/IEEE 60255-118-1-2018 and IEEE C37.247-2019, that define the requirements for PMUs and PDCs respectively.
- **IEEE Conformity Assessment Program (ICAP):** ICAP) is a program developed by IEEE for equipment manufacturers to certify their equipment to the applicable industry standards. The certification program was developed following a study by NIST that showed poor equipment compliance with standards. The certification ensures accurate and consistent measurements using IEC/IEEE 60255-118-1-2018, a widely used communications protocol standard which defines requirements for the PMUs.
- **Transformer Standards and Performance:** Utilities set and maintain standards for the performance and loading of transformers. Design standards often follow guidance from IEEE working group 57 and the IEEE/American National Standards Institute (ANSI) C57.91 standard. Operating transformers above their nameplate rating can accelerate aging effects and pose risks to the power system's reliability (US Department of Energy, 2022).

- **Inverter-Based Resources:** Standards like IEEE 1547-2018 address the interconnection and interoperability of distributed energy resources (DERs), including smart inverters. These standards specify requirements for electrical and communication interfaces to support grid needs and enable advanced capabilities like voltage management and grid support during disturbances.
- **Communication Interfaces**: Data flow is a critical aspect of SG. Communication channels and interfaces must allow unhindered flow. Standards often provide various options for compliance and gateway devices may be needed to translated between protocols. We give PMU's as an example of how communication interfaces feature in SG systems. PMUs use three key communication interfaces.
  - PMUs communicate with substation automation technology via protocols like IEC 61850.
  - PMU data from specific regions is transferred to a phasor data concentrator (PDC) using IEEE C37.118.2-2011 messaging, typically using low-latency, high-bandwidth methods like fibre optics.
  - PDCs then transmit this data to control centres via the Inter-Control Centre Communications Protocol (ICCP).
- **UL 1741 Certification:** The UL 1741 certification standard for inverters has been updated to align with IEEE 1547-2018, simplifying the interconnection process by ensuring that equipment meets specific testing and certification requirements.
- **EV Integration:** With the growth of electric vehicles (EVs), coordination is needed between standards organisations like SAE International and IEEE to integrate EV and charger technology with the electric power system. Standardising grid support capabilities within EV charging equipment is crucial for managing grid impacts and costs associated with EV adoption.
- **Smart City Standards:** Smart city standards aim to integrate various technologies, including networking, transportation, IoT, microgrids, and more, into a cohesive framework that helps cities meet their operational objectives. These standards are essential for efficient and sustainable urban development.
- **Interoperability Standards:** Interoperability standards are essential for ensuring that different devices and systems within the smart grid ecosystem can communicate and work together seamlessly. These standards define performance requirements for communication protocols, information models, and functional specifications. Achieving full interoperability can be challenging due to the diversity of communication protocols and information models in practice.
  - **NIST Efforts:** NIST plays a significant role in coordinating the development of a framework for smart grid interoperability standards. NIST's Framework and Roadmap for Smart Grid Interoperability Standards guide specific communication and interoperability requirements, taking into account changes in the grid landscape, including technological advancements and increased data generation.

- **Collaboration to Improve Optional Compliance:** Where compliance with standards is not required by regulation interoperability approaches can vary. Collaboration among stakeholders has been used in such cases as a strategy to improve interoperability.
- **Communication Interfaces**: Data flow is a critical aspect of SG. Communication channels and interfaces must allow unhindered flow. We give PMU's as an example of how communication interfaces feature in SG systems. PMUs use three key communication interfaces.
  - PMUs communicate with substation automation technology via protocols like IEC 61850.
  - PMU data from specific regions is transferred to a phasor data concentrator (PDC) using IEEE C37.118.2-2011 messaging, typically using low-latency, high-bandwidth methods like fibre optics.
  - PDCs then transmit this data to control centres via the Inter-Control Centre Communications Protocol (ICCP).
- **Cybersecurity:** Cybersecurity is a critical aspect of smart grid development. Various organisations, including NIST, NERC, IEC, and IEEE, have developed guidelines and standards to address cybersecurity risks related to smart grid systems. These standards help protect against cyber threats and ensure the resilience of the grid.

To give an appreciation of the extent of standards involved we provide below a list of cybersecurity guidelines and standards in the USA related to the smart grid and their purpose. The list is grouped by issuing organisation, refer to (United States Department of Energy, 2022) for more details.

- **NIST Standards:**
  - **NIST SP 7628 (2010):** Guidelines for Smart Grid Cybersecurity.
  - **NIST SP 800-82 (2015):** Guide to Industrial Control Systems Security.
  - **NIST SP 1108r3 (2014):** NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0.
  - **NIST SP 800-12 (2017):** Introduction to Computer Security: the NIST Handbook.
  - **NIST SP 800-53 (2020):** Security and Privacy Controls for Information Systems and Organisations.
- **IEC Standards:**
  - **IEC 62351-3 (2014+ AMD1:2018+ AMD2:2020):** Communications network and systems security, including transmission control protocol/Internet protocol (TCP/IP).
  - **IEC 62351-4 (2018+ AMD1:2020):** Data and communications security, including Manufacturing Message Specification (MMS).
  - **IEC 62351-6 (2020):** Data and communications security for IEC 61850.
  - **IEC 62351-7 (2017):** Data and communications security for network and system management.

- **IEC 62351-8 (2020):** Role-based access controls.
- **IEC 62443 series (2009-2020):** A series of standards to secure industrial automation and control systems, building on the IEC/ISO 27000 series.

▪ **IEEE Standards:**

- **IEEE P1547.3:** Draft IEEE Guide for Interoperability and Cybersecurity of Distributed Energy Resources Interfaces with Associated Electric Power Systems.
- **IEEE C37.240-2014:** IEEE Standard Cybersecurity Requirements for Substation Automation, Protection, and Control Systems.
- **IEEE 1686-2013:** IEEE Standard for Intelligent Electronic Devices Cybersecurity Capabilities.
- **IEEE C118 series of standards:** Data management and protection of synchrophasors.
- **IEEE 1711.2-2019:** IEEE Standard for Serial SCADA Protection Protocol for Substation Serial Link Cybersecurity.
- **IEEE P1711.1:** Draft standard for cryptographic protocol for cybersecurity of substation serial links: substation security protection protocol.
- **IEEE C37.118.2-2011:** Synchrophasor Data Transfer for Power Systems.

▪ **NERC Standards:**

- **CIP-002-5.1 (2015):** Bulk Electric System Cyber System Categorisation.
- **CIP-003-6 (2014):** Security Management Controls.
- **CIP-004-6 (2014):** Personnel & Training.
- **CIP-005-5 (2012):** Electronic Security Perimeter(s).
- **CIP-006-6 (2014):** Physical Security of BES Cyber Systems.
- **CIP-007-6 (2014):** System Security Management.
- **CIP-008-5 (2012):** Incident Reporting and Response Planning.
- **CIP-009-6 (2014):** Recovery Plans for BES Cyber Systems.
- **CIP-010-2 (2015):** Configuration Change Management and Vulnerability Assessments.
- **CIP-011-2 (2015):** Information Protection.
- **CIP-013-1:** Supply Chain Risk Management.
- **CIP-014-2 (2015):** Physical Security.

8.4 Benefits Included in the Smart Meter CBA of Individual European Countries

The table below is an overview of the benefits included by individual countries in the CBA of the smart meter roll out.

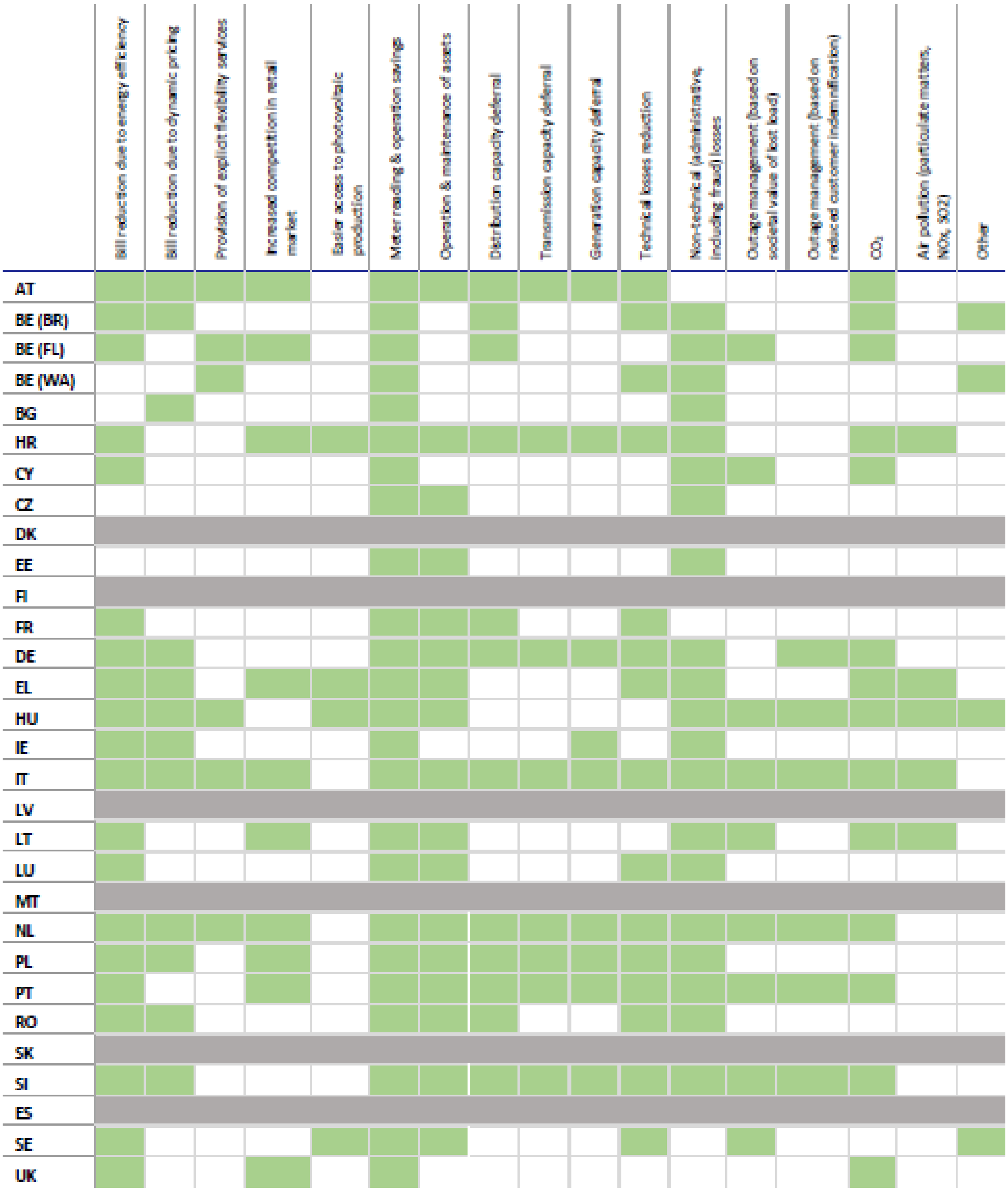

Table 10: Considered benefits in the CBA for each Member State (legend: green = considered, blank = not considered; grey = data not available).

Source: Tractebel December 2019, Benchmarking smart metering deployment in the EU-28 - Final Report. Table 10. European Commission 2020.