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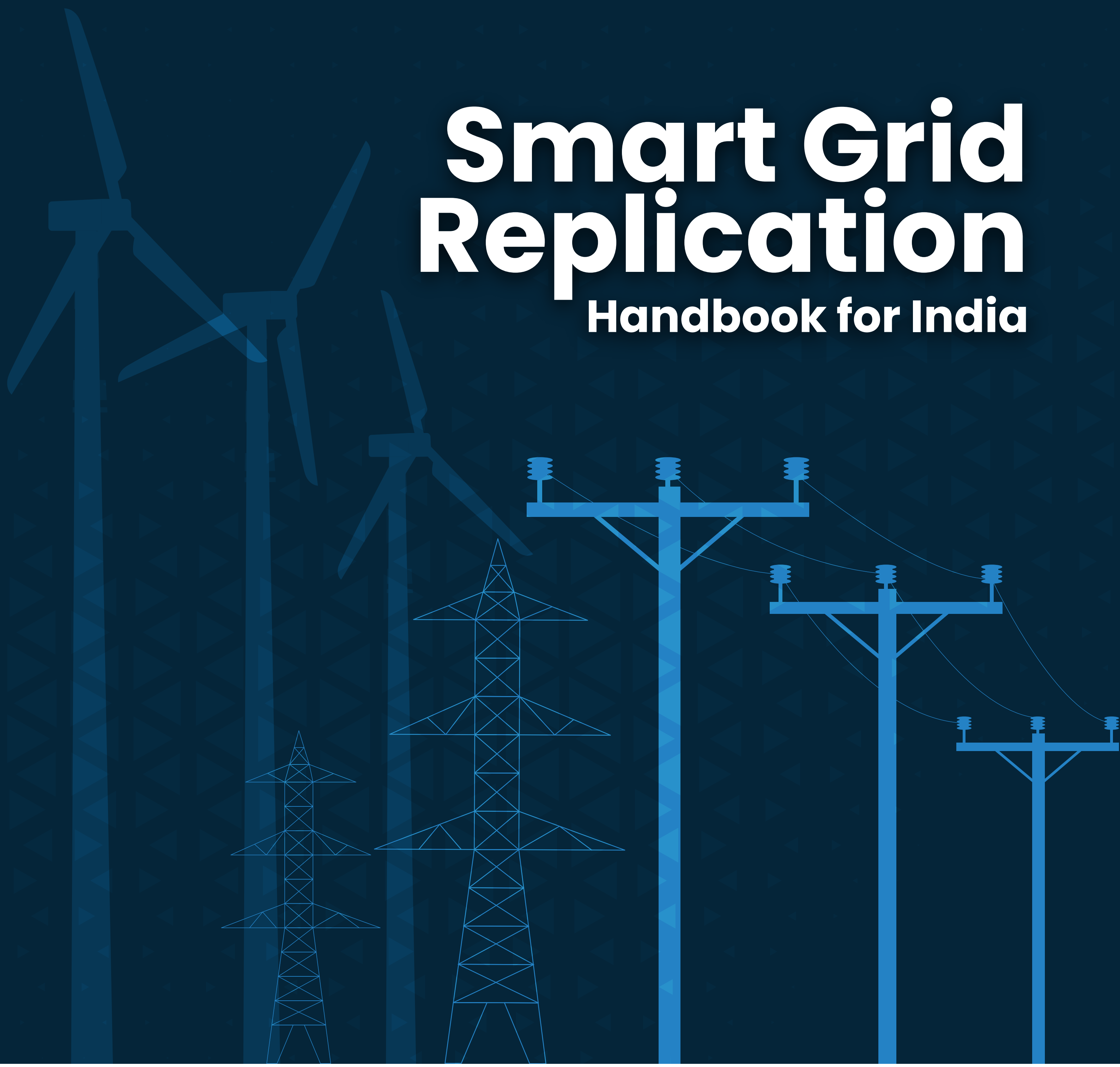
EUI FLORENCE SCHOOL OF REGULATION

EU-INDIA CLEAN ENERGY & CLIMATE PARTNERSHIP

Smart Grid Replication

Handbook for India



UNIVERSIDAD PONTIFICIA ICAI ICADE COMILLAS MADRID

ISGF India Smart Grid Forum

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About this Handbook

The EU-India High-Level Platform on Smart Grids chaired by the Florence School of Regulation-FSR Global and supported by the India Smart Grid Forum (ISGF) and Comillas University was established under the EU-India Clean Energy and Climate Partnership (CECP) to support faster replication and roll out of smart grids in India. As an outcome of the first year of the platform, this handbook was developed in collaboration with experts from both Europe and India.

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The EU-India High-Level Platform on Smart Grids would like to thank the platform experts, who gave their invaluable feedback, insights and support during the development of this handbook.

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A special thanks to the team that made the first year of the EU-India High-Level Platform on Smart Grids a success.

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Foreword

"Sharing knowledge where it is created"

A Mantra at the Florence School

India and the European Union come together to share their own knowledge to create a common new body of knowledge - the **'Smart Grid Replication Handbook for India'**.

The Florence School could not be more grateful to the *EU-India Clean Energy & Climate Partnership* for its vision and leadership. Together we are more than 1,800 million humans looking at a better future driven by new technologies promoting energy access and climate sustainability.

Two centuries of steam, mechanical or electrical engineering are ending with the supremacy of information & communication technologies, electronics and the coming "*Internet of Things*". Such powerful tools should facilitate giving an access to modern energy to all, and building a long-term horizon of carbon neutrality.

Smart grids have gained maturity in many domains, and several footholds in others, as with "Sm*art Cities*", "*Electric Mobility*", "*Mini Grids & Micro Grids*", "*Peer-to-Peer Exchange*" or "*Demand Response*". India, with its world-famous cohorts of engineers and top managers, has much to teach us, the Europeans, about the many futures that can come. EU, with its advanced energy regulatory frame and demanding climate policy, has many ideas and tools to be tested and challenged overseas. The remarkable quality and usefulness of the forty-four pages of this Handbook Chapter 4 ("*CBA & SRA Analysis*") testify beyond any dream.

As a school born in Florence (*Florence School of Regulation*), and re-born in New Delhi (*FSR Global*), we are so happy having worked so closely with the *Indian National Smart Grid Mission*, and for the outstanding cooperation with the *India Smart Grid Forum*, *Comillas University* and *Pricewaterhouse Coopers India*.

The financing by *EU Delegation to India* and the *European Commission – DG ENER* is graciously acknowledged.

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National Smart Grid Mission – PMU
राष्ट्रीय स्मार्ट ग्रिड मिशन – पी.एम.यू.

India operates one of the largest synchronous grids in the world with motto of "One Nation One Grid One Frequency" and 393 GW capacity. The power sector is to grow multi-fold to meet aspiration of citizens and demand of growing economy. The National Smart Grid Mission for India was established to ***'Transform the Indian power sector in to a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders'***. The Nation has already set goal of 500GW Renewable Energy Capacity and is investing in strengthening the electrical network at consumption end through Reform Linked Distribution Sector Scheme (RDSS).

The communications, information technology and automation systems will play critical role to build a strong and Smart Grid. NSGM and other institutions have piloted smart grid projects across the country. The time is ripe to scale up and it is always wiser to learn from local as well as global experiences. Hence when opportunity beckon, I was happy to Co-Chair the **'EU-India High Level Platform on Smart Grids'** an initiative by the EU-India Clean Energy Climate Partnership in collaboration with the Florence School of Regulation, where experts were to co-learn and contribute in the making of a handbook. **The Smart Grid Replication Handbook** will serve as a reference tool for practitioners, policy makers, regulators, utilities and other stakeholders on issues to be conscious and choices to be made, so many times competitive choice, and how to plan, access for scaling up smart grid projects across utilities landscape.

I particularly liked the engagement of experts at the high-level platform via policy dialogues and workshops which facilitated knowledge exchange, combining learnings from both academia and the world of practice. I look forward to continue this exchange by experienced stake holders and widening the ambit to include other Geographies and invite all Smart Grid stakeholders in India to engage with the platform and highly recommend reading this handbook.

Arun Kumar Mishra
Director
National Smart Grid Mission

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Glossary

Abbreviation	Description
A-CAES	Superconducting magnetic energy storage
ACS	Average Cost of Supply
ADE	Association for Decentralised Energy
ADMS	Advance Distribution Management System
ADR	Automated Demand Response
aFRR	Frequency Restoration Reserves with automatic activation
AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
APDCL	Assam Power Distribution Company Limited
APDRP	Accelerated Power Development and Reform Program
ARR	Average Revenue Requirement
ASIDI	Average System Interruption Duration Index
ASIFI	Average System Interruption Frequency Index
AT&C	Aggregate Technical & Commercial
AVL	Automated Vehicle Location
BESS	Battery Energy Storage Systems
BIS	Bureau of Indian Standards
BMS	Building Management System
BRP	Balancing Responsible Parties
CAES	Compressed Air Energy Storage
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CBR	Cost-Benefit Ratio
CEA	Central Electricity Authority
CED	Chandigarh Electricity Department
CERC	Central Electricity Regulatory Commission
CHP	Combined Heat and Power
CIS	Customer Information System
COSEM	COmpanion Specification for Energy Metering
CESC	Chamundeshwari Electricity Supply Company
DA	Distribution Automation

DCU	Data Concentration Unit
DDUGJY	Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
DG	Distributed Generation
DLC	Double Layer Capacitor
DLMS	Device Language Message Specification
DMS	Distribution Management System
DR	Demand Response
DRC	Development Resource Centre
DRES	Distributed Renewable Energy Sources
DSM	Deviation Settlement Mechanism
DSL	Digital Subscriber Line
DSO	Distribution System Operator
DSR	Demand side response
DT	Distribution Transformer
DTMU	Distribution Transformer Monitoring Unit
EHV	Extra High Voltage
EMS	Energy Management System
ENS	Energy Not Supplied
ERP	Enterprise Resource Planning
ESS	Energy Storage System
ETS	Emissions Trading System
EV	Electric Vehicle
EVCI	Electric Vehicle Charging Infrastructure
FAN	Field Area Network
FDIR	Fault Detection, Isolation and service Restoration
FDR	Financial Discount Rate
FES	Flywheel Energy Storage
FFA	Field Force Automation
FOR	Forum of Regulators
GHG	GreenHouse Gas
GIS	Geographical Information System
GoI	Government of India
GPRS	General Packet Radio Service

GSAS	Grid Sub-station Automation System
GW	GigaWatt
HAN	Home Area Network
HC	Hosting Capacity
HES	Head End System
HEMS	Home Energy Management System
HP	Heat Pump
HPSEB	Himachal Pradesh State Electricity Board
HT	High Tension
HVAC	Heating Ventilation Air Conditioning
ICCP	Inter Control Center Communication Protocol
ICT	Information and Communications Technologies
INR	Indian Rupee
IP	Internet Protocol
IPDS	Integrated Power Development Scheme
IRR	Internal Rate of Return
IT	Information Technology
ISGF	India Smart Grid Forum
ISGTF	India Smart Grid Task Force
IVR	Interactive Voice Response
IVRS	Interactive Voice Response System
JBVNL	Jharkhand Bijli Vitran Nigam Limited
JERC	Joint Electricity Regulatory Commission
JNNSM	Jawaharlal Nehru National Solar Mission
JRC	Joint Research Centre
JVVNL	Jaipur Vidyut Vitran Nigam Limited
KPI	Key Performance Indicator
kV	KiloVolt
kVARh	kilo volt amperes reactive hours
LED	Light Emitting Diode
LF	Load Factor
LT	Low Tension
LTMD	Low-Tension Maximum Demand
LV	Low Voltage
LVC	Low Voltage Controller

LVSE	Low Voltage State Estimator
M2M	Machine to Machine
MoP	Ministry of Power
MDMS	Meter Data Management System
MG	Micro Grid
ML	Machine Learning
MPOPF	MultiPeriod Optimal Power Flow
MTTR	Mean Time To Repair
MU	Million Units
MV	Medium Voltage
NAN	Neighbourhood Area Network
NEDO	New Energy and Industrial Technology Development Organization
NCIIPC	National Critical Information Infrastructure Protection Center
NHC	Network Hosting Capacity
NIEPI	Número de Interrupciones Equivalente de la Potencia Instalada
NPV	Net Present Value
NRGP	Non-Residential General Purpose
NSE	Non-Supplied Energy
NSGM	National Smart Grid Mission
NSH	Night Storage Heater
OLTC	On Load Tap Changer (Transformer)
OMS	Outage Management System
OPC UA	Open Platform Communications Unified Architecture
OPEX	Operational Expenditures
OPF	Optimal Power Flow
OPC UA	Open Platform Communications Unified Architecture
OPTCL	Odisha Power Transmission Corporation Limited
OT	Operational Technology
P2P	Peer-to-Peer
PED	Puducherry Electricity Department
PHS	Pumped Hydro Storage
PLC	Power Line Communication/Carrier
PLM	Peak Load Management
PMU	Phasor Measurement Unit
PRIME	PoweRline Intelligent Metering Evolution

PV	Photovoltaic (solar energy)
PQ	Power Quality
R/X	Reactance/Resitance
RAB	Regulatory Asset Base
R-APDRP	Accelerated Power Development and Reform Programme
REC	Renewable Energy Certificate
RE	Renewable Energy
REI	Renewable Energy Integration
RF	Radio Frequency
RES	Renewable Energy Sources
RESCO	Renewable Energy Service COmpany
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
RTPV	RoofTop PhotoVoltaic
RTU	Remote Terminal Unit
SA	Substation Automation
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control And Data Acquisition
SDR	Social Discount Rate
SERC	Separate Electricity Regulatory Commission
SERC	State Electricity Regulatory Commission
SG	Smart Grid
SGAM	Smart Grid Architecture Model
SMPS	Switch-Mode Power Supply
SMES	Superconducting magnetic energy storage
SNG	Synthetic Natural Gas
SOAP	Simple Object Access Protocol
SRA	Scalability and Replicability Analysis
SS	Safety System
T&D	Transmission and Distribution
TCP	Transmission Control Protocol
TIEPI	Tiempo de Interrupción Equivalente de la Potencia Instalada
ToU	Time of Use
TPDDL	Tata Power Delhi Distribution Ltd.
TS	Transmission System

TSECL	Tripura State Electricity Corporation Limited
TSO	Transmission System Operator
TSSPDCL	Telangana State Southern Power Distribution Company Limited
UDAY	Ujwal discom Assurance Yojana
UGVCL	Uttar Gujrat Vij Company Limited
UHBVN	Uttar Haryana Bijli Vitran Nigam Limited
UoS	Use of System Tariff
UPS	Uninterruptible Power Supply
UTs	Union Territories
V2G	Vehicle to Grid
VGI	Vehicle Grid Integration
VJTI	Veermata Jijabai Technological Institute
VOLL	Value Of Lost Load
VPP	Virtual Power Plant
VVC	VoltVar Control
WAC	Wide Area Control
WAMS	Wide Area Monitoring System
WAN	Wide Area Network
WBSEDCL	West Bengal State Electricity Distribution Company Limited

1
Introduction

1. INTRODUCTION

India has embarked on an ambitious sustainable development pathway by applying a multi-pronged approach spanning several sectors from developing smart cities to enabling electric vehicles. In the power sector, it is necessary to transform and prepare the grid at both the transmission and distribution levels to ensure the success of India's sustainability journey.

Smart grids are next-generation electrical power systems and are typified by increased use of communication and information technology in the generation, delivery and consumption of electrical energy. A group of technological innovations are combined to improve grid efficiency, facilitate automation, reduce cost and improve the quality of the grid. These solutions enable integration and optimisation of distributed and renewable generation, and promote interaction between consumers and utilities that will provide benefits for both.

The adoption of smart grids will help transform conventional grids making them transparent, intelligent and smart with bi-directional energy flow, and improve overall grid stability and reliability. Smart grids will also enable better utilisation of assets and help reduce capital expenditure for network companies. Furthermore, smart grids can enable greater participation by consumers. They will also enable optimal utilisation of assets and help reduce capex investments in infrastructure by DSOs and give them a higher return on investments.

India has significant potential for smart grid adoption. Some utilities are already experimenting with implementing smart grid solutions such as advanced meter integration (AMI) systems and supervisory control and data acquisition (SCADA) systems.

However, several challenges remain in realising wide effective implementation of smart grid solutions in India. Several financial support schemes have been introduced over the years to implement the foundational technologies needed to implement smart grids. The majority of state-owned distribution companies (discoms) across India have not yet rolled out the basic technological tools (such as smart meters, SCADA, etc.) needed for effective smart grid implementation. Smart grids can be seen as many different smart solutions and technologies combined together to mitigate various issues facing the electricity grid. When discussing the implementation and roll-out of smart grids, there are four major questions that need to be answered:

- What is the technology?
- How will it be financed?
- Does it have social acceptance?
- Are regulation and policy conducive?

The EU and its Member States have been fostering research and innovation in smart grids and have demonstrated several successful implementations through various initiatives like BRIDGE, GRID4U and Horizon 2020 in areas related to smart grids, energy storage, ICTs, digitalisation and markets. Gaining from the European experience, India could contextualise and build on the knowledge. The array of functionalities resulting from adoption of smart grids in India are highlighted in the figure below:

SMART GRID FUNCTIONALITIES

Smart Street Lights	Energy Storage	Common Command Control Room
SCADA/EMS & SCADA/ DMS	Electric Vehicle	Enterprise IT System
Substation & Distribution Automation	Renewable Energy	Application Integration & Analytics
Wide Area Monitoring System	Power Quality Management	GIS (Digital) Map
AMI (Smart Metering)	Outage Management System	Customer Engagement Social Media for Utility
Cyber Security	DT monitoring and control	Mobile Crew Management System

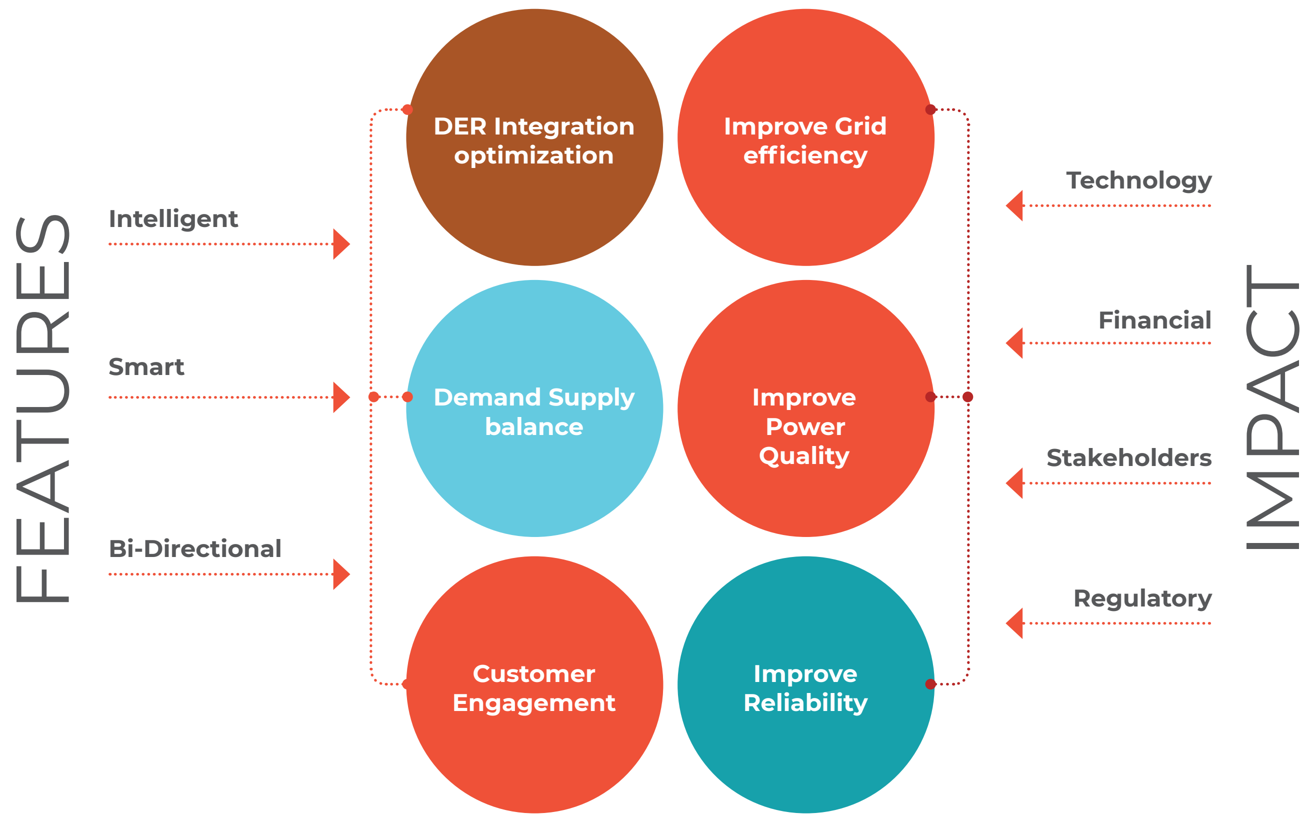
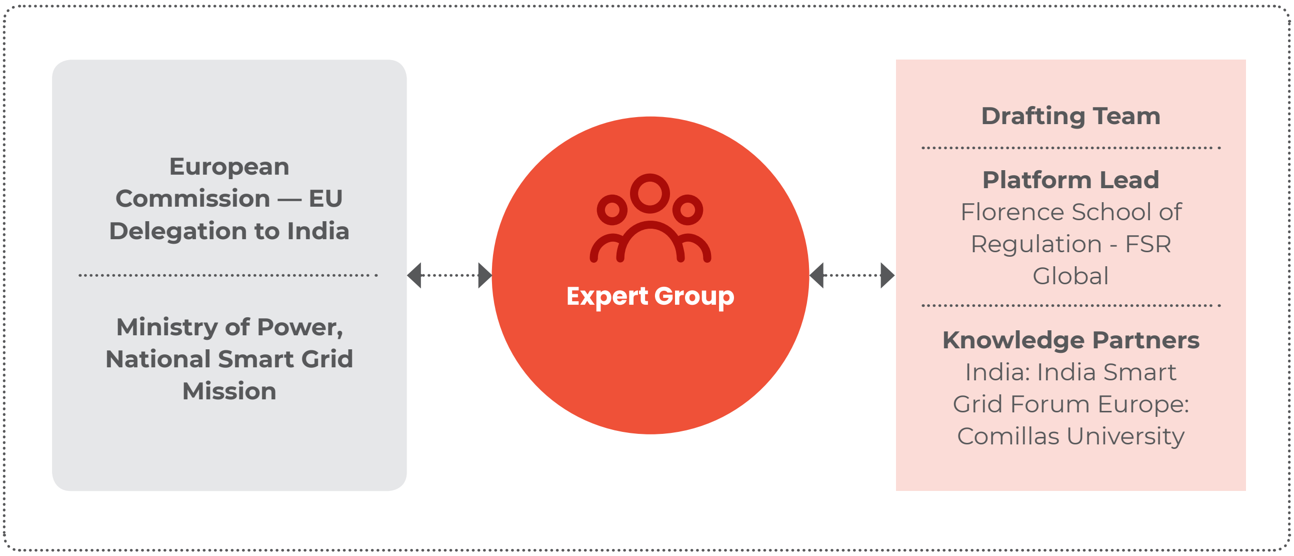


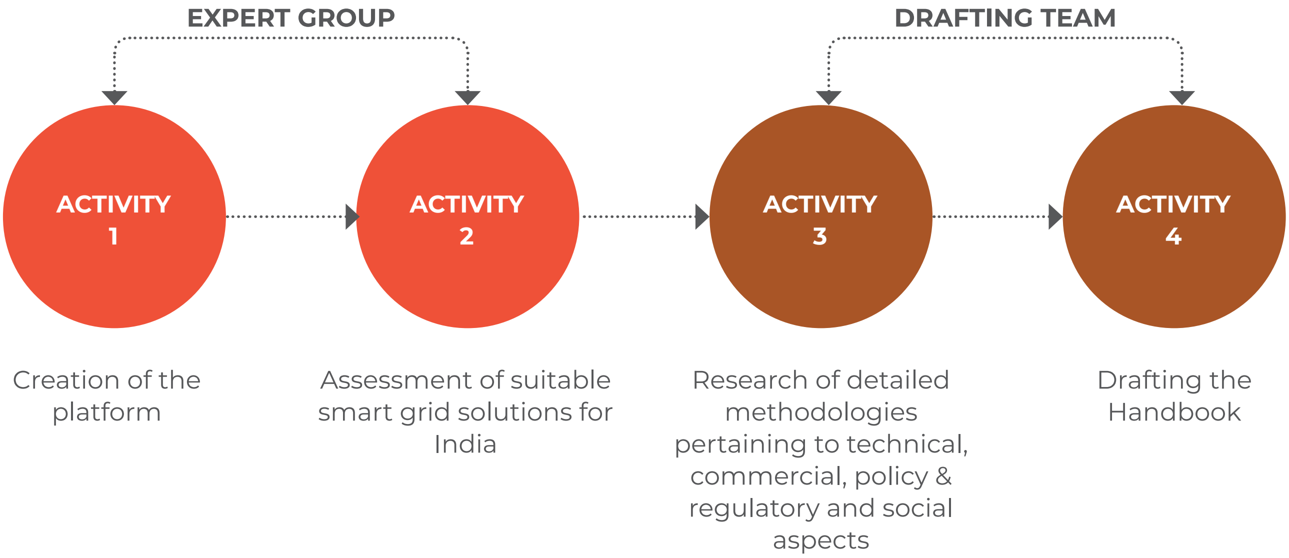
Figure 1: Smart Grid Functionalities, Features and Impact

1.1. EU-INDIA HIGH-LEVEL PLATFORM ON SMART GRIDS

The EU-India High-Level Platform on smart grids chaired by the Florence School of Regulation-FSR Global and supported by the India Smart Grid Forum (ISGF) and Comillas University was established under the EU-India Clean Energy and Climate Partnership (CECP) to support faster replication and roll out of smart grids in India. The structure of this platform is illustrated below.

In its first year of activity the platform aimed to identify smart grid projects in Europe and India to be considered as use cases to facilitate knowledge sharing among experts drawn from industry, academia, utilities and policymakers. Four key activities were envisaged under this platform, which culminated in this handbook and are as shown below.

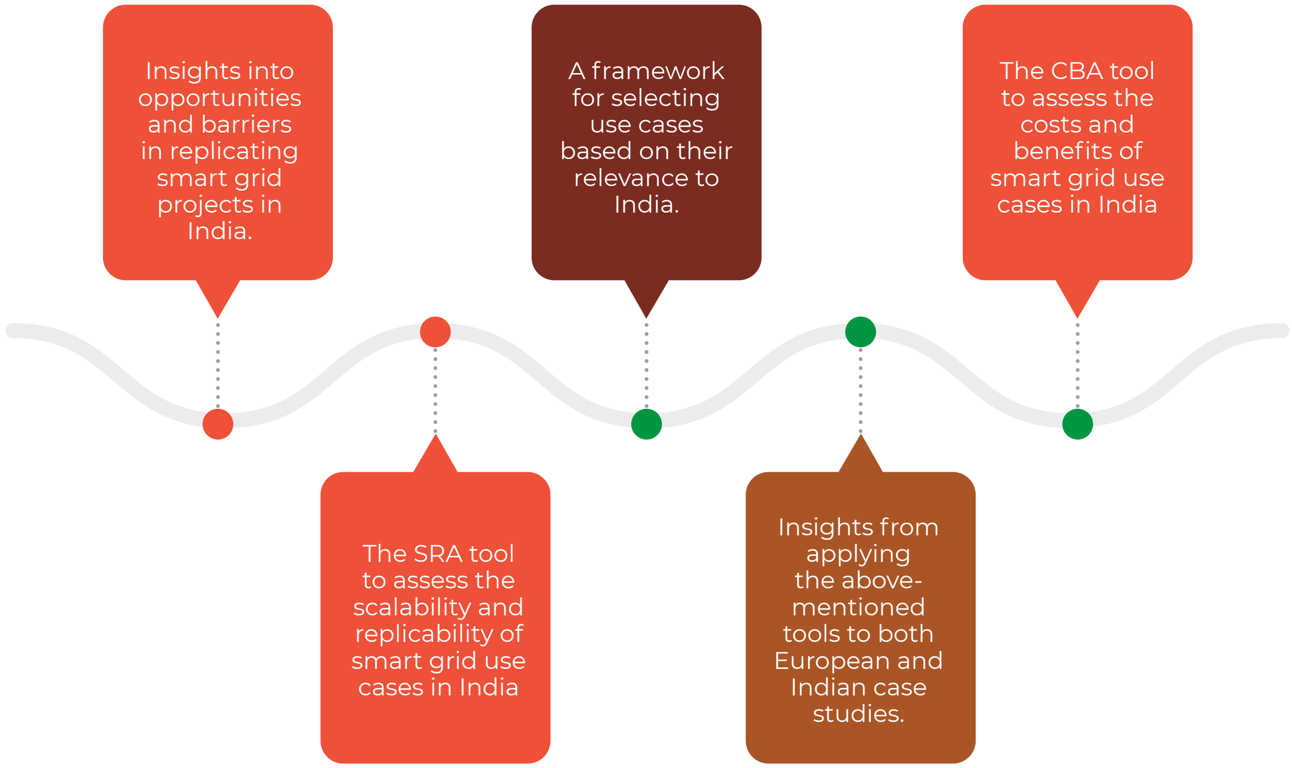




The platform activities were a combination of research and policy dialogue, which brought together a group of 30 experts from the European and Indian sides. Through a series of workshops and exchanges, the expert group and the drafting team helped develop this handbook over a period of a year.

1.2. HOW TO USE THIS HANDBOOK

The purpose of this research was to develop a handbook containing insights and tools that will aid implementation of innovative smart grid projects in India. Therefore, this handbook provides its readers with the following:



2
What are smart grids?

2. WHAT ARE SMART GRIDS?

A smart grid is an electricity grid with communication, automation and IT systems that enable real time monitoring and control of bi-directional power flows and information flows from the point of generation to the point of consumption at the level of appliances. Smart grid technologies provide an interactive grid which gives consumers the option to be prosumers and provides them with the opportunity to both consume and sell electricity according to their requirements and the price of the electricity available.

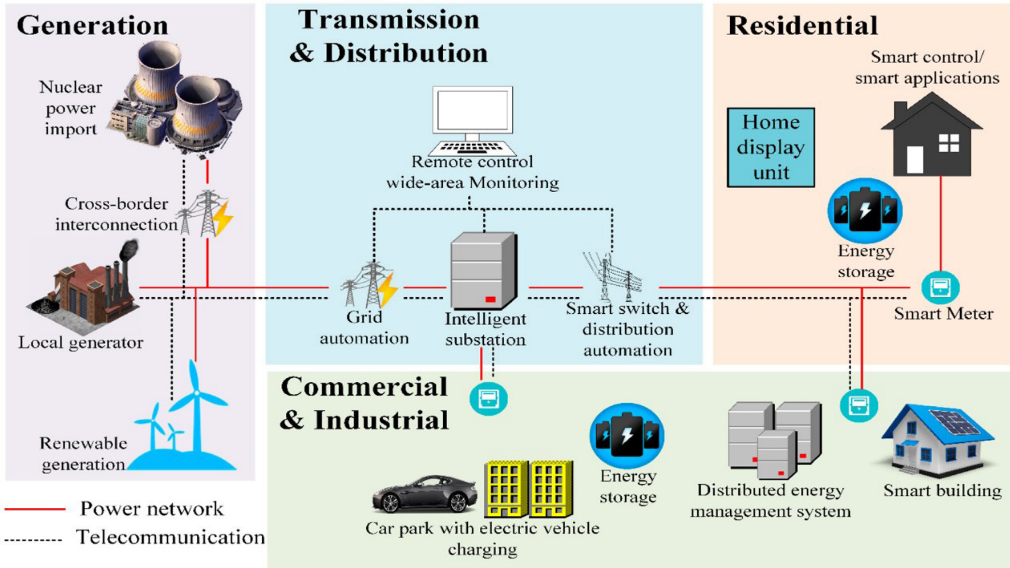


Figure 2: Smart grid general architecture

The drivers of smart grids for the different stakeholders are:

UTILITIES

- Reduction of T&D losses
- Peak load management
- Reduction in power purchase cost
- Better asset management
- Increasing grid visibility
- Self-healing grid
- RE integration

CUSTOMER

- Expand access to electricity
- Improve reliability of supply
- Increased choices for consumers
- Beneficial tariffs
- User friendly and transparent interface with utilities
- Improve quality of supply
- "Prosumer" (Producer and Consumer) enablement

GOVERNMENT AND REGULATORS

- Satisfied customers
- Financially sound utilities
- Tariff neutral system upgrade and modernisation
- Reduction in emission intensity

Figure 3: Smart grid drivers for different stakeholders

2.1 COMPONENTS OF SMART GRIDS

The key components of smart grids at the operational level and information level are:

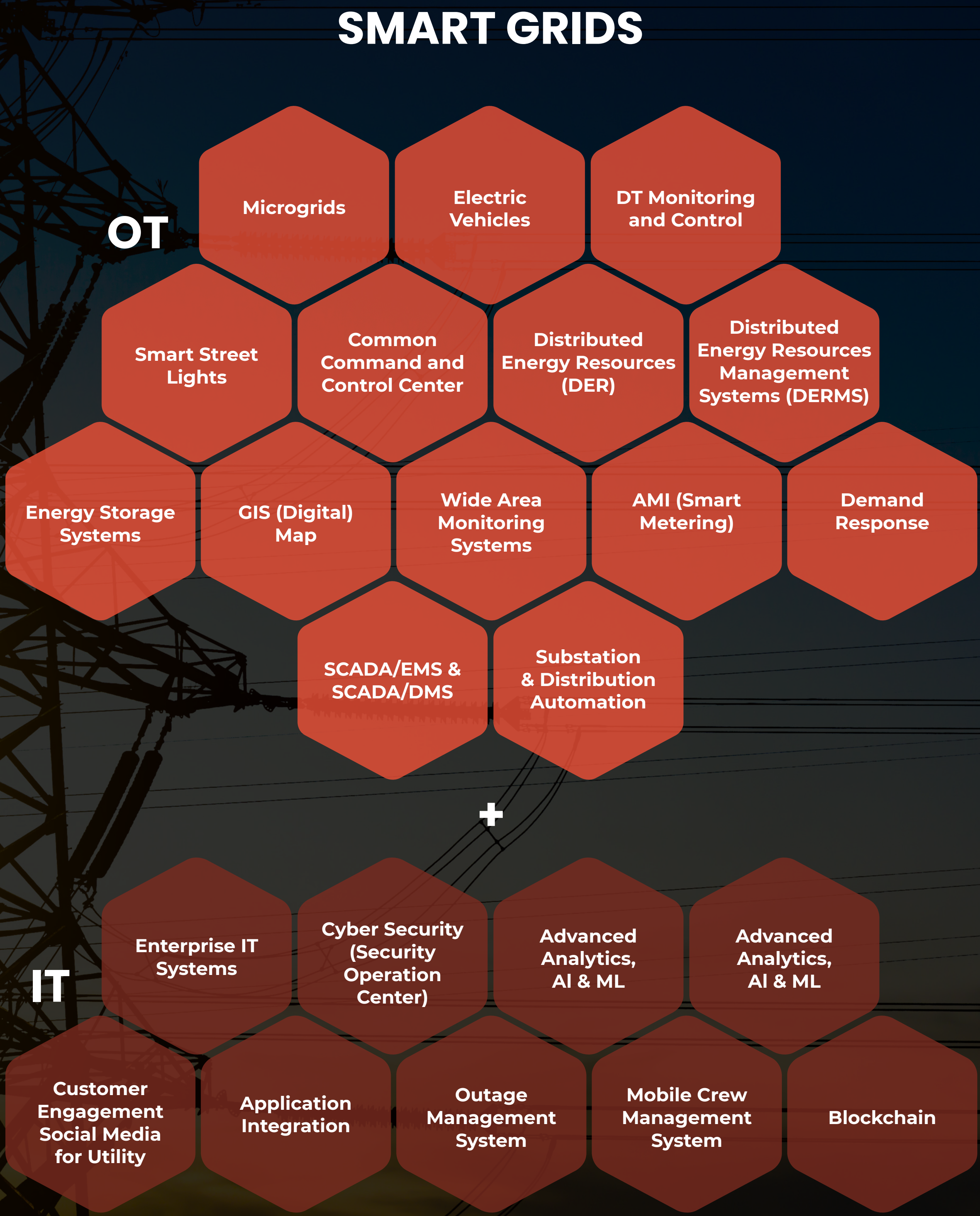


Figure 4: Smart grid components

2.2 SMART GRID TECHNOLOGIES

Some of the mature technologies that are being adopted by utilities are described below.

2.2.1 SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA)

Extra high voltage (EHV) transmission networks (110kV and above) can be smart or intelligent with automation and real time communication systems integrated for system operations. The load dispatch centres and control centres of EHV systems have SCADA and energy management systems (EMSs), which help monitor and control power flows in real time. In distribution grids, SCADA is implemented with a distributed energy management system (DMS). In order to facilitate the functioning of SCADA and EMS/DMS, networks need dedicated systems to communicate between the control centre and all the generating stations and substations.
At the control centre operators can control generation and loads at the substations.

The main functions of SCADA:

- Data acquisition from remote terminal units (RTUs) and storage of data in online databases
- Data processing to convert raw values to engineering values and check quality
- Historical data storage and retrieval
- Sequence of events recording, reconstruction and replay of events

2.2.2 ENERGY MANAGEMENT SYSTEMS (EMSS)

An EMS is a set of computer-aided tools used by electricity grid operators to monitor, control and optimise the performance of generation and/or transmission systems.

Functions of EMS:

- Real time network analysis and contingency analysis
- To study functions like power flow, the power factor, security enhancement etc.
- Reserve monitoring to calculate spinning reserve, operating reserve and regulating reserve
- Load forecasting
- Transaction scheduling

2.2.3 DISTRIBUTION MANAGE MENTSYSTEMS (DMSS)

A DMS is a collection of software applications designed to monitor and control the entire distribution network efficiently and reliably.

DMS Functions:

- Network visualisation and support tools
- Applications for analytical and remedial actions
- Utility planning tools

2.2.4 DISTRIBUTION AUTOMATION (DA)/ SUBSTATION AUTOMATION (SA)

DA refers to various automated control techniques that optimise the performance of power distribution networks by allowing individual devices to sense the operating conditions of the grid around them and make adjustments to improve the overall power flow and optimise performance. At present, grid operators in centralised control centres identify and analyse their power systems manually and intervene by either remotely activating devices or dispatching a service technician.
An SA system enables an electricity utility to remotely monitor, control and coordinate the distribution components installed in a

substation. SA focuses on automation functions such as monitoring, controlling and collecting data inside substations. SA overcomes the challenges of long service interruptions for reasons such as equipment failures, lightning strikes, accidents, natural catastrophes, power disturbances and outages in substations. The main components of SA are digital relays and associated communication systems which can be operated remotely.

2.2.5 DISTRIBUTION TRANSFORMER (DT) MONITORING SYSTEMS

In most distribution utilities in India, hundreds of DTs are burned out every summer due to overloading or phase imbalances. Remote monitoring of DTs prevents overloading, phase imbalances and burn outs. This makes huge financial savings given the high technical losses that occur in systems owing to phase imbalances – one phase is overloaded while the two other phases are low on load. With monitoring systems in place, loads can be redistributed to remove such imbalances in transformers. With DT monitoring systems, overloaded DTs can be identified and replaced with higher capacity DTs as load in the locality increases.

2.2.6 ADVANCED METERING INFRASTRUCTURE (AMI) OR SMART METERING

AMI or smart metering comprises smart meters, data concentrator unit (DCU)/gateway/router access points, a head end system (HES) and a meter data management system (MDMS) communicating over a bi-directional wide area network (WAN), a neighbourhood area network (NAN)/field area network (FAN) and a home area network (HAN). Multiple smart meters can connect to a DCU/gateway/router/access point, which in turn sends aggregated data to the HES.

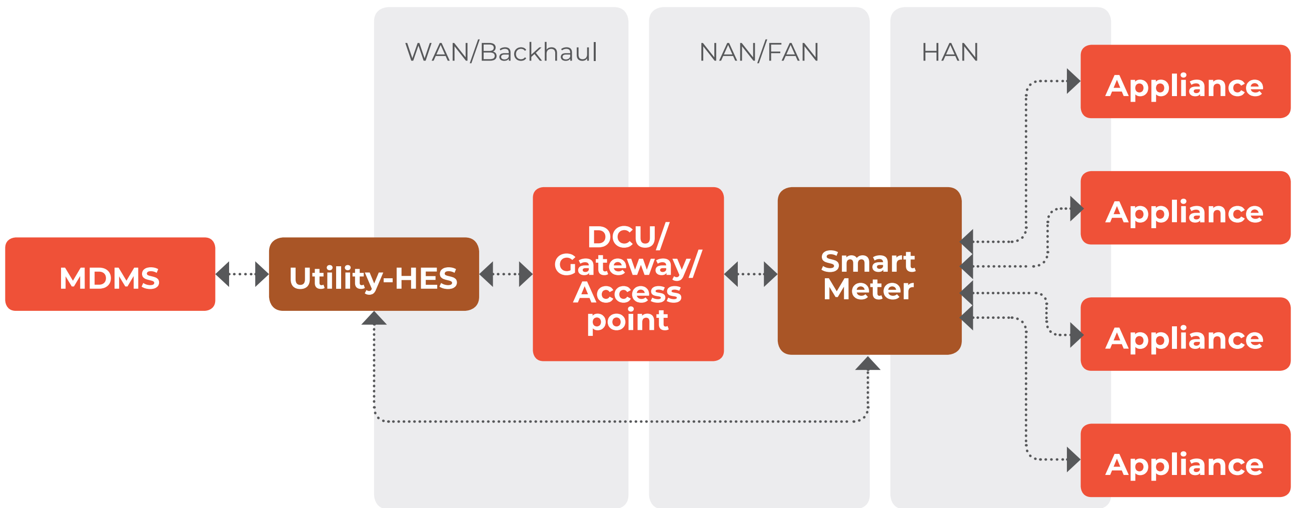


Figure 5: Typical AMI architecture

2.2.7 OUTAGE MANAGEMENT SYSTEMS (OMSS)

An OMS provides the capability to efficiently identify and resolve outages and to generate and report valuable historical information. A geographical information system (GIS)-based OMS helps to resolve customer complaints faster during power outages. The OMS enables quick identification of probable faulty locations and reduces customer complaint response time. The OMS works in conjunction with the GIS, the customer information system (CIS), enterprise resource planning (ERP), the mobile crew management system and automated call handling systems, such as an interactive voice response (IVR) system.

Geographical Information Systems (GISs)

All electrical assets mapped on a GIS or digital map and all customers indexed to that map are key inputs for a utility to plan and manage its assets and operations. A GIS map can be unified with other automation systems and its applications can be extended to asset optimisation, outage detection and faster network restoration.

GIS maps need to be updated on a regular basis. Whenever a new asset is added or removed, a new customer is connected or an existing customer is removed, the information must be captured in the GIS map so that it remains up to date.

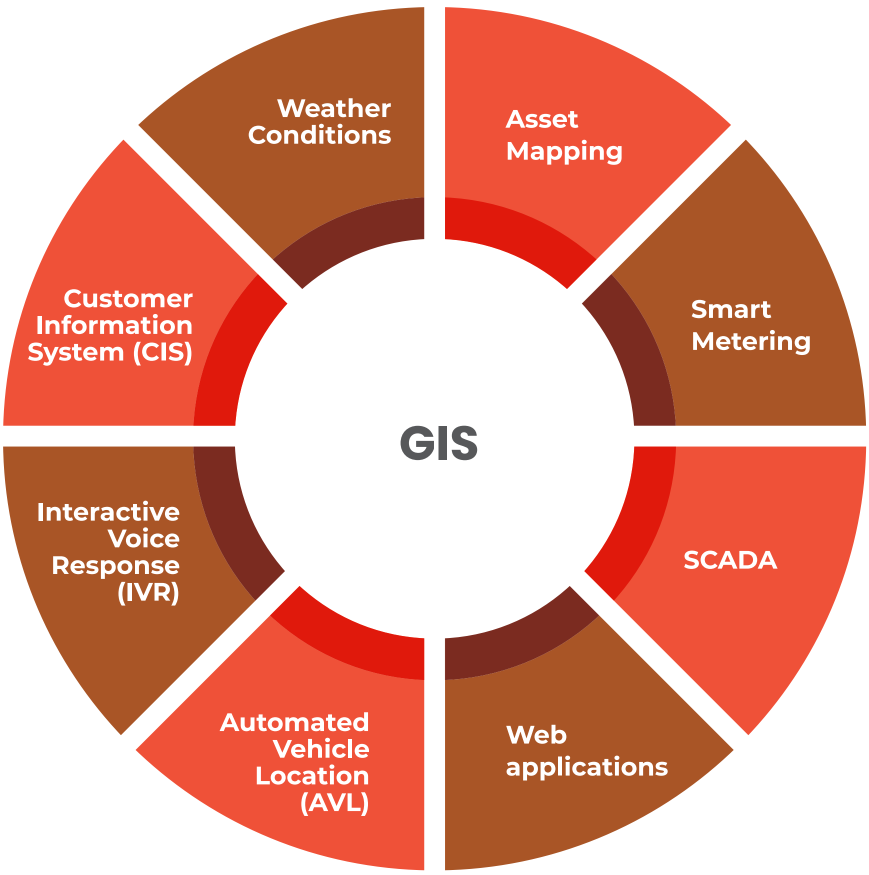


Figure 6: GIS functionalities

2.2.8 WIDE AREA MONITORING SYSTEMS (WAMSS)

With the deployment of phasor measurement units (PMUs), fast and accurate measurements from grid equipment is possible. Real time wide area monitoring applications have strict latency requirements in the range of 100 milliseconds to 5 seconds. A fast communication infrastructure is needed to handle the huge amounts of data from PMUs. Smart grid applications are designed to exploit these high throughput real time measurements. While SCADA data is collected in 1-5 seconds, PMU data is captured in milliseconds. SCADA data has no time stamps but PMU data is accurately time stamped.

2.2.9 DEMAND RESPONSE (DR)

DR is a strategy used by electricity utility companies to reduce or shift energy consumption from peak hours to off-peak hours, by curtailing the load at customer premises or disconnecting certain customer equipment remotely from the utility's control centre. Customer participation in a DR programme is sought through incentives and penalties. Equipment and communication systems to remotely control the equipment or appliances at customer premises and customer engagement are the main components of demand response programmes. The benefits of DR include averting utilisation of expensive generation plants during peak hours, avoiding construction of additional generation, transmission and distribution capacity, and avoiding brownouts and blackouts.

2.2.10 POWER QUALITY MANAGEMENT

Voltage variation beyond stipulated limits and interruptions are major power quality issues faced by customers. With the proliferation of distributed and variable generation resources such as solar and wind turbines, which operate intermittently, it is increasingly difficult to maintain quality of supply. On the other hand, modern appliances with switch-mode power supply (SMPS) such as computers, televisions, washing machines, air-conditioners, refrigerators, LED lights, furnaces, inverters, UPS etc. create harmonic distortion in the power system. Voltage and current have sinusoidal wave forms whereas the above category loads with power electronics in them have square wave forms, which leads to the generation of harmonics. With smart meters in the network, the utility is able to measure specific features such as power factors and voltages in near real time. This enables the utility to take appropriate actions to enhance the power quality.

2.2.11 MICROGRIDS

A microgrid is top on the list of smart grid technologies in developed countries as it can provide critical infrastructure with a UPS during the time of utility power outages by isolating the system from the utility grid. At the heart of a microgrid is an intelligent control centre that can island the local grid (microgrid) from the utility grid and can control and curtail (if required) the load within that microgrid to match the emergency demand with the generation and storage facilities available. Smart microgrids that can island from the grid are considered to be fall-back safety nets against cyber attacks. In the case of an attack and breakdown of the utility control centre, microgrids can island from the main grid and can serve critical loads until the main grid is back in operation.

2.2.12 ENERGY STORAGE SYSTEMS (ESSS)

ESSs play a significant role in meeting energy needs by improving the operating capabilities of the grid and deferring infrastructure investments. An ESS can address issues concerning the transmission and dispatch of electricity, while also regulating the quality and reliability of the power generated by traditional and variable sources of power. An ESS can also contribute to emergency preparedness. Modernising the grid will require substantial deployment of energy storage.

2.2.13 VEHICLE-GRID INTEGRATION (VGI)

Electric vehicle (EV) batteries can act as both load and generation resources. Millions of EVs connected to the grid can be aggregated as virtual power plants (VPPs) and support the grid during supply-demand imbalances. This is becoming increasingly relevant with the proliferation of rooftop PV (RTPV), which is intermittent. Vehicle to grid (V2G) technologies are ready for commercialisation. However, EV manufacturers are reluctant to facilitate V2G functionality in EVs owing to battery warranty issues. However, V2G trials in the past few years in several research centres have indicated that if the depth of discharge of the EV battery is limited within specified limits during V2G operations there will be little or no impact on battery life.

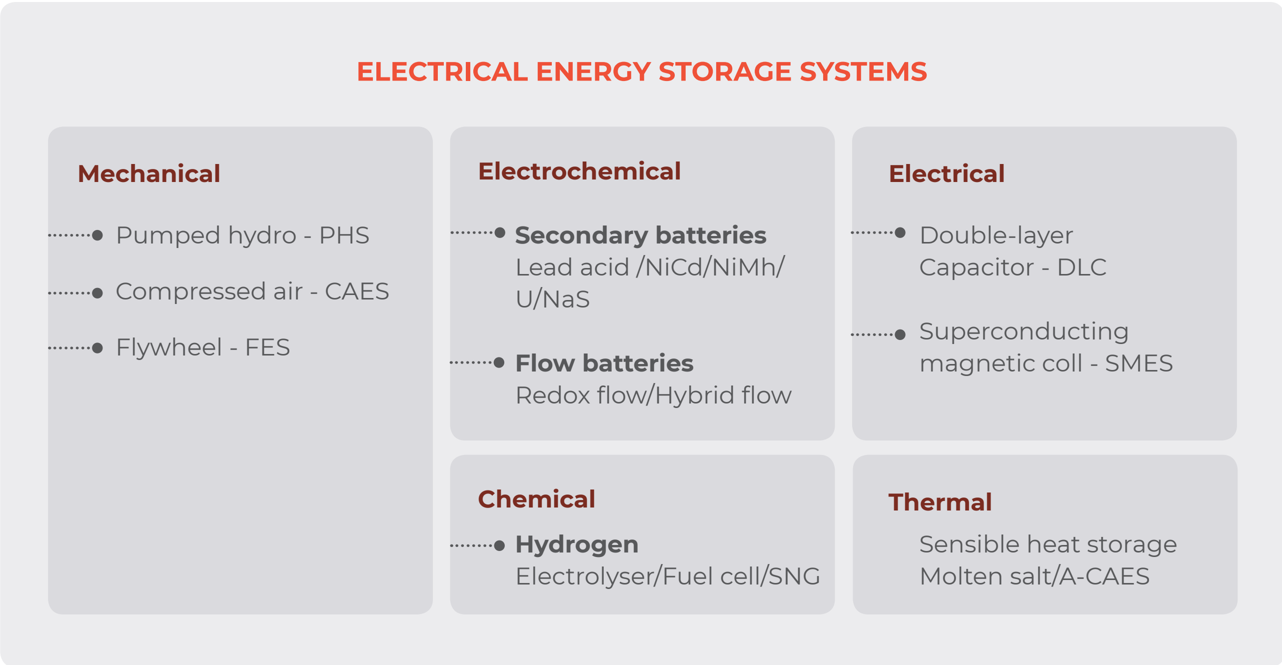


Figure 7: Electrical energy storage systems

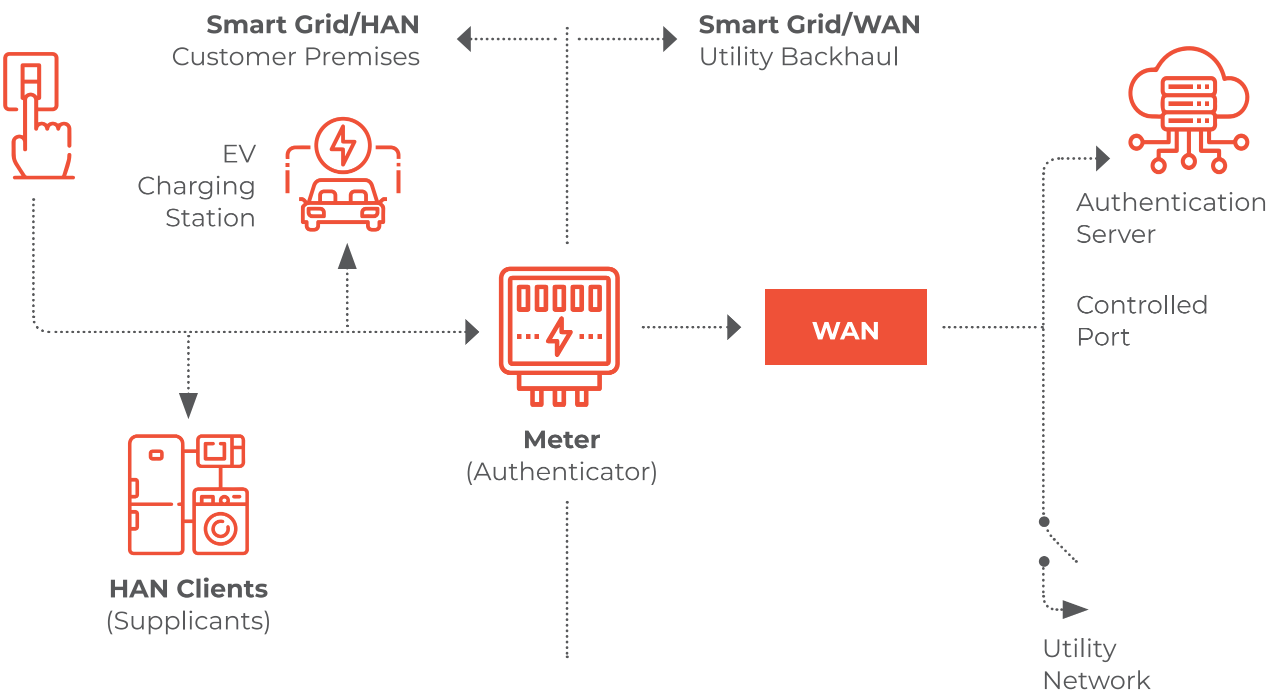


Figure 8: EV technologies and integration

2.2.14 DISTRIBUTED ENERGY RESOURCES (DERS) AND RENEWABLE ENERGY INTEGRATION (REI)

DERs are small modular energy generation and storage devices such as RTPV systems, micro wind turbines, energy storage batteries such as those in UPSs, inverters and EVs etc. DER systems may be either connected to the local electricity power grid or isolated from the grid in stand-alone applications. REI focuses on incorporating RE, distributed generation, energy storage and demand response in electricity transmission and distribution systems. A systems approach is used to conduct integration development and demonstration to address technical, economic, regulatory and institutional barriers against using renewable and distributed systems. In addition to fully addressing operational issues, integration also establishes viable business models to incorporate these technologies into capacity planning, grid operations and demand-side management. The aim of REI is to advance system design, planning and operation of the electric grid to:

- Mitigate the intermittency of RE resources through better forecasting, scheduling and dispatch in the power system and flexibility in demand and generation;
- Reduce emissions through increased use of RE and other clean DERs;
- Increase asset use through integration of distributed systems and customer loads to reduce peak load and thus lower the cost of electricity.

2.2.15 CYBER SECURITY

A nation's critical infrastructure and that in other sectors depends both directly and indirectly on the power sector. Cyber-physical security protects assets (both hardware and software) from natural and manmade disasters and intended and unintended activities. Since physical assets are associated with utilities' cyber space, cyber-physical security completely defines their security paradigms. This dependency of physical assets on cyber assets (and vice versa) has prompted utilities to incorporate resilience and robustness in their grids.

2.2.16 ADVANCED ANALYTICS AND ARTIFICIAL INTELLIGENCE

In evolving smart grids with sensors and smart equipment, most operational data is captured in digital format. This is a big shift from traditional grids, in which operational data was not recorded in digital format. The big data gathered are an invaluable asset that can give insights into asset performance and customer electricity consumption which can help utilities in their network planning and capex work. Advanced analytical solutions can help utilities to improve their operational efficiency by acting beforehand, thus improving the grid.

2.2.17 BLOCKCHAIN

Blockchain is a distributed ledger technology built on shared network infrastructure and public key encryption which will be able to provide secure transactions through smart contracts. In utilities, blockchain-based technology can be applied to various processes, such as energy credit management, scaling up of distributed energy resources, asset optimisation, P2P transactions etc. These are among the many cases that industry players are exploring in pilot projects.

<table>
<tr><th></th><th>GENERATION</th><th>TRANSMISSION</th><th>DISTRIBUTION</th><th>RETAIL/ CUSTOMER</th></tr>
<tr><td rowspan="3">Level 1: Foundational Technology</td><td>Renewable generation cryptocurrencies</td><td></td><td></td><td>Bill pay (cryptocurrencies)</td></tr>
<tr><td colspan="3">Supply chain/inventory management (requisition, usage delivery and reordering)</td><td>Customer switching</td></tr>
<tr><td colspan="2">IP contracts, execution, verification and settlement</td><td colspan="2">Electric vehicle charging authentication & payments</td></tr>
<tr><td rowspan="3">Level 2: Viable for Business</td><td colspan="2">Analytics to drive critical infrastructure monitoring and control</td><td>Distribution grid balancing and control analytics</td><td>Demand-side response and rewards</td></tr>
<tr><td>Renewable certificate trading</td><td colspan="2">Wholesale settlements</td><td>Smart metering (billing & settlements)</td></tr>
<tr><td></td><td colspan="2">Network outage and energy theft tracking</td><td>Internet of Things (Integration with utility systems)</td></tr>
<tr><td rowspan="3">Level 3: Robust & Scalable for Business</td><td colspan="3">Automated remote monitoring and control of power plants, transmission and distribution assets</td><td>Peer-to-peer trading Metering</td></tr>
<tr><td colspan="3">Decentralized exchange/integrated trading</td><td>Retail trading/ settlement</td></tr>
<tr><td colspan="4">Local energy markets</td></tr>
</table>

Figure 9: Blockchain conceptual framework

2.3 INDIAN POWER SECTOR OVERVIEW

The Indian power system is the third largest in the world, with 395 GW of installed capacity as of 2021 and close to 300 million customers in an area of over 3 million sq km. India has successfully completed village electrification and has brought electricity to citizens in over 638,365 villages. The Indian power system operates with ± 800 kV HVDC and ±500 kV HVDC lines; and 765 kV, 400 kV, 230 kV (or 220 kV in some states), 132 kV (or 110 kV in some states) and 66 kV AC lines.

Source	Installed Capacity
Thermal	235.92
Hydro	46.51
Nuclear	6.78
Renewables	105.85
Total	**395**

Source: CEA

Table 1: Installed capacity in GW

The objective of capacity addition in the generation and transmission domains will only be fruitful if the power distribution sector is also strengthened to carry the electricity generated to customers connected to the low voltage distribution network. To address problems in the distribution sector, the Government of India (GoI) has implemented various schemes like the Accelerated Power Development and Reform Programme (APDRP), Restructured APDRP (R-APDRP), Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), the Integrated Power Development Scheme (IPDS) and Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) with the aim of improving the sub-transmission and distribution network, separating agricultural feeders and rural electrification. The GoI has established a National Electricity Fund to promote investment in the distribution sector. In 2017, the GoI launched a new scheme called Saubhagya to fast-track electrify the unelectrified households in the country. Along with these schemes, the GoI has also launched the Ujwal discom Assurance Yojana (UDAY) scheme to ensure the financial revival of electricity distribution companies by taking over 75% of their debts and issuing bonds (by the discoms) for the remaining 25% of debt. UDAY also envisages reducing AT&C losses in the distribution sector and reducing the gap between the average cost of supply (ACS) and the average revenue requirement (ARR) and installing smart meters. A large-scale rollout of smart meters has already commenced.

2.3.1 POLICY AND REGULATIONS

In 1998 in a special act the GoI introduced electricity regulatory commissions in India. Electricity regulation was previously undertaken partly by the MoP, the CEA and state governments. India follows the US model of a Central Electricity Regulatory Commission (CERC) and separate electricity regulatory commissions (SERCs) in each state. There are 27 SERCs, 2 Joint electricity regulatory commissions and one CERC. The chairpersons of all the 30 commissions form a statutory body called the Forum of Regulators (FOR), which is chaired by the chairperson of CERC. Some key policies, regulations and laws in the electricity sector are listed in the table below:

Electricity Act, 2003	Sector reorganisation and competitive markets, providing the legal framework for making electricity theft an offence.
National Electricity Policy	Overall sector development.
National Tariff Policy	Performance-based regulation.
Guidelines for Competitive Bidding	Transparent tariff-based bidding for new generation.
Rural Electrification Policy	Electrification of villages and remote areas.
Indian Electricity Grid Code Regulations	Grid operations with competitive markets and renewables.
REC Regulations	Trading of renewable energy certificates.
Power Market Regulations	Transparent power market operations.
Guidelines for Cross Border Trade of Electricity 2016 (draft regulation)	Guidelines regarding cross border trade of electricity between India and neighbouring countries.
Renewable Energy Policy	A target of 175 GW Renewables by 2022; Net metering policies in all states.
Power for All	Focus on universal access to electricity and measures to incorporate modern energy sources to supply round-the-clock electricity to all.
Licence Regimes	Increased private investments to simplify and deregulate the business environment.
Model Smart Grid Regulations	Issued by the FOR in October 2015
Ancillary Services Regulations	Issued by the CERC in August 2015
Electricity (Amendment) Bill 2021	The bill seeks to de-license power distribution to reduce entry barriers for private players to create competition in the sector, which will ultimately enable consumers to choose among multiple service providers.

Table 2: Policies and regulations

2.4 SMART GRID DEVELOPMENTS IN INDIA

Electricity utilities are on the threshold of a rapid transformation with the advent of distributed renewable generation, EVs and energy storage systems etc., a much needed move towards a new era of decentralised systems. The growing concern about the environment, government policies supporting environmentally sustainable solutions and rapidly falling technology costs have also pushed these new generation and demand sources to be connected to the low voltage grid. This has led to operational challenges for grid operators as they have to deal with both intermittent generation and variable demand sources, which requires the grid to be more flexible and robust and thus paving the way for adoption of smart grid technologies.

The grid modernisation journey in India started in 2008 with the R-APDRP, which laid the foundation for smart grids by introducing IT and automation systems for reliable energy accounting and loss reduction. The need for modernisation was further strengthened with the government's target to add 20 GW of grid connected solar power in the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010. Considering the growth in the RE portfolio and the envisaged market proliferation of EVs, in 2010 the GoI set up two bodies, namely the India Smart Grid Task Force (ISGTF) and the India Smart Grid Forum (ISGF), with the objectives of developing a roadmap for smart grid implementation and assisting utilities with the deployment of smart grid technologies in a cost effective, efficient and scalable manner.

The GoI Ministry of Power (MoP) in consultation with the ISGF and the ISGTF in September 2013 formulated a Smart Grid Vision and Roadmap for India aligned to the MoP's overarching objectives of "Access, Availability and Affordability of Power for All" and has envisaged transformation of the entire power system with smarter grids by 2027.

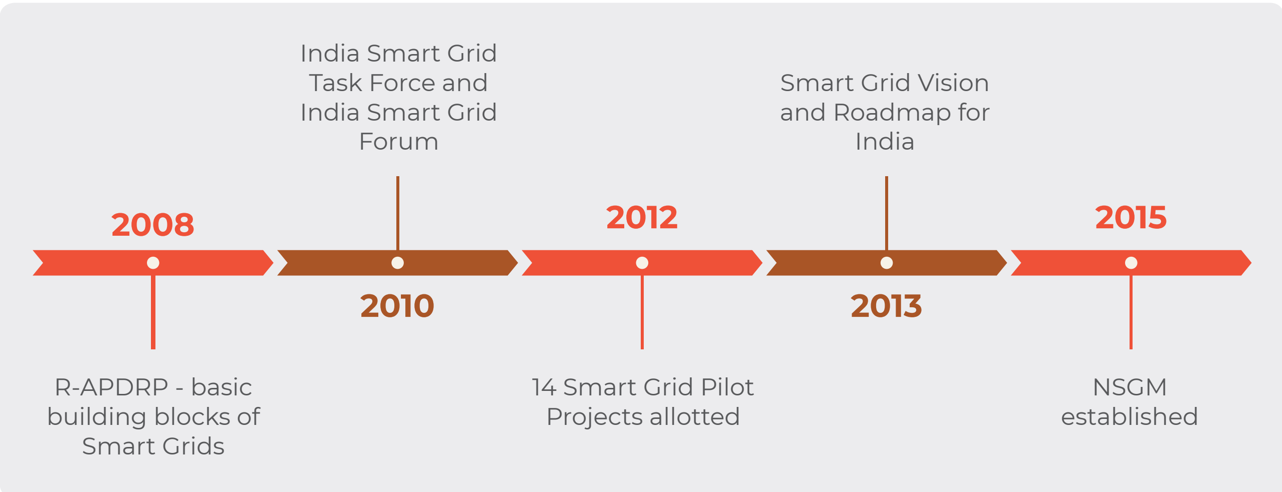
In order to take these smart grid initiatives forward and to address various technicalities in SG applications like RE integration, demand response etc., the MoP with the help of the central and state regulatory bodies has issued various regulations such as the Model Smart Grid Regulations 2015, Net Metering Regulations in each state, Ancillary Services Regulations etc., which not only promote and support the adoption of smart grid technologies by utilities but also ensure consumer participation in the distribution grid ecosystem.

Model Smart Grid Regulations, 2015

- The State and Joint Electricity Regulatory Commission (SERC and JERC for UTs) is to issue guidelines on the formulation, implementation and monitoring of smart grid programmes.
- Constitution of smart grid cells.
- Development of multi-year smart grid programme, transmission and distribution licensees to adopt CEA standards or BIS standards to be met in the execution of smart grid projects.

2.4.1 SMART GRID PILOT PROJECTS IN INDIA

In August 2013 the MoP approved a Smart Grid Vision and Roadmap for India, which also envisaged the launch of a National Smart Grid Mission (NSGM) with its own resources, authority and functional and financial autonomy to plan and monitor the implementation of the policies and programmes prescribed in the roadmap. The NSGM was approved by the GoI in 2015 and it became operational in 2016. The NSGM in two Empowered Committee meetings approved four projects in 2016 with grant support from the GoI to the tune of 30% of project cost. Details on these projects are given below:



2.4.1.1 NATIONAL SMART GRID PROJECTS

S. No	Utility/Project Area	Location	Project Functionalities	Consumers	Project Cost	Project Status
1	Chandigarh Electricity Department (CED), Chandigarh (Sub Div-5)	Sub Division 5 of Chandigarh	AMI, DTMU, SCADA	29,433	Approved project cost: ₹28.58 Cr. GoI support: ₹8.57 Cr. Released: ₹7.7124 Cr	To date, a total of 9,443 smart meters installed in the field.
2	Jaipur Vidyut Vitran Nigam Limited (JVVNL), Rajasthan (6 Towns)	Baran, Bharatpur, Bundi, Dholpur, Jhalawar, Karauli	AMI	1.5 Lakh	Approved project cost: ₹87.43 Cr. GoI support: ₹26.23 Cr. Released: ₹2.61 Cr	To date 23,675 smart meters installed.
3	Chandigarh Electricity Department (CED), Chandigarh (Complete City Excl. SD-5)	Complete Chandigarh City	AMI	1.84 Lakh	Revised project cost: ₹119.58 Cr. (Under concurrence). GoI support: ₹35.87 Cr. Released: ₹7.25 Cr.	As the empowered committee directed during its 6th meeting held on 7 June 2021, revised sanctions with AMI/smart metering are under approval/ concurrence from the MoP.
4	Odisha Power Transmission Corporation Limited (OPTCL), Odisha (Rourkela)	Rourkela City	AMI, DTMU	0.87 Lakh	Approved project cost: ₹96.97 Cr. GoI support: ₹29.09 Cr. Released: ₹2.91 Cr.	Project dropped by OPTCL after an Odisha DRC decision.
5	Jharkhand Bijli Vitran Nigam Limited (JBVNL), Jharkhand (Ranchi)	Ranchi City	AMI, DTMU	3.6 Lakh	Approved project cost: ₹228.69 Cr. GoI support: ₹68.61 Cr	Revised proposal considered subject to demonstration of synchronisation of both contracts and in-house IT capability by JBVNL while seeking release of funds from the MoP as in NSGM guidelines.

Source: NSGM

Table 3: Status of NSGM Smart Grid Projects as of June 2021

2.4.1.2 SMART GRID PILOT PROJECTS UNDER THE IPDS

S. No	Utility/ Project Area	Location	Project Functionalities	Consumers	SGIA	Project Cost	Project Status
1	IIT Kanpur Smart City Pilot	Smart City Pilot in IITK Campus	NA	NA	NA	Approved project cost: ₹11.394 Cr. GoI support: ₹5.697 Cr.	Completed
2	Chamundeshwari Electricity Supply Company (CESC), Mysore	V V Mohalla, Mysore	AMI, OMS, Peak Load Management (PLM), MG/DG	21,824	M/s Enzen	Approved project cost: ₹32.56 Cr. GoI support: ₹16.28Cr.	Completed
3	Uttar Haryana Bijli Vitran Nigam Limited (UHBVN), Haryana	Panipat City Sub Division	AMI, PLM, OMS	10,188	NA	Project implemented under grant from NEDO (Japan)	Completed
4	Smart Grid Knowledge Center, Manesar	POWERGRID Complex, Manesar	AMI, OMS, MG/DG, Electric Vehicle Charging infrastructure (EVCI), HEMS, Cyber Security and Training Infra	NA	M/s Genus	Approved project cost: ₹5.96 Cr. GoI support: ₹5.96 Cr.	Completed
5	Himachal Pradesh State Electricity Board (HPSEB), Himachal Pradesh	Kala Amb Industrial Area	AMI, OMS, PLM	1,335	M/s GE T&D	Approved project cost: ₹19.45 Cr. GoI support: ₹9.73Cr.	Completed
6	Uttar Gujrat Vij Company Limited (UGVCL), Gujrat	Naroda	AMI, OMS, PLM, Power Quality (PQ)	22,230	M/s Genus	Approved project cost: ₹23.18 Cr. GoI support: ₹11.59Cr.	Completed
7	Electricity Department, Government of Puducherry (PED)	Division 1 of Puducherry	AMI	33,499	M/s DFE, China	Approved project cost: ₹35.43 Cr. GoI support: ₹17.72Cr.	Completed
8	West Bengal State Electricity Distribution Company Limited (WBSEDCL), West Bengal	Siliguri Town	AMI, PLM	5,265	M/s Chemtrols	Approved project cost: ₹6.955 Cr. GoI support: ₹3.48 Cr	Completed

S. No	Utility/ Project Area	Location	Project Functionalities	Consumers	SGIA	Project Cost	Project Status
9	Assam Power Distribution Company Limited (AP-DCL)	Guwahati Division	AMI, PLM	14,519	M/s Fluentgrid	₹20.92 Cr. GoI support: ₹10.46 Cr. Released: ₹8.368 Cr.	Completed
10	Tripura State Electricity Corporation Limited (TSE-CL), Tripura	Electrical Division No.1, Agartala	AMI, PLM	45,290	M/s Wipro	Approved project cost: ₹63.43 Cr. GoI support: ₹31.72Cr. Released: ₹25.373 Cr.	Project declared go-live on 30.06.2019. Commu-nication issues after Go live. Revised plan with alternate commu-nication under de-liberation by TSECL.
11	Telangana State South-ern Power Distribution Company Limited (TSSPDCL), Telangana	Jeedimetla Industrial Area	AMI, PLM, OMS, PQ	11,906	M/s ECIL	Approved project cost: ₹34.93 Cr. GoI support: ₹17.47 Cr. Released: ₹13.981 Cr.	Project declared go-live on 30.03.2019. End-to-end testing and closure activities in progress.

Source: NSGM

Table 4: Status of Smart Grid Pilot Projects (Under IPDS) as of June 2021

2.5 UNDERSTANDING THE SMART GRID STATUS QUO IN INDIA

The platform as part of its first workshop aimed to understand the current smart grid status quo in India from a multi-stakeholder perspective and from a multi-dimensional perspective. The key question it addressed was:

What are the possible opportunities and barriers for replicating and upscaling smart grid projects in India in the context of technology, financing, social acceptance and regulatory and policy issues?

Some of the key insights were:

Technology

- Smart Grid solutions should take a bottom-up approach as one size will not fit all.
- The role of technology in the evolution of smart grids is evident, but what needs to be explored is what technology, how smart it should be and where and on whom does it impact. For example, the roll-out of fundamental technologies such as smart meters brings value to both grid operators and consumers. Some distribution companies are able to scale up quickly as they have the advantage of already having certain foundational technologies, while others do not.
- In order for the right set of solutions to be implemented, capacity building of the work force handling smart grid projects – from policy to implementation – is needed.
- While looking for solutions, we need to look at the system as a whole. At times a simpler and cheaper solution may do the trick, and with technologies evolving rapidly we are all in a learning curve.
- In planning, we must keep in mind all the layers in the system, technology, communication, access to data etc., and therefore an integrated approach to planning smart grids is essential.
- A more collaborative approach among various technological service providers will be beneficial.

Financing:

- First and foremost a clear roadmap on planning and implementing smart grids will allow much needed investments to flow. Currently, investors are unable to judge value at the stakeholder level vs system level and it is still unclear who will fund the smart grid transformation.

- There is a need for business model innovation to enable both technical and economic viability. For example exploring the use of second-life PV panels to lower costs.
- While some organisations have a strategic advantage in implementing smart grid solutions due to either their good performance or resource availability, others may address their lack of the same benefits to make a business case, e.g. by building their own operating models to rein in finances to boost their business performance.
- The private sector can bring in the investments and innovation needed to speed-track smart grid implementation. It can also work in tandem with state-owned distribution companies to implement smart grid solutions.

Social Acceptance

- On-boarding and awareness are key, which includes both implementers and adopters
- A bottom-up approach is needed for faster replication of smart grid solutions.
- Consumer engagement and involvement are needed in all phases, i.e. from development to implementation.

Policy and Regulation

- Long-term planning and signals are needed to attract investors and businesses to implement smart grids.
- Regulation should allow data transparency, data sharing and data security to enable business innovation.
- Enabling standardisation across the layers of smart grids, including products, services and processes, is essential to enable system-wide applications in the long run.
- Target-based regulation is needed to kick start smart grid projects.
- Regulatory sandboxes will allow experimentation with innovative solutions and will determine upscaling potential.
- Cost-benefit analysis of various projects will help evaluate solutions and determine the future course of action.
- Regulation should address the health of distribution companies, which is a major deterrent to uptake of smart grid solutions.
- Going beyond the energy sector and looking at sector integration (or coupling) will allow cross-sector benefits technically, economically and socially.

3
Smart grid use case selection

3 SMART GRID USE CASE SELECTION

To select appropriate use cases to study in this research, it is necessary to quantify the value of each use case under consideration. This consists of a four-stage process that is described in this section. The section also includes insights from the second platform workshop.

3.1 STAGE 1: DEVELOPING A BENEFIT SCALE

In the first stage a use case rating scale was developed based on possible benefits from smart grid use cases. A two-step process was utilised to develop the scale. In the first step a comprehensive list of benefits was developed based on a detailed literature review. The second step in the process consisted of conducting a survey of the participants in the smart grid platform. The survey respondents were asked to priorities the importance of each benefit from the Indian power sector perspective on a scale from 1 (low) to 5 (high). The benefits were ranked based on the average scores given by the respondents. The Table 5 below presents the list of benefits and the average scores.

3.2 STAGE 2: QUANTIFYING THE IMPACT OF USE CASES ON THE BENEFITS

The next step in selecting the most relevant use case for this study consisted of identifying key use cases in the EU and India and rating them according to their impacts on the various benefits identified in the previous step. A literature review was conducted of various smart grid projects in various stages of development and implementation in India and the EU to identify and comprehensively list the various use cases. In the list of use cases, a value from 1 (low) to 5 (high) was given to each use case for each benefit indicated in Table 5. This quantification was based on the literature review and expert insights from the project partners. Quantifications of the impacts of each use case for India and the EU are presented in the Tables 6 and 7.

Expert Survey: Prioritising potential smart grid benefits

Benefit	Relevance to the Indian context
Optimized generation operation	4.09
Reduced generation capacity investment	3.64
Reduced cost of ancillary services (balancing)	3.82
Reduced congestion costs (redispatch)	3.55
Reduced/deferred transmission grid investments	3.82
Reduced/deferred distribution grid investments	4.09
Reduced equipment failure/longer useful life of assets	4.27
Reduced distribution maintenance costs	4.27
Reduced network operation costs (lower labour/vehicle-related costs)	4.27
Reduce technical losses	4.36
Reduce non-technical losses	4.36
Reduced electricity costs (for end user)	3.73
Reduced sustained outages	4.55
Reduced voltage sags and swells	3.73
Reduced CO2 emissions	3.64
Reduced SOx, NOx, and/or PM2.5 emissions	3.36
Enhanced grid observability, with applications for planning and operation	4.45
Improved phase balancing	3.91
Increased hosting capacity for distributed resources / faster grid connection	4.64

Table 5: Expert survey for selection of Indian use case

	Use case goals and benefits																		
	Optimized generation operation	Reduced generation capacity investment	Reduced cost of ancillary services (balancing)	Reduced congestion costs (redispatch)	Reduced/ deferred transmission grid investments	Reduced/ deferred distribution grid investments	Reduced equipment failure/ longer useful life of assets	Reduced distribution maintenance costs	Reduced network operation costs (lower labour/vehicle-related costs)	Reduce technical losses	Reduce non-technical losses	Reduced electricity costs (for end user)	Reduced sustained outages	Reduced voltage sags and swells	Reduced CO_2 emissions	Reduced SOx, NOx, and/or PM2.5 emissions	Enhanced grid observability	Improved phase balancing	Increased hosting capacity / faster grid connection
Use case name - EU																			
MV automation and reconfiguration	0	0	0	0	0	3	0	0	3	2	0	0	5	3	2	0	4	0	3
Controlled islanded operation	0	0	0	0	0	4	0	2	4	0	0	4	5	2	0	0	4	4	2
Advanced voltage control in MV grids	0	0	0	0	0	5	1	1	0	4	0	0	1	5	2	0	4	0	5
Demand response/consumption optimization at end-user premises	4	2	3	2	1	4	1	1	1	2	4	5	1	2	4	0	4	3	4
Predictive maintenance of network assets	0	0	0	0	0	2	5	5	4	0	0	0	4	0	1	1	0	0	0
LV supervision and control	0	0	0	0	0	2	2	2	2	3	5	0	3	4	0	0	5	4	4
Aggregation of DER to provide balancing services to the TSO	4	2	5	0	0	0	0	0	0	0	0	4	0	0	2	1	0	0	0
Local management of flexible DER to alleviate network constraints	2	1	0	5	1	5	1	1	1	2	0	4	2	0	2	1	3	2	4
Anti-islanding protection	0	0	0	0	0	0	4	5	4	0	0	2	5	2	0	0	3	2	0
Voluntary demand response based on advanced tariff schemes or through gamification	2	1	1	4	2	4	1	0	0	2	0	5	0	0	2	1	2	1	3
Implementing Agency - India																			
POSOCO	5	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POWERGRID	5	0	0	0	0	0	0	0	0	4	0	4	0	0	5	0	0	0	0
POWERGRID	0	0	0	4	4	0	3	0	5	3	0	0	0	5	0	0	5	5	0
Tata Power DDL	0	0	0	0	0	5	0	0	0	0	0	4	4	0	5	0	0	0	4
Tata Power DDL	0	0	0	0	0	5	5	5	5	4	5	5	5	5	5	5	5	5	4
CESC Mysore	0	0	0	0	0	5	4	5	4	4	5	4	5	4	4	4	4	4	4
UGVCL, Gujarat	0	0	0	0	0	5	4	5	4	4	5	4	5	4	4	4	4	4	4
TSSPDCL, Telangana	0	0	0	0	0	5	4	5	4	4	5	4	5	5	4	4	4	5	4
TSECL, Tripura	0	0	0	0	0	5	4	5	4	4	5	4	5	4	4	4	4	4	4
APDCL, Assam	0	0	0	0	0	5	4	5	4	4	5	4	5	4	4	4	4	4	4
MPPKVVCL, MP	0	0	0	0	0	5	4	5	4	4	5	4	5	4	4	4	4	4	4

Table 6 and 7: EU / Indian use case goals and benefits

3.3 STAGE 3: CALCULATING THE FINAL RATING

In the third stage of this process, the 'use case impact rating' for each benefit was multiplied by the corresponding 'benefit priority rating' developed in the first stage. The total score was then summed for each use case and Indian project to develop a final rating, as is illustrated in the table below.

EU Use cases	Final Score
Demand response/consumption optimisation at end-user premises	194.64
LV supervision and control	153.73
Local management of flexible DER to alleviate network constraints	149.73
Controlled islanded operation	129.82
Voluntary demand response based on advanced tariff schemes or through gamification	122.82
Advanced voltage control in MV grids	117.91
Anti-islanding protection	114.36
MV automation and reconfiguration	106.73
Predictive maintenance of network assets	93.18
Aggregation of DERs to provide balancing services to the TSO	68.27

Indian Projects	Final Score
Tata Power DDL	279.18
TSSPDCL, Telangana	255.45
CESC Mysore	247.82
UGVCL, Gujarat	247.82
TSECL, Tripura	247.82
APDCL, Assam	247.82
POWERGRID	137.18
Tata Power DDL	90.27
POWERGRID	71.00
POSOCO	35.73

Table 8: Final rating of EU and Indian use cases

3.4 STAGE 4: MAPPING INDIAN PROJECTS AND EU USE CASES

A fourth and final step was needed as it was observed that the Indian projects consisted of a combination of several use cases. Therefore, in order to harmonise the comparison and ensure that the most relevant use cases were selected, the highest scoring Indian projects were compared with the various European use cases, as is illustrated in the following table

Indian Projects	Discom	European use case					
		Demand response/ consumption optimisation	LV supervision and control	Local Management of DER to alleviate grid constraints	Advanced voltage control in MV gids	MV automation and reconfiguration	Predictive maintenance of network assets
Better network management and resource optimization	Tata Power DDL			X	X	X	
Increase in revenue through better load management, loss reduction and resource optimization	TSSPDCL, Telangana	X	X			X	X
Better load and asset management for improving DISCOM revenue	CESC Mysore	X	X			X	
Increase in revenue through better load management, loss reduction and resource optimization	UGVCL, Gujarat	X	X			X	X
Better network management and higher revenue realization	TSECL, Tripura	X	X				
Better load and asset management for improving DISCOM revenue	APDCL, Assam	X	X			X	
Keywords from indian projects		PLM, load optimization	AMI, Revenue management, loss reduction	ADMS, load optimization	ADMS	OMS, improve outage restoration time	Improved asset life

Table 9: Mapping EU and Indian use cases

3.5 SHORTLISTED USE CASES

At the end of the fourth step, four use cases were shortlisted as described below. These four uses cases were presented in the next workshop to the experts and were voted on to choose the top three cases for further study..

1. Demand response/ consumption optimisation

Technologies: smart meters, in-home display, mobile apps, HEMS/BMS/EMS, load automation, smart appliances/ plugs, ZigBEE/wifi/ethernet.
Functions: load automation/ management in response to tariff/price signals and/or active power set-points.

KPIs: bill reduction (€), drop in energy consumption (kWh), peak load reduction (kW), user acceptance/ engagement/satisfaction (%).

Pros:

- Largest market potential with respect to the other use cases. Has a market dimension whereas the others are more tech-focused.
- Drives energy efficiency
- Strong business case for residential consumers in high rise residential projects.
- The demand curve has more peaks, which warrants more ramping capability. Therefore, demand response will help flatten the curve.
- Same assets if done with case (ii)

Cons:

- Residential consumers would not be interested because of low tariffs/less savings for those who can afford these technologies, so the focus should be on large consumers.
- Previous pilot projects did not provide adequate benefits to make them attractive to consumers.

2. LV supervision and control (including AMI)

Technologies: AMI (smart meters, PLC/GPRS/mobile communications, LV supervisor (secondary substation), software.

Functions: loss reduction, phase balancing, improvement of connectivity model, state estimation.
KPIs: Loss reduction, PQ indicators, OPEX reduction, communications performance.

Pros:

- Provides increased consumer satisfaction due to reduced disruptions, which also reduces losses for discoms.
- Application should focus on last mile connection.

- Scalability and replicability should focus on revenue for the utility.
- Solutions should factor in the geographical context and consider applicable use cases in rural and urban communities.

Cons:

- The existing regulatory framework has not evolved to encourage utilities to invest enough.

3. Local management of DER to alleviate network constraints (includes voltage management with discom own resources)

Technologies: ADMS, OPF/MPOPF, state estimation, load/generation forecast, RTU, DER, OLTC, capacitor banks, BESS, VPP.

Functions: manage either discom-owned resources only or both discom-owned and third-party-owned resources (DG, DR, BESS) to alleviate grid constraints (from operational planning to operation).

KPIs: loss reduction, drop in voltage violations and overloads, grid investment deferral, grid hosting capacity, drop in RES curtailment.

Pros:

- Very closely related to the first use case.

Cons:

- Not enough DERs to look at scalability.
- Rooftop DER is presently not within the discom scheme of things in terms of visibility and definitely controllability.

4. MV grid automation and reconfiguration

Technologies: fault detectors, telecontrol (breaker primary SS, switch secondary SS), OMS, RF/GPRS/others

.

Functions: monitoring and automation to reduce the frequency and duration of network outages.

KPIs: SAIDI/SAIFI reduction, restoration time, OPEX reduction (crews, vehicles).

Pros:

- Very easily applicable in all discoms.
- Industry islanding should be explored.

Cons:

- Utilities have not been actively investing in the MV grid.

The final three use cases that were selected on the basis of the votes of the expert group were

- Demand response/consumption optimisation
- LV supervision and control (including AMI)
- MV grid automation and reconfiguration

4
CBA and SRA Analysis

4 CBA AND SRA ANALYSIS

Assessment of investment activities is a pillar in strategic management at any level. When investment activities involve the deployment of projects, project evaluation aims to determine the effects caused to foster the best allocation of scarce resources (e.g. capital, labour, land, water). In project evaluation, laws of economics are pivotal to determine the profitability of an initiative [1]-[3]. However, projects of social interest have to be assessed considering a broader range of impacts [2]-[4]. Assessment can be performed before project deployment to forecast the effects expected (ex-ante), during project deployment to check the performance level to identify corrective measures (in medias res) or after the time horizon of the project to verify the actual impacts generated (ex-post) [3].

Regardless of timing, project appraisal approaches can be classified according to the assessment perspective, and therefore the scope of the evaluated impacts. Figure 10 provides an overview of the project appraisal approach classification. A financial analysis only considers the investor viewpoint. It assesses the profitability of the projects only considering monetary impacts [3]–[5]. Cost-benefit analysis (CBA) is the most acknowledged tool for financial viability assessment [1], [6], [7]. An economic analysis of initiatives enlarges the evaluation perspective to include the national and societal viewpoints [3]–[5]. Direct and indirect monetary and monetisable impacts are part of a social CBA that assesses the economic viability of projects [3]–[5]. A wider project assessment is obtained if soft effects, and intangible and non-monetisable impacts are included in the project assessment. Quantitative and qualitative project impacts can be contextually assessed using multi-criteria analysis approaches [4], [7]–[9].

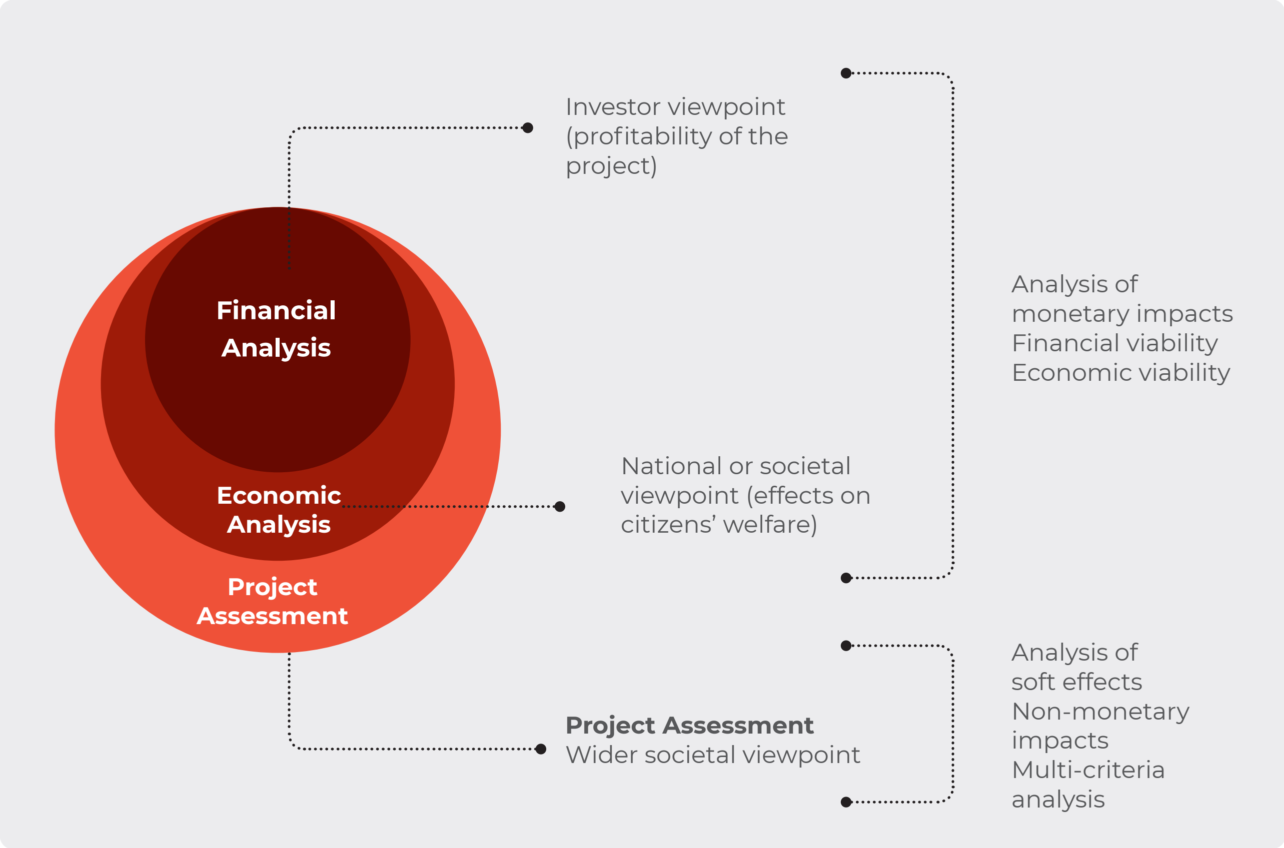


Figure 10 : Overview of the classification of project appraisal approaches.

The main objective of a scalability and replicability analysis (SRA) is to determine if a specific use case, system or service can be carried out in different places and/or under different technical and non-technical conditions. Three main concepts must be considered in an SRA: scalability, replicability and boundary conditions.

Scalability. The scalability part of the analysis tries to determine the ability of a process, system or network to increase in size or range to correctly meet a growth in demand. Two types of scalability analysis can be carried out [22]:

- Scalability in density. This shows the effects of varying one or more controllable parameters. For example, the location and penetration level of a technology in the grid or the number of consumers.
- Scalability in size. This shows the effects of implementing the use case in a larger area where different types of networks might be present but that is still under the same or a similar regulatory framework.

Replicability :

The replicability part of the analysis tries to determine how regulatory, technical, environmental and social conditions affect the conclusions from the use case with the objective of applying it in other regions, either intranational or international. For example, changing network characteristics (e.g. topology) or regulatory constraints (e.g. allowed voltage levels) according to a network representative of the country.

Boundary conditions:

These are defined as the technical, regulatory, environmental and social conditions that characterise a location. For example, the maximum loading of transformers in the grid, the maximum power capacity allowed for self-consumption etc. Modification of these boundary conditions is part of the replicability analysis.

4.1 METHODOLOGIES

4.1.1 CBA METHODOLOGY FOR SMART GRIDS

Cost-benefit analysis (CBA) is the most acknowledged tool for financial assessment of industrial projects [1], [3], [6], [7]. A CBA relies on neoclassical welfare economics principles and provides a systematic assessment framework that seeks the most profitable investment alternative [1]. Typically, CBA of industrial projects considers only financial aspects (monetary and directly monetisable) from the investor's perspective [1]. CBA relies on the Kaldor-Hicks criterion: the benefits related to the deployment of an alternative must exceed the costs. The investment has to maximise investors' profits. [1].

The procedure for conducting a CBA essentially consists of five steps [6], [10]:

1. Definition of the goals and context of the investment;
2. Identification of impacts caused by the investment (costs and benefits);
3. Conversion of the impacts into monetary terms;
4. Composition of costs and benefits and evaluation of the CBA output indices;
5. Evaluation of the outcome and sensitivity analysis.

Definition of goals is the very first step in a CBA. Moreover, the context of the initiative has to be studied since it strongly influences investment profitability. The context appraisal involves auditing the territory, stakeholders and the time horizon. Costs and monetary benefits are the negative and positive impacts caused by the initiative. To be included in the CBA, the impacts have to be identified, quantified and converted into monetary terms. Several approaches can be used to monetise different impacts [6]. The monetary values are then discounted considering a reference discount rate to obtain the equivalent monetary value for a reference year [1], [10]. Calculation of the performance indicator consists of composition of the discounted costs and benefits. Typically, the CBA indicators are net present value (NPV), internal rate of return (IRR), and the cost-benefit ratio

(CBR) [6]. NPV measures the profitability of the investment. If the NPV is positive, the benefits produced outclass the costs [2], [11]. IRR is the discount rate value that makes the NPV equal to zero [2], [11]. The investment is profitable if the IRR is greater than the discount rate. The CBR is calculated as the ratio of the present value of benefits and costs [2], [11]. The alternative that achieves the highest NPV is considered the best option because the highest profitability is expected. A sensitivity analysis assesses the robustness of the results concerning the ranges of parameters in expected future scenarios [1], [10].

CBA is the fundamental tool for determining the viability of an initiative [3], [12]. Several CBA guidelines have been proposed for several sectors to tailor the general approach to the context and sectoral particularities [4], [8], [9], [11], [13]–[15]. Regarding smart grid projects, the main particularities are related to the functionalities and services enabled that require inclusion of grid customers in the operation of the power system [7]. The novelty of these functionalities and services and a lack of historical information require designing dedicated methodologies to quantify and monetise project-related positive and negative impacts. Moreover, because of active inclusion of customers in the power system processes and the emergence of novel stakeholders, such as flexible service providers, only relying only on a financial project analysis appears unsound. Finally, because of objectives related to energy transition strategies, project assessment has to verify compliance with policy objectives [4], [16]. The European Commission Joint Research Centre (JRC) has devised a dedicated guideline for conducting a CBA of smart grid projects to address the challenges mentioned [4]. The recommendations in the JRC CBA guideline help to identify, quantify and monetise project impacts while considering context characteristics. Moreover, recommendations are also provided to analyse unquantifiable and non-monetisable impacts.

According to the JRC, the CBA guidelines are a structured set of suggestions and a checklist of essential elements to analyse smart grid initiatives [4], [13]. The JRC assessment framework consists of an economic-oriented CBA tailored for smart grid initiatives to appraise costs, benefits and externalities from the societal perspective [4]. The economic analysis is accompanied by a qualitative analysis (non-monetary appraisal of non-quantifiable impacts and externalities, e.g. social impacts, contribution to policy goals) [4].

The economic analysis includes impacts generated by the smart grid initiative that pass on to the electricity system (e.g. enabling future integration of distributed energy resources, impact on electricity prices and tariffs) and society at large (e.g. environmental costs). However, the extent to which these impacts can be included in the CBA depends on the reliability of the monetisation process. As is depicted in Figure 11, the approach proposed by the JRC for CBA of smart grid initiatives comprises several steps that can be grouped in three main stages.

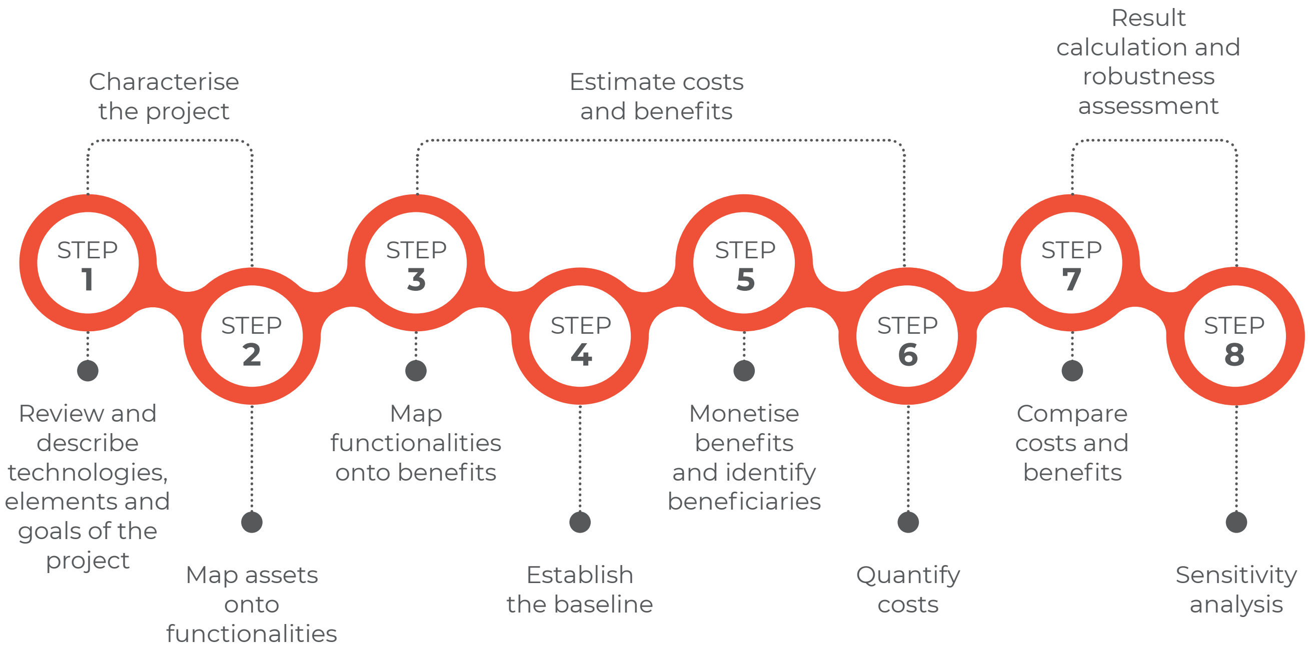


Figure 11 : Steps in the EC-JRC Cost-Benefit Analysis methodology (adapted from [4]).

The first stage in the JRC CBA methodology involves characterising the project. The project's objective, context and the main technology involved have to be identified and comprehensively described. Analysis of the context is fundamental to define the baseline and relevant economic parameters [17]. Furthermore, a deep analysis of the project's features leads to identification of the functionality enabled. The JRC guidelines provide recommendations that help the analyst map project assets onto the functionalities enabled [4], [13]. In the second main stage, the potential benefits resulting from deploying the project are identified through a mapping activity that starts with the functionalities enabled. The baseline established allows definition of the reference level at which to quantify the benefits. The JRC CBA guidelines also provide recommendations to quantify and monetise all the positive and negative impacts and understand the benefit allocation [4]. The last stage in the JRC CBA methodology concerns calculating the CBA indicators (e.g. NVP) by comparing the discounted costs and the benefits. Sensitivity analysis allows understanding of the robustness of the CBA outcome regarding changes in the values of the variables that define the baseline scenario and the monetisation of costs and benefits [4].

4.1.2 SRA BRIDGE METHODOLOGY FOR SMART GRIDS

The SRA analysis can be done for different dimensions (e.g. communication layer, function layer etc.) and if the scope of the analysis and the steps to follow are not clear the conclusions can be confusing. Furthermore, given the great number of projects funded by the European Commission that include an SRA, a common approach to performing it can be extremely useful when sharing results and comparing them.

For these reasons, the H2020 BRIDGE[1] initiative has developed some guidelines or methodology to support projects when performing SRAs, regardless of the particularities of each project, by providing common and consistent grounds. This methodology is presented in [24] and gathers the experience of different projects. It consists of four main steps:

[1] The H2020 BRIDGE initiative unites Smart Grid, Energy Storage, Islands and Digitalisation EU H2020 projects with the objective of sharing knowledge and creating a structured view of issues that can constitute barriers to innovation. It is organised in four working groups: data management, business models, regulations and customer engagement.
URL: https://www.h2020-bridge.eu/

1. **Definition of the scope of the SRA.** Which SGAM (smart grid architecture model) [23] layers and dimensions within them will be analysed: regulatory, economic, business models, stakeholders' perspectives, functionality, software scalability and replicability, ICT scalability and replicability and components.
2. **Definition of the methodology for each SRA dimension selected.** Technical analysis (e.g. functional, ICT) is usually based on simulations and the approach followed is more quantitative than qualitative, involving a sensitivity analysis by changing the critical parameters and assessing a set of KPIs specifically defined for it. On the other hand, non-technical analysis (e.g. regulatory, stakeholders' perspectives) follows a more qualitative approach and usually relies on questionnaires or interviews as main information sources to make comparisons and identify possible barriers.
3. **Perform the SRA for each dimension selected.**
4. **Extract conclusions and SRA rules/ roadmap.**

4.2 EU CBA AND SRA ASSESSMENT

The overall aim of this section is to assess the results of different CBA and SRA methodologies applied in the European context to extract conclusions for future implementations. To achieve this aim, we identified an appropriate set of European projects the CBA and SRA assessments of which could be relevant for the three case studies selected in section 3, namely Demand Response, LV Supervision and Control, and MV Grid Automation and Reconfiguration. A list of these projects and their references and use cases are included in Table 30 in the Appendix.

Moreover, after collecting information on the projects, it was analysed and processed to present it in an organised and summarised way. For this EU assessment relevant demo projects were identified for the three categories presented in Table 10. It is important to note that the projects analysed in the CBAs and SRAs are not the same, as the most relevant or comprehensive applications of both types of analyses were not always found in the same projects.

The remainder of this section is organised as follows. Section 4.2.1 provides an overview of the main concepts and the CBA methodology and analyses the use cases reported in Table 10 Section 4.2.3 also examines the use cases reported in Table 10 and describes the main characteristics of the SRA methodology. Section 4.4 summarises the section and discusses the main conclusions stemming from the CBA and SRA assessments.

Analysis		Use Cases		
		Demand response/ consumption optimisation	LV supervision and control (including AMI)	MV grid automation and reconfiguration
CBA	Financial (investor perspective)	InteGrid HEMS (Swedish demo) InteGrid DSM programme (Swedish demo) InteGrid HEMS (Portuguease demo) InteGrid Flexibility Market (Portuguese demo)	Malagrotta and Rome Smart Grid Project (AMI not included)	Malagrotta and Rome Smart Grid Project Optimal Smart MV/ LV Substations
	Economic (Social perspective)		Malagrotta and Rome Smart Grid Project (AMI not included)	Malagrotta and Rome Smart Grid Project Optimal Smart MV/ LV Substations

Table 10 : Summary of selected use cases for CBA assessment

4.2.1 EU COST-BENEFIT ANALYSES

4.2.1.1 CBA IN DEMAND RESPONSE USE CASES OF

This section analyses the impact of demand side response by describing different use cases performed in the InteGrid project [18]. Two of the use cases described are implemented in Sweden, while two others are implemented in Portugal [19]. In both the Swedish and Portuguese demos the baseline scenario considers houses without any kind of smart management. In UCCBA04, the aggregator is part of the evolutive scenario, meaning that a building cannot provide the TSO with any flexibility in the reference scenario.

The **Home Energy Management (UCCBA01)** use case implemented a HEMS called Active House in several households of different types (single apartments, 2-member apartments and family apartments). The objective of the use case was to maximise energy efficiency, leading to a reduction in household energy bills.

The **Engage Consumers in Demand Side Management Programmes (UCCBA02)** use case implemented a social network called LocalLife. LocalLife advises customers on reducing household energy bills and encourages them by showing them the importance of efficiency.

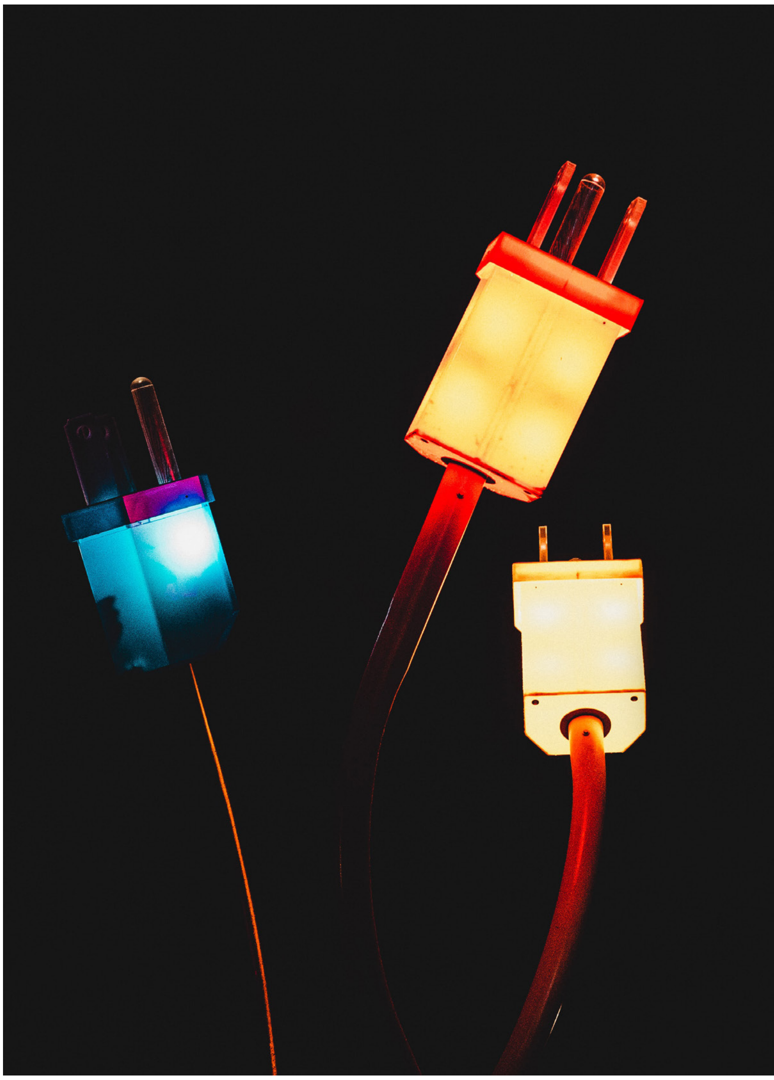
Home Energy Management (UCCBA03) also implemented a HEMS in several households to automatically manage the start-up and shutdown of various appliances. The HEMS developed enables shifting consumption by appliances to time slots when the price of electricity is lower to achieve a reduction in energy bills. There are three types of households involved in the use case: Basic, Premium and Self-generating.

The **Aggregate and communicate multiperiod behind-the-meter flexibility from LV prosumers (UCCBA04)** use case selected several buildings to participate in the ancillary services market by providing their flexibility. The flexibility comes from heating ventilation air conditioning (HVAC) systems since these systems can be switched off in certain periods of the day to provide upward flexibility.

Benefits

In UCCBA01, the benefits considered are electricity consumption reduction and CO2 emission reduction. However, only the electricity energy saving is considered a monetised benefit in the CBA. The beneficiaries are the people who pay energy bills. In all the use cases reviewed the benefits are calculated by multiplying the energy saving by the respective unitary price.

CO2 emission reduction is a social benefit. The main difference between the Swedish and the Portuguese HEMS use cases is the tariff structure. In Sweden, a flat energy price of 0.15€/kWh is used, while dynamic pricing is used in Portugal. Figure 12 shows how the HEMS shifts the appliances used to minimise the energy bill in dynamic electricity pricing. The maximum household contracted power is a constraint of HEMS optimisation.



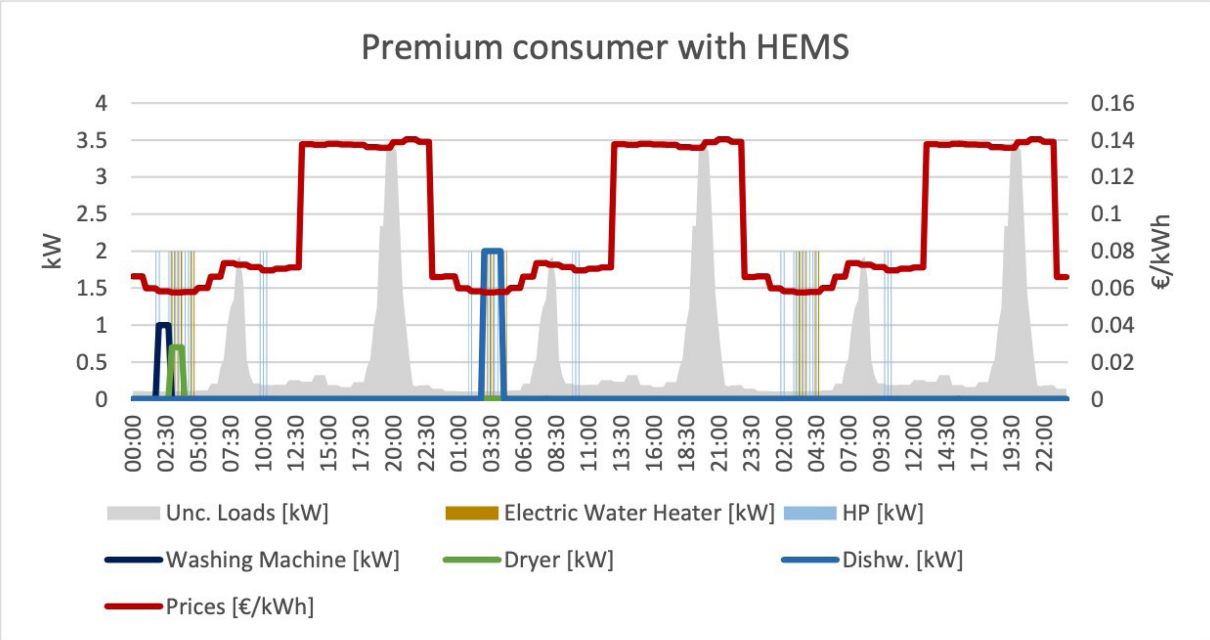


Figure 12 : Three-day adaption of the HEMS simulation results for a Premium Customer

In UCCBA04, the benefits come from the flexibility sold on the secondary reserve market (aFRR). The overall monetary benefits come from the capacity and the activated energy remuneration. The flexibility potential of the provider depends on the use of the building. Normal operation of HVAC is considered to be in the range 21-23°C. The flexibility potential is obtained through simulation. The building can offer flexibility twice a day, at 6:00 before the start of the working day and at 18:00 after the end of the working day. The benefits in this use case are reported in Table 11.

	aFRR band	aFRR energy	Total benefit
Benefit [k€]	2.1	0.879	2.9

Table 11: aFRR benefits for a building that provides flexibility

Costs

The CBAs in the use cases reviewed represent financial assessments. The costs accounted correspond to expenditures by the beneficiaries of the projects' impacts. In the Home Energy Management use case, the costs are related to the HEMS, smart home appliances and secondary equipment CAPEX and OPEX. CAPEX is the investment cost for the equipment needed to participate in DSR programmes while OPEX is related to maintenance costs and fees in DSR programmes. The UCCBA04 use case only considers the cost of auxiliary meter equipment. In this case, the control and monitoring equipment is already installed in the buildings, so only the communication equipment is needed. Although other buildings may not have a centralised thermal management platform installed, its cost is not assumed since it would be not only for selling flexibility. Costs related to other equipment enabling the building to participate in the ancillary services market, such as a VPP (virtual power plant) and a gm-hub (grid and market hub), are excluded from the CBA. It is assumed that these costs are covered by the aggregator, which is in charge of the technical viability of the solution.

Discussion and closing remarks

Table 12 presents the results of the CBA in the UCCBA01 Home Energy Management use case [19] with a discount rate of 3% and a lifetime of 10 years. A positive NPV is achieved for both single and 2-member apartments and a negative one for family apartments. This is due to energy management being harder to realise in a family apartment than in a single or 2-member apartment since the appliance activations (such as hot water use, number of washing machine uses) are more and more dispersed throughout the day and therefore harder to optimise.

Table 13 provides the results of the CBA for the UCCBA02 Engage Consumers in Demand Side Management Programmes use case with a discount rate of 3% and a lifetime of 10 years. This solution achieves a positive NPV. The single apartment cases in UCCBA01 and UCCBA02 can be compared since both scenarios assume only one person per house. The costs are higher in UCCBA01 as this solution needs more expensive tools such as smart grid appliances (Active House) while UCCBA02 only needs the LocalLife app and an e-agreement (contract). In UCCBA01, energy management is automated, leading to greater benefits. Instead, in UCCBA02, energy management is implemented manually following recommendations from the app, leading to lower benefits since the person needs to change the consumption on purpose.

Table 14 provides the result of the CBA in UCCBA03 Home Energy Management with a discount rate of 5% and a lifetime of 12 years.

The CBA shows that profitability depends on the type of customer who installs the device. Due to the low operating margin of Basic customers, the benefits observed are low. However, comparing both Premium and PV customers, it can be seen that with the same costs the benefits are much higher for Premium customers. This is because PV customers already have low prices for electricity since they consume what they generate so moving consumption to cheap time slots does not make as big a difference to the price of electricity as for Premium customers. Therefore, the best results are found for premium customers as the HEMS can manage smart appliances to achieve the biggest savings in the price of electricity.
In UCCBA03, dynamic pricing of electricity is used. Due to the great volatility, a sensitivity analysis is performed. In the basic scenario, a price reduction of at least 20.2% leads to a negative NPV. In the premium scenario, a price reduction of 58% leads the CBA to become negative. However, it should be noted that this price reduction is unlikely to happen in the near future.

	Single apartment	2-member apartment	Family apartment	Total
Number of households	43	46	44	133
Total discounted costs [€]	357	357	357	47500
Total discounted benefits [€]	463	378	216	46800
Net Present Value [€]	106	21	-142	-711

Table 12: Results of the CBA in the UCCBA01 Home Energy Management use case [19]

	Per household	Total
Total discounted costs [€]	162	8900
Total discounted benefits [€]	286	15700
Net Present Value [€]	124	6800

Table 13: Results of the CBA in the UCCBA02 use case

	BASIC	PREMIUM	PV
Total discounted costs [€/household]	543	943	943
Total discounted benefits [€/household]	680	2200	394
Net Present Value [€/household]	137.32	1300	-549

Table 14 : Results of the CBA in the UCCBA03 use case

As Table 15 shows, UCCBA04 (Aggregate and communicate multiperiod behind-the-meter flexibility from LV prosumers) shows a positive NPV with a discount rate of 15% and a lifetime of 12 years, meaning that it is a profitable solution. Based on the benefits observed, a fee from the aggregator can be assumed. A share of 50% of total income can be assumed. Although it would reduce the benefits drastically, the NPV is still positive and around €5000.

	Value
Total discounted costs [€]	6300
Total discounted benefits [€]	18300
Net Present Value [€]	12000

Table 15 : Results of the CBA in the UCCBA04 use case

To conclude, the option to provide flexibility with commercial buildings is very attractive since negative impacts in terms of comfort level are negligible. In contrast, home energy management may require profound changes in people's daily habits. It is important to highlight that engagement of people in energy efficiency programmes that do not involve any HEMS is a promising option. However, the boundary conditions and the actual customer engagement rate influence the monetary benefits that can be achieved.

4.2.1.2 CBA OF MV AND LV GRID AUTOMATION, SUPERVISION AND CONTROL

This section presents the application of the CBA methodology described in section 4.1.1 to a full-scale project (Malagrotta and Rome Smart Grid Project). The smart grid project is composed of three additive enhancer sub-projects considered as subsequent phases, which include advanced MV-grid automation, monitoring and remote control of the MV/LV grid and new management criteria for the MV grid [20]. Defining sub projects allows assessing chunk benefits and overall profitability [9], [20]. The use case includes financial and economic assessment of the project. Table 16 presents the values of the parameters that describe the boundaries in the financial and economic CBAs for the use case. The reference scenario for the CBA is a distribution network without any innovative intervention. Only planned maintenance is considered.

Parameter	[Unit]	Value	Sensitivity range
Time Horizon	years	15 - 19	
Reference year for discounting		2014	
Real Financial Discount Rate (FDR)	%/year	3%	0%±8%
Real Social Discount Rate (SDR)	%/year	2.5%	0%±5%
Inflation rate	%/year	2%	-2%±17%
Average uncertainty in the monetisation of benefits	%	3%	2%±11%
Average rate of decrease of benefits related to investments in infrastructure	%/year	5%	0%±8%
Average rate of decrease of benefits related to investments in software	%/year	1%	0%±6%
Average rate of electricity demand increase	%/year	1%	0%±16%
Emission factor	ton CO2- eq/MWhe	0.708	0.5±0.95
1 ton CO2-equivalent average price in EU ETS	€	15	0±50

Table 16 : Value of parameter boundaries in the CBA, Source: [20]

Main features	Pilot project (Malagrotta)	Rome
LV consumers involved	1200	~ 1600000
Mv distributed generation	4	~ 200
Number of HV/MV primary substations	2	~ 70
Number of MV/LV secondary substations	76	~ 13000

Table 17 : .Main features of the Smart Grid project for the city of Rome, Source: [20]

Each of the smart grid subprojects involves different assets. Table 17 provides an overview of the smart grid project dimensions. The subprojects for automation and monitoring develop advanced grid automation for fast fault detection and chronometric selectivity. This involves the installation of smart switchgears on the nodes and mutual connection through low latency radio channels. Moreover, the secondary substations are upgraded with electricity and environmental real-time measurement assets and two-channel data communication with the central information system. Remote control of LV switches is enabled by substituting or upgrading the existing switchgears. The new management criteria for MV grids subproject involves development and implementation of algorithms and software for SCADA-based state estimation to minimise electricity losses.

Once the assets involved in the project are identified, the mapping of assets into functionalities is accomplished considering the number of MV and LV users, the fault probability and expected improvements in the SAIDI and SAIFI indicators. The corresponding functionalities are automated fault identification/grid reconfiguration reducing outage times, enhanced monitoring and control of power, flows and voltages, enhanced monitoring and observability of grids down to low voltage levels, improved monitoring of network assets, identification of technical and non-technical losses by power flow analysis, system security assessment, management of remedies and safety monitoring, particularly in public areas [4].

The benefits that are included in the CBA of the Smart Grid project that correspond to the functionalities enabled or enhanced are reduced operation and maintenance costs, deferred distribution capacity investments, reduced electricity technical losses, reduced outage times and frequency, and reduced CO2 emissions [4]. The corresponding monetised benefits are regulated remuneration of CAPEX (incentives for investment in innovative solutions) and decreased costs of penalties, maintenance and fault clearance measures. Since automation and remote control and monitoring sub-projects are based on physical assets, these benefits are assumed to accrue with a 5% yearly decrease rate. The New Grid Management Criteria subproject is based on software algorithms. The related benefits would flow with a decreasing trend of 1% a year. The sensitivity analysis considers ranges for these values of 2-8% and 0-6%.

Benefit allocation is different between financial and economic CBAs. In a financial CBA, the benefits are only the quota for the investor, the cash flows realised and the costs avoided. In the CBA described in this section, the financial benefits are regulatory remunerations due to investment in innovative projects, the penalties avoided due to increase in supply quality and reduced maintenance and intervention costs due to improved fault management. Taxes are not included as recommended by the JRC. Regulatory remuneration and penalties avoided are included in an economic CBA as social benefits since they are considered welfare gains due to the expected increased security and quality of supply. Moreover, an economic CBA considers as benefits the GHG emissions avoided, which represent the main positive externality. The reduction in air pollution is due to increased energy efficiency. The new grid management criteria reduce grid losses in the range 4.33%-3.10%. This impact is appraised using the equivalent monetary value of the CO2 emissions avoided calculated considering the decreased energy need from the bulk power system and the corresponding GHG emissions.

In the pilot project, considering the size of the intervention, the benefits are considered to accrue from year 0 of project implementation. Conversely, in the scale-up CBA, since full deployment of the project lasts several years, the value of corresponding benefits grows over time until the year in which the project is fully deployed.

The costs considered in the project are the CAPEX and OPEX related to MV and LV monitoring, MV grid automation and implementation of the new MV management criteria. All the assets are considered to last until the economic time horizon of the project (fifteen years). Hence, replacement costs and the residual value of assets are not included in the CBA. Considering the deployment time of the project, the costs are spread across several years. This influences the accrual of benefits.

The results of the financial and economic CBAs for the overarching smart grid project and the subprojects it is composed of are presented in Table 18. The CBAs consider the parameters in Table 16. The financial and economic CBAs reveal that the pilot project is not profitable as a standalone project. On the contrary, the scaled-up project achieves both financial and economic viability. The result of the economic CBA is also higher due to the lower discount rate value used. The impact of this factor is higher than the monetised externalities (reduced GHG emissions). However, it is worth highlighting that the result of the economic CBA may underestimate the actual social benefits since it is impossible to account for all impacts in the CBA framework. A more comprehensive project appraisal is possible by exploiting approaches able to consider non monetised and unquantifiable impacts [4].

Assessment type	Subproject	Pilot		Scale-up	
		NPV [k€]	IRR [%]	NPV [k€]	IRR [%]
Financial CBA	Smart Grid Project	-1262	1.23	35972	16.6%
	Automation	-374	1.86	10026	12.55
	MV/LV monitoring	-456	0.61	24608	21.17
	New Management Criteria	-432	1.13	1406	12.28
Economic CBA	Smart Grid Project	-1104	1.25	39119	16.67
	Automation	-362	1.55	11033	12.55
	MV/LV monitoring	-410	0.61	26274	21.17
	New Management Criteria	-376	1.18	1688	12.74

Table 18 : CBA results of the Smart Grid Project and its subprojects (base year 2014), Source: [20]

The sensitivity analysis is performed to highlight the impact of variations and uncertainties in the values of the key parameters on the CBA results. The parameters and the corresponding value range used in the sensitivity analysis are reported in the third column of Table 16. The sensitivity analysis confirms that the pilot project is not able to generate positive financial and economic NPVs. Nevertheless, pilot projects are fundamental to develop corresponding large-scale initiatives. The scaled-up project achieves a positive NPV for the range of parameters in the sensitivity analysis. Even considering a 17% reduction in monetised benefits, the NPV is positive in both the financial and economic CBAs.

4.2.1.3 CBA FOR OPTIMAL INVESTMENT IN SMART MV/LV SUBSTATIONS

The use case described in this section highlights that a CBA-based project assessment can help regulatory bodies determine their policies in terms of incentives and performance targets for investments in the deployment of smart MV/LV substation initiatives.

Initiatives involving deployment of smart MV/LV substations determine a significant improvement in continuity of supply. However, these initiatives are capital-intensive so it is crucial to achieve a compromise between implementation costs and benefits to optimally allocate resources. The case study described in this section is an example of a methodology for identifying the optimal degree of MV/LV substation automation [21].

The assets involved in the use case described include smart and automated transformer substations. With respect to traditional substations, several additional functionalities are enhanced, such as monitoring, data analysis for autonomous decision-making, communication with other elements in the network and remote control of protection. Furthermore, smart substations perform automatic fault detection, isolation and service restoration (FDIR) in distribution networks. Therefore, faults may be quickly isolated so that the number of consumers affected by interruptions of supply is reduced, and service restoration is achieved in a shorter time for the consumers affected. The benefits related to these functionalities are mainly associated with enhanced operation and maintenance and thus increased continuity of supply.

The costs considered in the analysis are investments in upgrading MV/LV substations. The monetised benefits are savings related to increased continuity of supply. The net cost for the system is the sum of the investment in smart MV/LV substations and the cost of supply interruptions. The benefits are monetised using two different approaches: the cost of non-served energy for the network users affected and the economic incentives granted to distribution companies to achieve satisfactory continuity of supply. The first approach is the actual cost, but it can only be estimated, while regulatory incentives are actual payments to distribution companies set by the regulator. Costs of supply interruptions are assessed over a certain time period (the useful life of equipment, typically 15 years for automation projects). Therefore, costs and benefits are discounted considering a suitable discount rate.

Smart MV/LV substations involve additional costs in comparison with conventional MV/LV substations. These additional costs are related to improved protection switchgear and communications infrastructure, and the operation and maintenance of these elements. In the cost analysis, an incremental approach is employed. The automation costs for any given degree of automation are computed for the case of no automation (conventional MV/LV substations). In the use case described, the cost of automation is assumed to be linear with an average unit cost of €12,500 per smart MV/LV substation.

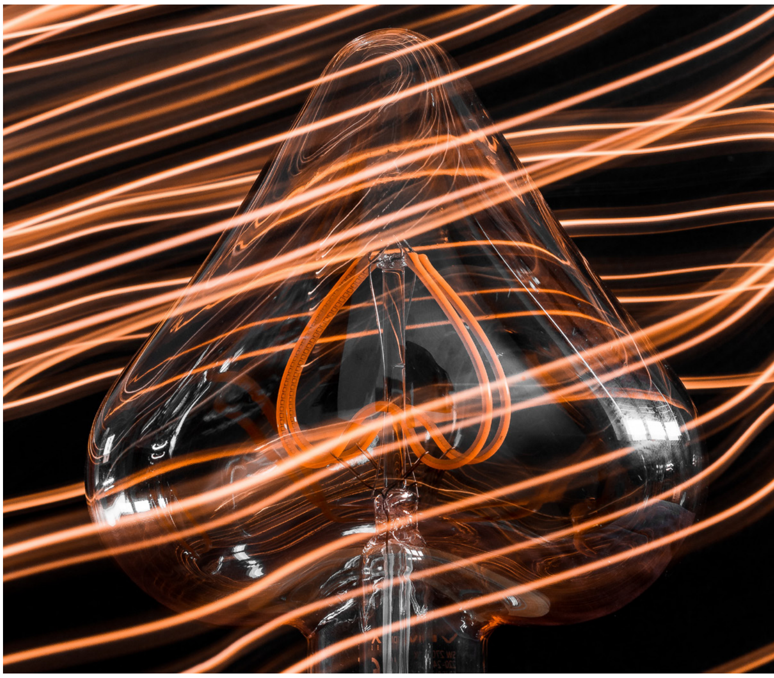
The cost of supply interruption in the system captures the economic loss caused to consumers by interruptions of supply, thus reducing the cost of non-supplied energy (NSE), also known as the value of lost load (VoLL). The cost of interruptions changes with the degree of system automation. In the case study described, the cost of interruptions for network users is calculated using equation (4.2.1).

$$C_t = \sum_i (C_{NSEi} \cdot (ASIDI \cdot Pinst_i \cdot \mathrm{LF}_i)), \quad (4.2.1)$$

where C_{NSEi} is the NSE cost, which is estimated at 3 €/kWh; LF_i is the average load factor (LF), estimated at 0.6; $Pinst_i$ is the maximum power demand; and $ASIDI$ is the average system interruption duration index.

Incremental costs are considered. The interruption cost for a certain degree of automation is the difference between the volume of NSE for a given degree of automation and the NSE for full automation. The net present value of the cost of interruptions is computed for 15 years considering a discount rate of r = 7%. The optimal degree of automation is found at the intersection point between the marginal interruption of supply cost function and the marginal cost function of automation investments.

Continuity of supply at the system level is monitored and regulated using different bonus/penalty mechanisms linked to the performance of DSOs regarding certain reliability index targets. In this mechanism, distribution companies internalise the costs of interruptions in their investment strategies. This creates an incentive to invest in improving the continuity of supply until the marginal incentive received for the improvement in continuity of supply equals the marginal cost of smart MV/LV substations. Monetisation of the benefits in the incentive-based approach considers unitary incentives associated with reducing ASIDI and ASIFI set at 1 €/kW h and 1.50 €/consumer per interruption respectively. A cap on this remuneration is set at 3% of the total annual remuneration received by the company in the previous year.



It is worth noting that the reduction in NSE is the actual benefit perceived by customers. However, from the DSO's perspective this benefit is an externality. From the DSO's perspective the direct benefits are the regulatory incentives. The payments received motivate investments in smart automation. Therefore, if benefits are monetised considering the reduction in NSE, the project appraisal can be considered an economic analysis. Conversely, if the benefits are monetised considering the regulatory incentives received by the DSO, the project appraisal is a financial analysis made from the DSO's perspective.

In the use case described, irrespective of the methodology used to monetise the benefits, the marginal cost approach is used. This approach allows determination of how much it is worth investing to increase the degree of automation. Furthermore, marginal costs are not affected by the size of the network so the results obtained for different networks may be compared.

The use case analyses an urban and a semi-urban large-scale distribution network. The main features of the two scenarios are presented in Table 19.

The benefit of improved continuity of supply is quantified in two scenarios by considering key performance indicators (KPIs): the average system interruption frequency index (ASIFI) and the average system interruption duration index (ASIDI). The values of the KPIs in the two scenarios are reported in Table 20 .

	Urban	Semi-urban
Number of MV/LV substations	278	62
MV/LV installed capacity (kVA)	170320	31950
Number of MV consumers	76	43
Number of LV consumers	60686	13925
Total contracted power (kW)	418956	116198
MV network length (km)	131	165
LV network length (km)	122	38
ASIDI (h)	0.68	1.16

Table 19 : Characteristics of the reference networks, Source: [21]

Degree of automation [%]	Urban		Semi-urban	
	ASIDI (h)	ASIFI (int)	ASIDI (h)	ASIFI (int)
0	0.68	0.93	1.16	1.59
10	0.38	0.5	1.05	1.28
20	0.23	0.26	0.92	1.11
30	0.15	0.15	0.85	1.01
50	0.08	0.08	0.75	0.89
70	0.04	0.04	0.69	0.8
100	0	0	0.63	0.71

Table 20 : Quantified benefits of improved security of supply for the two scenarios in the use case. Source: [21]

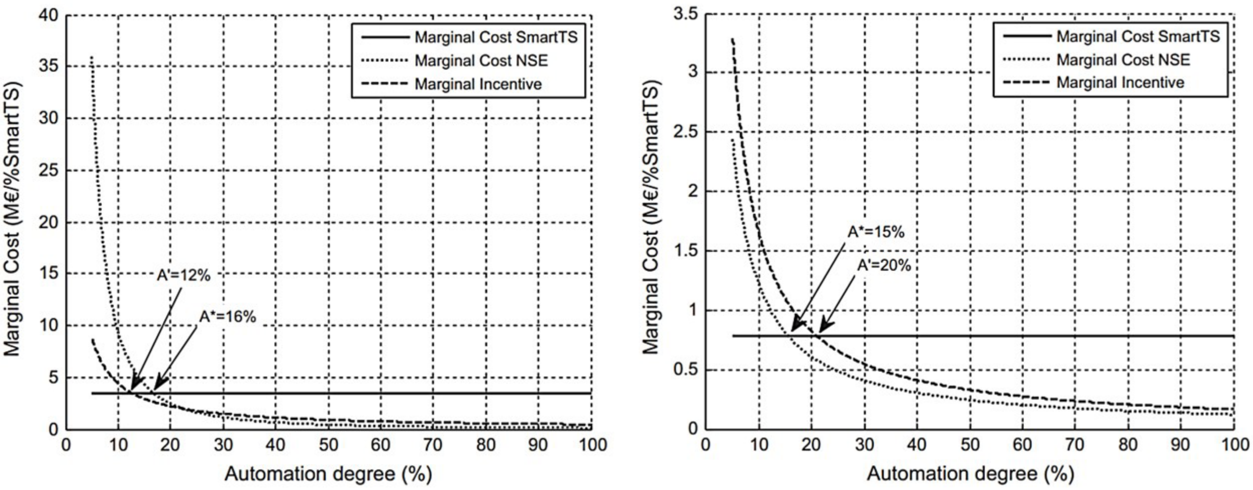


Figure 13 : Outcome of the appraisal of smart automation in the urban (a) and semi-urban (b) scenarios.

Figure 13 presents the outcome of the appraisal for smart automation in the urban and semi-urban scenarios. For each scenario, the marginal curves of the investment cost (smart TS cost), the cost of NSE and regulatory incentives received are depicted. In addition, the relevant intersection points are highlighted to make evident the optimal degree of automation corresponding to the different benefit monetisation approaches.

In the semi-urban scenario, the optimal degree of automation is 12% if the benefits considered are regulatory incentives (in the financial analysis). In comparison, the optimal degree of automation is 16% if the benefits are monetised as the marginal cost of NSE (economic analysis). In the urban scenario, the optimal degrees of automation are 15% and 20% in economic and financial analyses respectively. According to these results, in the urban scenario the regulatory payments to the DSO do not incentivise enough investment to reach the optimal degree of automation. On the contrary, in the semi-urban scenario, the payments received by the DSO incentivise investment to reach a degree of automation higher than the expected optimal value. The different values of NSE and regulatory incentives influence the CBA results in the two scenarios. The load-based indicators used to monetise security of supply reflect that in semi-urban areas customers are assumed to have a higher average contracted power value.

4.2.1.4 EU CBA CONCLUSIONS

Project assessment is fundamental to devise and select investment initiatives that promote optimal allocation of resources and improve social welfare. CBA is the most acknowledged approach to project assessment. In both financial and economic CBAs the project benefits are accounted for in monetary terms and compared with the monetary cost required to develop the initiative. The result of the CBA may underestimate the actual impact of initiatives. However, if the analysis is conducted systematically the CBA results represent a solid basis on which to make decisions. Nevertheless, an economic CBA should be complemented with assessing non-monetary and non-quantifiable impacts and externalities (e.g. social and health impacts, contribution to policy goals) to enlarge the social perspective. Like the ones produced by the JRC, several CBA guidelines have been proposed to enhance as much as possible the ability of CBA to capture the particularities of smart grid initiatives and standardise the assessment procedure.

The CBA approach developed by the EC JRC is a cornerstone for decision-making in the smart grid sector. The entire procedure is widely used in European Union funded projects and part of it or some aspects of it are also employed as a basis for framing cost-benefit appraisal in research activities. However, the reliability of the data available influences the reliability of the appraisal outcome. Ideally, the design and development of initiatives have to be coordinated with appraisal activities to make key metrics available to assess relevant project impacts. In any case, assessment of the financial and social profitability of projects is fundamental to decide which initiatives to invest in. Even if pilot projects may have negative CBA results, these initiatives are essential to develop corresponding large-scale initiatives. The combination of CBA with SRA allows results obtained from pilot projects to be extrapolated and ex-ante understanding of the financial and social viability of large-scale initiatives. CBA has been proven to be a fundamental tool in defining strategic policies and tuning regulatory incentives.

CBAs of demand response use cases aids definition of business cases to obtain flexibility from third-party providers. The existence of a monetary incentive fosters participation by electricity customers in demand side response programmes. The CBA of use cases presented in section 4.2.1 highlights the conditions under which households and commercial customers can profit from flexibility provision. The use cases presented formalise different approaches to procuring and remunerating flexibility and appraising the impact of boundary conditions.

Initiatives concerning MV and LV grid automation, supervision and control involve upgrading network infrastructure, which produces benefits for the DSO which invests and customers connected due to increased security of supply. The use cases described in section 4.2.1.2 regard application of the EC JRC CBA to smart automation pilot projects propaedeutic for corresponding large-scale implementation. Appraisal of the pilot project provides necessary inputs for appraisal of the large-scale initiative. The outcome of the corresponding financial and economic CBAs highlights the profitability of the initiative and its sensitivity to uncertainties in the future scenario. The CBA approach described aids identifying the benefits and externalities that stem from project development. The use case described in section 4.2.1.3 provides a CBA-based assessment of the impacts of upgrading distribution substations. Comparing the costs and the economic and financial benefits considering several incremental upgrading scenarios allows determination of the optimal degree of automation for a distribution network. This assessment help regulatory bodies to optimally set incentives to remunerate DSO investments to achieve more efficient and secure distribution grids.

4.2.2 EU SCALABILITY AND REPLICABILITY ANALYSIS

Analysis		Use Cases		
		Demand response/ consumption optimisation	LV supervision and control (including AMI)	MV grid automation and reconfiguration
SRA	Functional	German demo in InterFlex, Portuguese demo in InteGrid, Swedish demo in InteGrid.	Swedish demo in GRID4EU, Austrian demo in IGREENGrid	German demo, Spanish demo and Czech Republic demo in GRID4EU
	ICT	German demo in InterFlex, Portuguese demo in InteGrid.	Portuguese demo in InteGrid	
	Regulatory Framework	Cluster 2 in InteGrid	Swedish demo in GRID4EU	German demo, Spanish demo and Czech Republic demo in GRID4EU
	Stakeholders Perspective	GRID4EU SuSTAINABLE	GRID4EU	GRID4EU

Table 21 : Summary of selected use cases SRA assessment.

4.2.2.1 SRA OF DEMAND RESPONSE USE CASES

Technical SRA

Functional : For functional SRAs, two types of DR use cases can be distinguished in EU projects according to their objectives:

- Use cases focused on DSO services, using controllable loads to provide congestion management services. For example, the German InterFLEX demo tries to control residential night storage heaters and heat pumps to increase network hosting capacity.
- Use cases focused on grid users, using price signals and home automation systems. For example, the Portuguese and Swedish InteGrid demos considers the use of HEMS. Apart from providing flexibility for the grid, the focus in this type of use case is on reducing consumers' energy bills.

An additional type of DR use case would be behavioural DR, which is based on developing behavioural strategies to promote and improve energy efficiency. However, SRA of this type of use case, which involves human interaction, is usually too complex to conduct without having previously tested the solution in the field.

A functional SRA of DR is usually based on simulations (load flows) and follows a quantitative or a mixed (quantitative-qualitative) approach. Depending on the type of use case, the parameters in the sensitivity analysis and the scenarios simulated vary. Therefore, the KPIs that better evaluate the use case and the conclusions may be different.

Table 22 summarises the main characteristics and lessons learned from functional SRA of the selected DR use cases.

Project demo	DR devices	Sensitivity parameters	KPIs	Main lessons learned
InterFLEX German demo	• Night storage heaters (NSH) • Heat pumps (HP)	• Penetration of NSH, HP and solar PV. • Seasonality	• % increase in hosting capacity • % flexibility power available • % successful customer recruitment • % technologies leveraged (active participation)	• Seasonality must be considered to design incentives. • DR from NSH is better than from HP to reduce network loading. • With 50% penetration of flexible loads, network violations were still detected
InteGrid Portuguese demo	• HEMS	• Number/location of HEMS • N° loads controlled by HEMS • RES penetration • Network size and R/X ratio • Presence of OLTC and storage control. • Availability of historical data	• Peak demand reduction ratio: 4% with PV panels • Ratio between min. and max. daily demand: 1% with solar PV • Electricity cost per kWh in DR • Amount of self-consumption: 57% on average, with HEMS	• HEMS is good for flexibility in resistive networks. • The location of the HEMS is important; it is better at the end of the feeders for voltage control. • The quality level of historical data is not a barrier. • Real-time operation is not significantly affected by the n° of HEMS. • HEMS contribute to significant power loss reduction (maximum of 4.26%) in networks with high DER penetration.
InteGrid Swedish demo	• HEMS	• Type of household • N° of HEMS • Type of signal • Response rate	• Peak load reduction: 5% on average. • Energy use reduction: 10% on average. • Self-awareness of household energy used (surveys)	• Single households are more flexible for DR. • Incentives could be based on the type of household. • Price signal is more reliable. But the environmental signal has more potential impact on load reduction. • Incentives require compatibility with household comfort

Table 22 : Summary of SRAs of different types of DR use cases in EU projects

Use cases focused on DSO services

As was mentioned previously, in the German InterFLEX demo the purpose of flexible demand was to provide LV congestion management to increase the network hosting capacity for distributed generation. In this case, **input data** to build SRA simulations consisted of grid characteristics, load profiles (including flexible loads) and PV production curves.

The parameters the **sensitivity analysis** of which would provide valuable information are those related to the location and degree of penetration of the flexible loads used in the DR use case in combination with the penetration and location of DG resources. In the German demo, the flexible loads were residential night storage heaters (NSH) and heat pumps (HP) controlled by a smart grid hub. The analysis included different combinations of solar PV, NSH and HP and provided the following conclusions [25]:

- **Controllable devices:** Control of NSH proved to be better at reducing network loading than control of HP, so the DSO would have to ensure enough participation of demand.
- **Penetration level:** Even with 50% penetration of these controllable devices in households, some network violations were still detected (e.g. maximum line loading). In general, the analysis shows difficulty in achieving an optimised balance between demand response and feed-in management even if the strategies have been designed to work together.
- **Seasonality:** Due to the thermal nature of the devices used in the German demo, seasonality was also considered relevant in the analysis (replicability). There was a big seasonality impact in winter that should be considered by the DSO even when DR is used. To tackle this, it was advised to develop season-based flexibility incentives.

To assess the impact of the DR scheme implemented in the project, the network hosting capacity was considered a KPI together with other KPIs evaluating flexibility (% flexibility power available in a reporting period) and demand participation (% of successful customer recruitment and active participation by measuring the % of technologies leveraged).

Use cases focused on grid users

In the Portuguese and Swedish InteGrid demos [26], flexibility is not provided by direct control of loads as in InterFLEX. In these cases, a HEMS acts as an aggregator of different consumption devices in a household to provide the LV grid with flexibility and reduce energy bills.

The analysis of the Portuguese demo is more focused on the provision of flexibility. The **input data** for the simulations consisted mainly of grid characteristics, and it was assumed that for each time period the flexibility provided by the HEMS could reach 10% of consumption (pessimistic assumption).

To assess the impact of HEMS, the main parameters in the **sensitivity analysis** were the number and location of consumers equipped with HEMS and the number of devices that these HEMS can control. The scenarios also included the tariff used. Other parameters considered were the rate of RES penetration and the network size. To assess replicability, factors such as the presence of alternative flexibilities (e.g. OLTC, storage), the R/X ratio and historical data availability were also considered. The following conclusions can be extracted from the sensitivity analysis, [26]:

- HEMS can offer good control capabilities for voltage control and imbalance reduction in resistive networks and can also enable significant RES hosting.
- **Impact of HEMS location:** The location of the HEMS was found to have a significant impact on performance. DSOs should try to engage customers that are close to areas with the highest potential for voltage problems, commonly at the end of feeders.
- **Flexibility provided by HEMS:** When the

HEMS is at the end of a feeder, a high number of controllable HEMS are present or the network is large, the decrease in power losses as a result of exclusive use of HEMS flexibility was greater than that achieved through combined use of HEMS and energy storage in the network. Only using HEMS flexibility, power loss decrease varied from 0.15% (HEMS at the end of a feeder) to 4.26% (high integration of DER in the grid).

- **Real-time operation:** It is interesting that the computational burden in the LV controller did not critically increase when increasing the number of HEMS, so even in this case real-time operation would be possible.

- **Forecast error:** In terms of replicability, the quality level of the historical data available (which affects the forecast error) was not considered a barrier.

Different KPIs were defined to assess the performance of the Portuguese demo,:

- The peak demand reduction ratio (comparison between before and after implementation). If the participant had PV panels installed the average reduction was 4%, whereas if the participant did not have PV panels there was no reduction in the peak load.

- The ratio between the minimum and maximum demand in a day. The average value of this KPI was 13% when there was no solar PV and 1% when there was solar PV. Without customer engagement with the HEMS, load distribution over the day cannot be optimised by the system on its own.

- Demand Response: electricity cost per kWh to check flexible demand optimisation of the energy plan.

- Amount of self-consumption achieved. On average, 57% of self-consumption was achieved in the demo thanks to implementation of a HEMS.

On the other hand, the Swedish InteGrid demo [26] tried to determine how the number of HEMS and the signal type affect the overall peak load and demand in a distribution network. Apart from grid characteristics, the **input data** included demographic demand data (e.g. type of household) and signals sent to consumers.

In consonance with the objective of the use case, the parameters to change in the **sensitivity analysis** scenarios were the type of household (single, couple or family), the share of households with HEMS, the type of signal (price or environmental) and the response rate.

The main results of this analysis were [26]:

- **Impact of the type of household:** Single households have a more flexible routine to respond to DR signals than couple and family households. However, family households are larger consumers and their impact should also be considered. The DSO could try to implement different incentives according to household type.

- **Impact of response rates:** The increase in the share of households with HEMS showed that overall network electricity consumption could be reduced by up to 10 kW (~6% of the load) with 100% of HEMS in the network. The analysis was also carried out for different response rates and showed an average decrease of around 680 kWh (~1 %) in monthly energy consumption with a response rate of 10% and 6230 kWh (~11 %) with a 100% response rate. Figure 13 shows the impact of different response rates on the electricity consumption curve in two different days in April. As can be observed, most of the energy savings would be achieved during off-peak hours.

- **Impact of the type of signal:** Despite price signals proving to be more reliable (average reduction of 15 kW, maximum of 79 kW), environmental signals had a larger potential (average reduction of 3 kW, maximum of 90 kW) load reduction. Since this type of DR scheme requires customers equipped

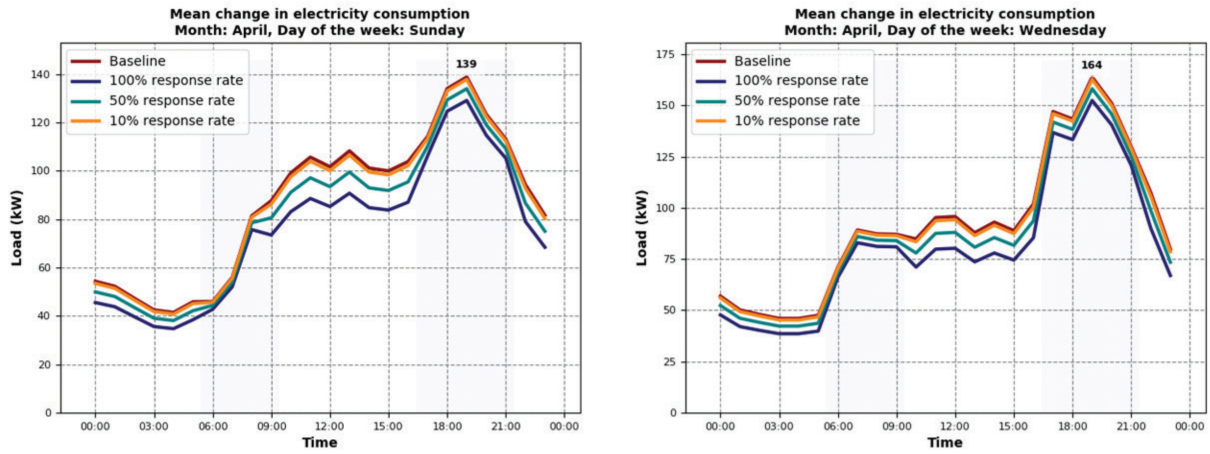


Figure 14 : Impact of the response rate in two different days in April. Source:[26]

with HEMS to have some discipline, the incentives should be prolonged over time and compatible with overall household comfort. In any case, the DSO must consider the possibility of not enough responses to signals.

The following **KPIs** were used in this use case to evaluate performance:

- Peak load reduction. On average, 5% of peak load reduction was achieved.
- Energy use reduction. On average, 10% of energy use reduction was achieved.
- Self-awareness of household energy used (based on surveys).

ICT

An ICT SRA is usually applied to the entire ICT architecture that is implemented in a demo site. This means that due to its complexity a specific SRA of the ICT used in a DR use case (i.e. devices on customer premises behind the meter) is not usually carried out, is limited to smart metering or the conclusions are presented at a high level even when a specific scenario is considered in the overall analysis. This was the case of the ICT SRA of the German InterFLEX demo, in which communications with flexible loads were routed through a smart meter. Conclusions regarding DR are limited to recommendations to use plug&play devices and correct dimensioning of the smart meter gateway to support a potential increase in the data flow processed on the customer side.

However, although the SRA is not available, different ICTs for DR can be listed. Multiple ICT architectures for residential DR have been proposed in the literature [27] and the different technologies can be enumerated at a high level. In any DR scheme, three data domains can be identified [28]: the smart meter domain, the internet domain and the home area network (HAN, gateway to the internet/smart meter domain for controllable loads or HEMS). Neighbourhood area networks (NANs) and wide area networks (WANs) may also be considered to enable DR. Two types of technologies are distinguished: wired and wireless technologies [27].

Wired technologies such as fibre optic, DSL and coaxial cable are usually used in WAN and NAN domains due to their large coverage range and high data rate. Power line communications (PLC) can be used in HANs (HomePlug) and in NANs (Narrowband PLC).

Wireless technologies such as cellular or satellite should not be employed due to expensive implementation. Other technologies such as Z-wave, Bluetooth and Zigbee have a lower data rate and a short coverage range so they are only appropriate for HANs. Although Wi-Fi provides a good data rate and coverage range, channels are subject to noise. On the other hand, WiMAX could be a good wireless communication technology appropriate for NANs in terms of data rate and coverage.

In the Portuguese InteGrid demo, for example, Zigbee was used for communication between the HEMS device and the smart meter and smart plugs, Wi-Fi to communicate with smart appliances (i.e. controllable devices) and Wi-Fi/ Ethernet to connect with the internet router.

Non-Technical SRA

Regulatory framework

How different market mechanisms and the interaction between system operators and consumers are regulated may constitute a barrier or a facilitator in replication of a DR demo. Therefore, a regulatory SRA is usually carried out to focus on regulation in the countries participating in the corresponding project.

The first common step in a regulatory SRA is to identify which regulatory topics are relevant in the DR use case that is being studied. These topics should then be characterised in terms of different alternatives and compared to successfully assess the replicability and scalability potential of the solution.

One general regulatory topic is smart metering. The existence of advanced metering infrastructure (AMI) is generally considered key in implementation of DR schemes [25], [29].

However, apart from this common regulatory topic, depending on the purpose or service that DR is expected to provide, regulatory topics may vary. One example can be found in InteGrid, where the Portuguese demo considered the provision of flexibility in the LV grid by residential consumers (HEMS).

In this case, some relevant regulatory topics are ones related to local flexibility mechanisms in place and the type of incentives DSOs receive to reduce energy losses. What regulated charges and retail tariffs exist is very relevant in DR, also since they can provide price signals (i.e. incentives) to consumers or weaken these incentives if the regulated charges and taxes are high or show no or little time discrimination. The principal regulated charges that can distort DR are ones related to policy costs (e.g. extra remuneration for RES) and reducing them has proven challenging in Europe. Regarding prices, dynamic prices that follow hourly energy prices could be the most appropriate for successful implementation of DR using HEMS [30].
Figure 15 shows the specific regulatory questions that were assessed (maturity level) in InteGrid for eight participant countries. As can be observed, the UK's and Slovenia's regulations on charges and retail tariffs were found to be the most suitable to incentivise DR, although they still need improving.

Description	Regulatory topic	Key regulatory question	Maturity level							
			PT	SI	SE	ES	AT	UK	IT	DE
Flexibility Management for Optimized LV Network Operation	Local flexibility mechanisms	Are DSOs enabled by regulation to procure flexibility from grid users to support grid operation?	1	0	0	0	2	4	0	3
	Incentives for the reduction of energy losses	Do DSOs recieve (Strong) economic incentives to reduce energy losses?	2	4	4	2	3	1	4	NA
		Is the impact of DER and smart grid solutions considered when setting baseline / target levels for losses?	1	2	2	2	1	NA	3	NA
	Regulated charges and retail tariffs	Are taxes and/or other regulated charges distorting flexibility incentives embedded in the tariffs?	1	3	2	2	2	3	2	0

Figure : 15 Regulatory maturity assessment of InteGrid's cluster 2 (which includes provision of flexibility by DR). Assessment for eight participant countries. [2] Source: [30]

[2] Maturity level: 0-red: current regulation prohibits or prevents implementation; 1-orange: current regulation does not explicitly prohibit/prevent implementation but fails to promote it effectively; 2-yellow: current regulation enables implementation but regulation is still immature; 3-light green: current regulation enables implementation and some advanced regulation is in place but is still not fully developed; and 4-dark green: regulation enables and promotes implementation.

Stakeholder perspectives

For successful implementation of a DR scheme, besides the corresponding technical analysis and regulatory assessment, stakeholders' opinions on possible barriers and how scalable or replicable they consider the DR solution to be must also be considered.

First, relevant stakeholders must be identified. In addition to the perspective of the TSO and DSOs, which are relevant in most smart grid use cases, the perspectives of suppliers/aggregators, regulators, manufacturers, software providers and consumers can be important when considering implementation of a DR scheme [29].

Once the relevant DR stakeholders have been identified, the methodology that is commonly followed is to ask for stakeholder perspectives in a survey (i.e. survey-based method), usually only of a single stakeholder group or the project participants. These are then presented in the form of aggregated answers.

This was the methodology followed in both the GRID4EU and SusTAINABLE EU projects. In the case of GRID4EU [31], the stakeholders could select three factors they considered the main barriers to general implementation of DR (in order of importance). As Figure 16 shows, the main factors were considered to be insufficient compensation and a lack of awareness of retailing alternatives, whereas data privacy was not considered an issue. When asked about the means of communication that would be the best to contact consumers and engage them, the responders considered that a website or an in-home display would be the best options.

In SusTAINABLE [32], the analysis is not as general as in GRID4EU and focuses on the scalability and replicability of the specific use case of implementing a virtual power plant (VPP) that includes DR resources. The survey found that all the respondents considered the VPP scalable with minor modifications for residential, commercial and industrial customers. However, the stakeholders considered there were high or very high barriers related to unwillingness of customers to provide DR, to the current regulation of ancillary service markets and to existing communication infrastructure, among others, as shown in the figure 17.

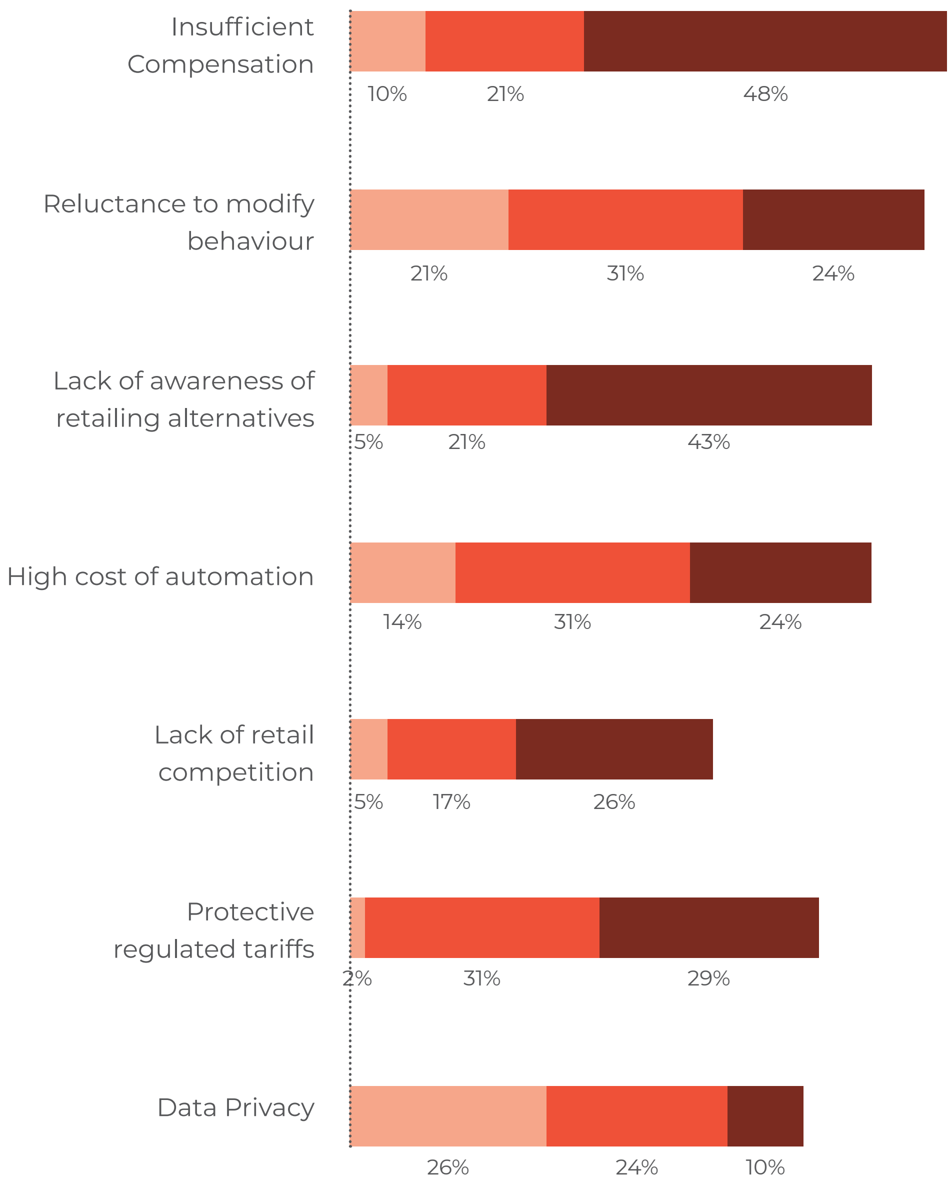


Figure 16 : GRID4EU stakeholder perspectives on factors limiting implementation of DR. Brown: % of stakeholders who selected it as 1st answer, orange: 2nd answer, Light Orange: 3rd answer. Source: [31]

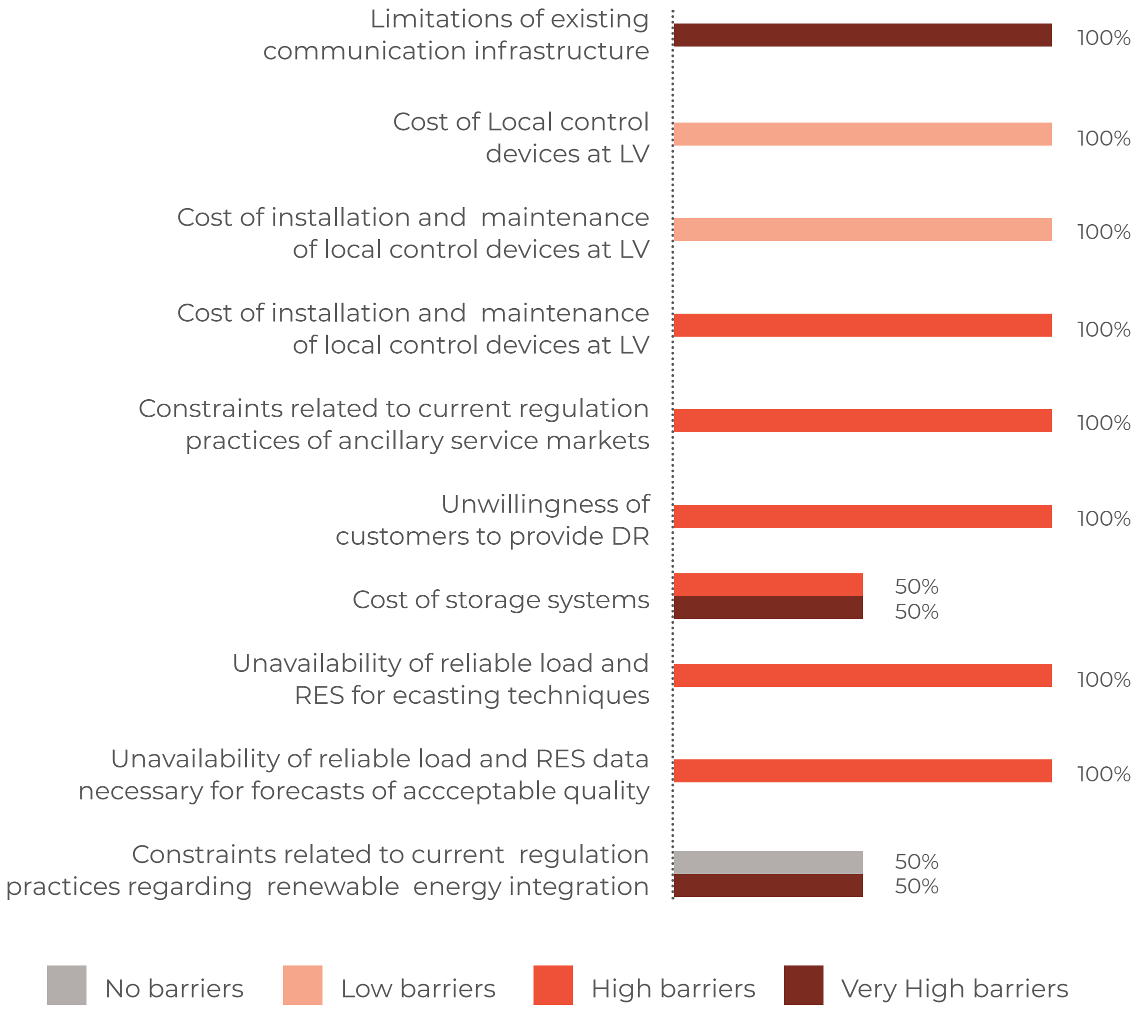


Figure 17 : SusTAINABLE stakeholder perspectives on scalability and replicability barriers for the implementation of VPP (including DR). Source: [32]

4.2.2.2 SRA OF LV SUPERVISION AND CONTROL USE CASES

Technical SRA

Functional : Depending on the solution implemented, two types of analysis can be distinguished for these use cases:

- Focused on LV supervision, analysing where and under what conditions operational problems arise so that network monitoring would be needed. This was the approach followed in the Swedish GRID4EU demo

- Focused on LV control. If the main network problems have already been identified and supporting monitoring infrastructure is assumed to be deployed, the impact of different control solutions on the network can be studied. The analysis carried out of the Austrian IGREENgrid demo is a representative example of this approach.

Table 23 presents a summary of the main characteristics and lessons learned in the selected LV monitoring and control use cases.

Project demo	Scope	Sensitivity parameters	KPIs	Main lessons learned
GRID4EU Swedish demo	• Operational problems in LV networks. • Effects of different loads on phase unbalance that justify the implementation of LV monitoring solutions (e.g. AMI)	• Type of network. • DER characteristics (size and location of DG). • Loading of the network. • Level of EV penetration.	• Loss factor. • N° buses experiencing over-voltages.	• The effects on power losses must be monitored in heavily-loaded unbalanced networks. • Implementation of EV slow-charging strategies and DR schemes may mitigate the effects on power losses of EV slow-charging infrastructure (loss factor ranging from 2 to 3.8). • Moderate levels of PV (50-75%) are better, in terms of losses, than very high or very low shares of PV.
InteGrid Portuguese demo	• Voltage control solutions (VoltVar control VVC, Wide Area Control WAC)	• Type of voltage control solution implemented. • Installed generation (solar PV)	• % increase in network hosting capacity.	• There is a high potential of voltage control solutions in voltage-constrained feeders in rural areas which are not overloaded. • The average increase in hosting capacity when WAC is implemented is higher (250%) than with VVC (16%), but its deployment is more limited (in less than 30% of feeders versus 70% for VVC). • The combined solution of WAC and VVC resulted in an average increase of 340% in hosting capacity. • In a network with non-homogeneous penetration of PV, the hosting capacity provided by VVC might be enough for actual requirements.

Table 23. Summary of SRAs of different types of LV monitoring and control use cases in EU projects

Use cases focused on LV supervision:

In the analysis done for the Swedish demo in the GRID4EU project, the objective was to evaluate the grid (e.g. effects of phase unbalance, penetration of EVs, etc.) for implementation of AMI to detect faults and increase the number of new DER units connected. For this analysis, the **input data** were different representative LV networks (rural and semi-rural) in which all the consumption is residential and follows the same pattern.

The **sensitivity parameters** were ones that determine the type of network (i.e. grid characteristics) and mainly DER characteristics (e.g. size and location of DG), network loading and the level of EV penetration.

According to the objective of the use case, the KPIs that were used to evaluate the different scenarios in the analysis were the loss factor (main indicator) and the number of buses experiencing over-voltages.

The **analysis** in [29] was focused on effects of phase imbalance on power losses in the network since both EV slow-charging points and PV units usually have a single-phase connection to the LV grid and residential loads are not commonly triphasic. The main results of this analysis were:

- **Impact of loading:** In an unbalanced network increasing the loading level also increases power losses, ranging from 1.3 to 3.9 times the losses that a balanced network would have. Therefore, the effect of unbalance, which also affects voltages and the hosting capacity of the network, must be specifically considered in heavily loaded networks with long overhead feeders.

- **Impact of slow-charging points for EVs:** Increasing penetration of slow-charging EVs (up to 20%) had a larger effect, ranging from 2 to 3.8 times the losses in a balanced network. By implementing charging strategies and related demand response schemes, this effect could be partially controlled. On the other hand, fast charging points (i.e. typically triphasic) would not represent a risk.

- **Impact of PV penetration:** It is interesting that moderate levels of solar PV penetration (between 50% and 75%) reduce the effects on losses driven by network unbalances, whereas a high share of PV (e.g. 100%) drastically increases them, up to 7.7 times the losses in a balanced network. A high share of PV may also produce over-voltages if generation does not match demand, limiting network hosting capacity, mainly in longer lines.

Therefore, from the Swedish GRID4EU demo it can be concluded that if unbalance cannot be avoided LV grid monitoring and control solutions would be more useful in unbalanced networks with a high (or low) share of DG, heavily loaded networks and ones with high penetration of EV slow-charging points. AMI functionalities such as voltage monitoring and phase-detection (through algorithms applied to smart meter data), would be extremely useful in control of unbalanced LV networks.

Use cases focused on LV control:

In contrast to the scope of GRID4EU SRA, in the IGREENgrid project [33] the analysis is focused on the impact that different voltage control solutions may have in some Austrian LV networks (Austrian demo). The decentralised voltage control solutions considered in IGREENgrid were:

- VoltVar Control (VVC). The voltage is controlled through local control of distributed RES (active and reactive power control of solar PV).

- Wide Area Control (WAC). The voltage is controlled through use of OLTC transformers based on field measurements and data from smart meters.

- Combined implementation of WAC and VVC using field measurements and data from smart meters.

In the analysis, the **input data** consist of two representative Austrian DSOs with DRES (solar PV) networks (high share of rural). The load and generation data were used to generate Monte Carlo samples for probabilistic load flow computations. An available voltage band of ±10% [34] and a maximum allowed loading of 100% in the case of reverse power flow were assumed.

The **sensitivity analysis** consisted of modifying the type of voltage control solution that was implemented in constrained feeders and evaluating the resulting percentage increase in the network hosting capacity (KPI). This was done by increasing the installed generation until the network is constrained again with the solutions already implemented, and assuming a homogeneous distribution of PV penetration on each feeder. The main conclusions of this analysis were [33]:

- Impact of voltage control solutions: Despite the VVC solution being able to be implemented in more than 70% of voltage-constrained feeders, its impact on network hosting capacity would be very low, with an average increase of just 16%. On the other hand, the WAC solution could be implemented in less than 30% of constrained feeders but its impact would be considerably higher, with an average increase of 250% in hosting capacity. The combined WAC and VVC solution allowed an average increase of 340% in hosting capacity. Therefore, the use of OLTC transformers seems to be crucial to achieve high hosting capacity in the network. Figure 18 shows the average increase in hosting capacity and the variation for each voltage control solution.
- In general, the results show a high potential of the solutions considered in networks with a high share of rural areas. They should be applied in feeders which are voltage-constrained (the main constraint in LV networks) and only if maximum loading has not been reached.
- Despite these results, for non-homogeneous penetration of PV in the network the hosting capacity provided by the VVC solution might be enough to meet the actual PV potential of the network.

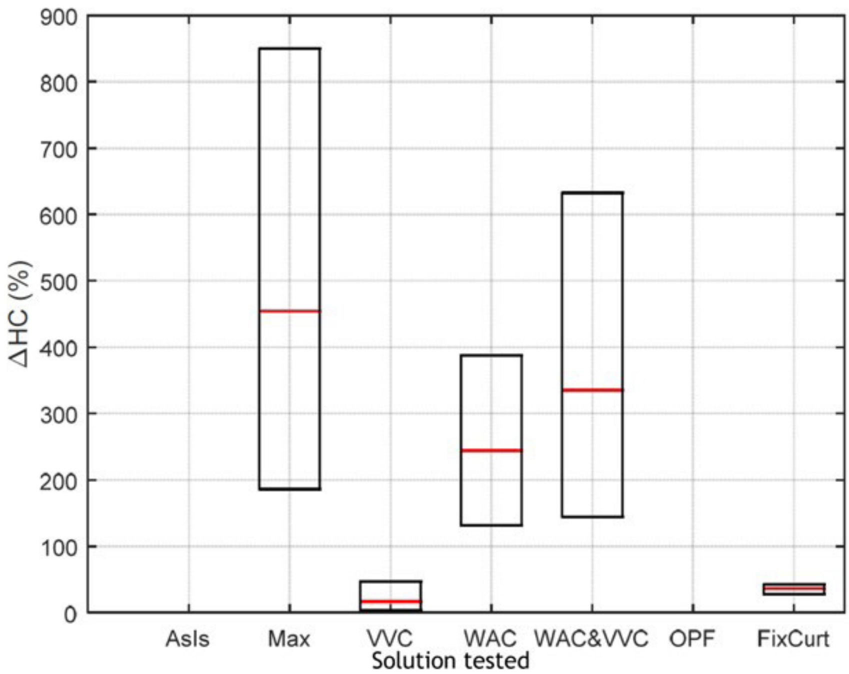


Figure 18 : Hosting capacity (HC) increase for each voltage control solution for all feeders that benefit from them. 'AsIs' indicates a network without solutions or reinforcements and 'Max' indicates the expected result assuming 100% observability and controllability. Source: [33]

ICT

ICT architecture that enables smart grid functionalities is usually developed ad hoc for demos and for the DSOs which will implement them, considering available communication technologies so that interoperability with other DSO systems can be guaranteed.

Although no two ICT architectures are the same, the conclusions extracted from an ICT SRA analysis may be illustrative.

In the Portuguese InteGrid demo, the DR use case of which was explained in the previous DR section, the objective was to operate the LV grid using the flexibility available. For this, a low voltage controller (LVC) and a low voltage state estimator (LVSE) were employed to manage the available flexibility based on grid measurements provided by different devices. An SGAM representation of the entire ICT architecture (component layer) of the Portuguese demo is presented in the table below, with the placement of the LVC and LVSE (disruptive elements for LV control and monitoring) circled in red.

The analysis in InteGrid considered reliability (cybersecurity, protocol robustness/reliability), the computational resources available/needed (storage, processing speed, channel capacity and latency) and manageability (configuration effort and level of automation) of the components. These attributes had to be characterised and classified by the partners.

Starting with reliability, the analysis only found that the LVC and LVSE should improve cybersecurity to adapt to the DSO's requirements. In terms of processing speed, it is recommended to follow a cluster approach with the LVC and LVSE, which adapts better to large deployments, instead of dedicated machines. This ICT system requires human interaction for configuration and integration of components, so for manageability plug&play devices are recommended instead. To increase the reliability of the LVSE application, it was advised to place it in the cloud and use it when necessary [26].

Regarding communication links, high latency in the links responsible for transmitting monitoring data (links 4, 6 and 62 in the table below) would have a significant impact on the entire network performance. The technologies used in these links are shown in the table below.

The scalability analysis concluded that to make real-time decisions based on monitoring data in large networks technology with a higher data rate may be needed. For example, the round-trip time calculated for the smart meter data is around 2 seconds, which may not be enough for this real-time operation. Use of PRIME version 1.4, which is under development, will include a quality of service mechanism and will increase the transmission speed, which will be useful to manage the increasing number of smart meters. The ICT SRA of InteGrid concluded that the best application protocols were found to be OPC UA for real-time data, SOAP for non-continuous data and DLMS/COSEM for meter data [26].

Link ID	Application Protocol	Data Structure	Communication Technology
4	IEC 60870-5-104	According to IEC104	TCP/IP
6	RS232/RS485	Proprietary	Modbus
62	DLMS/COSEM	DLMS	PLC PRIME

Table 24 : ICT technologies used in some of the links in the Portuguese InteGrid demo. Source: [26]

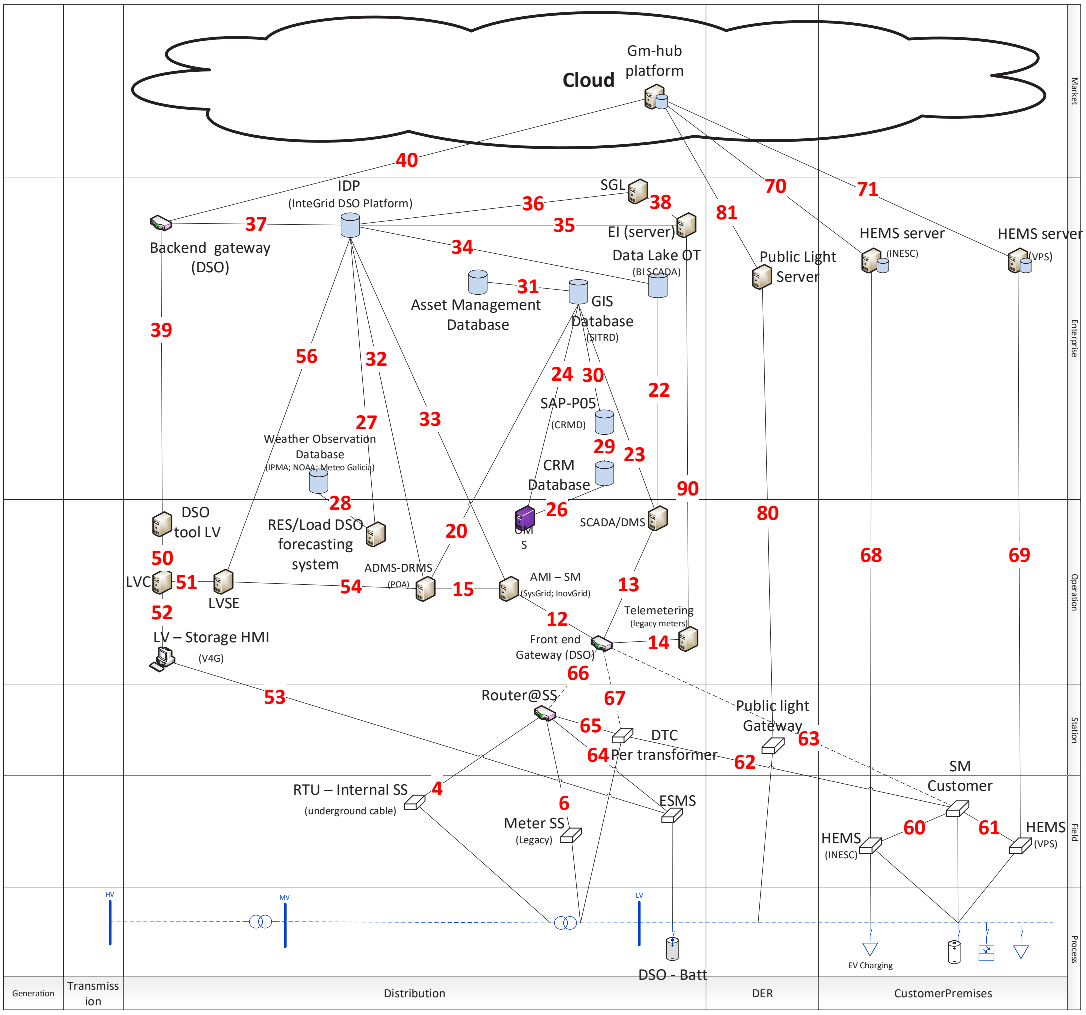


Figure 19 ICT architecture in the Portuguese InteGrid demo. SGAM representation. Source: [26]

Non-Technical SRA

Regulatory framework

The regulatory framework must be appropriate so that DSOs will be willing to invest in LV grid supervision and control solutions to increase continuity of supply or hosting capacity. In a use case such as the GRID4EU demo to implement outage detection in the LV grid, the main regulatory topics are [29]:

- How DSO revenue is regulated.
- What types of incentives are implemented/ designed to promote DSO innovation.
- What types of incentives are implemented to promote DSO reliability, and if a contribution of DER is considered.
- Smart metering. Plans for roll-out, functionalities of smart meters and ownership/access to data.

The cost of every use case solution must be recovered by the DSO through **regulated revenue.** LV grid automation or voltage control constitutes a way of avoiding grid reinforcements for connection of new DG. How regulation treats investment related to DG so that deployment of new units is not affected by the lack of hosting capacity and incentives to replace CAPEX (e.g. grid reinforcement) with OPEX (e.g. grid automation), may constitute drivers or barriers in the scalability and replicability of solutions. In general, investment in LV grid automation and control should be eligible for inclusion in the regulatory asset base (RAB) of the DSO and subject to remuneration [29].

To **incentivise** DSOs to implement **innovative solutions,** the regulator may adopt an input or output approach. In an input approach the regulator sets the technologies/projects eligible for support and approves and monitors the implementation, hampering large deployments. On the other hand, an output approach may be a better regulatory option since the regulator only sets the output desired and the DSO is free to select and implement technologies that it believes most appropriate to meet the objectives.

How a lack of **continuity of supply** (i.e. reliability) is measured also affects the scalability and replicability of a solution. The best known indicators are SAIDI and SAIFI. However, some countries have alternative indicators (e.g. TIEPI/NIEPI in Spain). The use of one or the other does not affect implementation of the solution but the roll-out strategy followed by the DSO. The DSO can opt to prioritise areas where a larger number of consumers are affected (SAIDI/SAIFI), where a larger amount of capacity is affected (ASIDI/ASIFI) or where consumers have greater energy consumption (ENS) [29].

Some LV grid monitoring and control solutions require the use of **smart meters** to operate. In Europe, recommendation 2012/148/EU contains a list of minimum functionalities in which power quality monitoring is not considered. Successful implementation of these solutions depends, therefore, on what functionalities are imposed by the regulator or by the DSO. The types of smart meter data management and ownership that are implemented are also important. Ideally, the DSO should be in charge of deployment and smart meter data management, but while keeping transparency and accessibility for retail market functioning [29].

Stakeholders' perspectives

In a use case consisting of LV grid monitoring and control, consumers and DG/storage owners/providers are indirect stakeholders and are more interested in the results than in how it is done. Therefore, apart from the DSO, the most relevant and direct stakeholders are the regulator, manufacturers and software/ICT providers. It would be useful to know the regulator's perspective on current regulation (i.e. the regulatory topics in the previous section) to see if changes are expected in the near future. If the regulator does not have the appropriate human resources, budget or training, its capacity to change regulation and oversee companies is reduced [29].

The views of manufacturers and ICT/software providers should match the views of DSOs regarding the functionality of the solution and specifications. These types of stakeholder may be interested in retaining/improving their market share or in creating captive demand by using proprietary standards and protocols that hamper interoperability with other manufacturers' solutions. To avoid possible concerns of a manufacturer regarding low returns when standardising a solution in a highly competitive market, the best approach may be joint development of common interoperable specifications by DSOs, manufacturers, ICT/software providers and others [29], as in the case of the Prime Alliance and, in Spain, Futured[4] working groups.

4.2.2.3 SRA FOR MV GRID AUTOMATION AND RECONFIGURATION USE CASES

Technical SRA

Functional : Four use cases in the GRID4EU project have implemented an SRA methodology for MV grid automation and reconfiguration. These use cases are divided in two main groups for analysis:

- **Reliability improvement:** solutions aiming to improve grid reliability through network automation and reconfiguration, applied in the following use cases: Germany Demo 1 – Load Control in MV, Spain Demo 3 – Automatic Grid Recovery, and Czech Republic Demo 5 – Failure Management in MV.

- **Increase in DG hosting capacity:** seeking to increase DG hosting capacity with different solutions. This section will focus on the Germany Demo 1 – Decentralised grid operation MV use case, which employs network reconfiguration.

Table 25 gives a summary of the main characteristics and lessons learned from the selected MV grid automation and reconfiguration use cases. Further details are given below.

Project demo	Scope	Sensitivity parameters	KPIs, additional indicators	Main lessons learned
GRID4EU: Reliability improvement use cases	Solutions aiming to improve grid reliability through network automation and reconfiguration.	• Network length. • Network failure rate. • Type of automation solution. • degree of implementation of monitoring and control.	• Fault awareness, localisation and isolation time. • Reliability indices: SAIDI, ASIDI, SAIFI, ASIFI. • Number of switching operations.	• There is a saturation effect around an automation degree of 20-40%, according to the SAIFI and SAIDI indices obtained for different shares of telecontrol in urban and sub-urban networks. • The architecture of the automation control system impacts on the time required by the system to perform reconfiguration. Therefore, the time response of the system has an impact on both SAIDI and SAIFI. • The use of SAIFI and SAIDI will prioritise reliability improvement in areas with a higher number of consumers, while ASIFI and ASIDI will prioritise reliability improvement in areas with greater demand.
GRID4EU: Increase of DG hosting capacity use case	Increase network hosting capacity (NHC) achieved by implementation of automation and reconfiguration.	• Based on low demand and concentrated DG at maximum production • Sensitivity to DG location. • Different voltage limits. • Different degrees of automation	• % increase in network hosting capacity. • Energy losses. • Quality of service indicators (line voltage profiles, overload avoided). • Number of switching operations.	• NHC can be increased by reconfiguration. Results have shown increases of up to 65% of initial network hosting capacity for degrees of automation below 20%. • Higher degrees of automation may not improve hosting capacity since the configurations allowed may not be aligned with the distribution of load and DG.

Table 25 : Summary of SRAs of different types of MV grid automation and reconfiguration use cases in EU projects

[3] http://www.prime-alliance.org
[4] https://www.futured.es/en/

Use cases focused on reliability improvement:

A functional SRA for this group of use cases consists of computing indices of continuity of supply to compare the situation before and after implementation of smart grid use cases. For this purpose, a **simulation tool** has been designed which emulates the actual process of fault location, isolation, service restoration and repair performed by DSOs and computes the interruption time suffered by each consumer for each possible fault in the MV system.

Regarding **input data**, eight representative MV networks were used for simulation, representing demo countries for different types of distribution zones (urban, sub-urban and rural). Special attention was paid to grid architecture, meshing the network, protection schemes, registered indices of continuity of supply and the existing level of automation.

A wide range of **sensitivity parameters** were simulated to assess the effect of the different boundary conditions that may be involved in scaling-up and replication of these use cases, including network length, network failure rate, type of automation control system (local vs decentralised and autonomous vs supervised) and the degree of monitoring and control of implementation.

In general, the **KPIs and additional metrics** that were used to evaluate the different scenarios in the analysis were 1) fault awareness, localisation and isolation time, 2) reliability indices: SAIDI (system average interruption duration index), ASIDI (average system interruption duration index), SAIFI (system average interruption frequency index) and ASIFI (average system interruption frequency index), and 3) the number of switching operations.

Regarding the **sensitivity analysis**, in GRID4EU the following lessons learned and SRA rules were obtained for improving reliability through network automation use cases [29]:

- **Impact of automation:** Telecontrol of load break switches has a significant impact on both the frequency and duration of supply interruptions suffered by consumers. By contrast, monitoring has a much milder impact on the duration of supply interruptions. Moreover, the effect of increasing the number of secondary substations with telecontrol is not linear. There is a saturation effect around a degree of automation of 20-40% according to the SAIFI and SAIDI indices obtained for different shares of telecontrol in urban networks. See Figure 20 and Figure 21. Moreover, the same effect on these indices is found for sub-urban networks, and the impact of implementing a certain degree of automation is much higher for networks with lower reliability.

- **Network structure:** Automation has a much deeper impact on reliability in meshed networks with switches in the MV line. Ideally, automation should be introduced gradually in distribution networks, prioritising the full automation (monitoring and telecontrol) of a share of secondary substations (up to 20-30%) distributed along the MV line in urban networks.

- **Architecture of automation control system:** The control system may be local or centralised and autonomous or supervised. The architecture of the automation control system impacts on the time required for the system to perform reconfiguration. Therefore, the time response of the system has an impact on both SAIDI and SAIFI. If the regulatory threshold is surpassed, no reduction in SAIFI is achieved. Typically, the difference in time response between centralised and local control systems is negligible. Moreover, it is highlighted that human supervision introduces a longer more arbitrary response time, so the regulatory threshold may be surpassed. Finally, another SRA rule stressed is that the effect of the response time of the automation system becomes more relevant at higher degrees of automation.

- **Network length and failure rate:** These are related to the initial reliability level. Given a specific network architecture and demand, the reduction in SAIDI and SAIFI achieved with automation is larger for lower initial reliability levels (longer lines and higher fault rates).

- **Reliability indices:** Use of different reliability indices to compute reliability improvement achieved by automation leads to slightly different results depending on the structure of demand and the reliability throughout the MV network. The use of SAIFI and SAIDI will prioritise reliability improvement in areas with higher numbers of consumers, while ASIFI and ASIDI will prioritise reliability improvement in areas with greater demand. Typically, in urban areas the differences between the two sets of indices are less visible.
- **Voltage level:** It is advisable to prioritise automation in the MV grid rather than the LV grid since reliability improvement at the MV level affects a much higher number of network users.

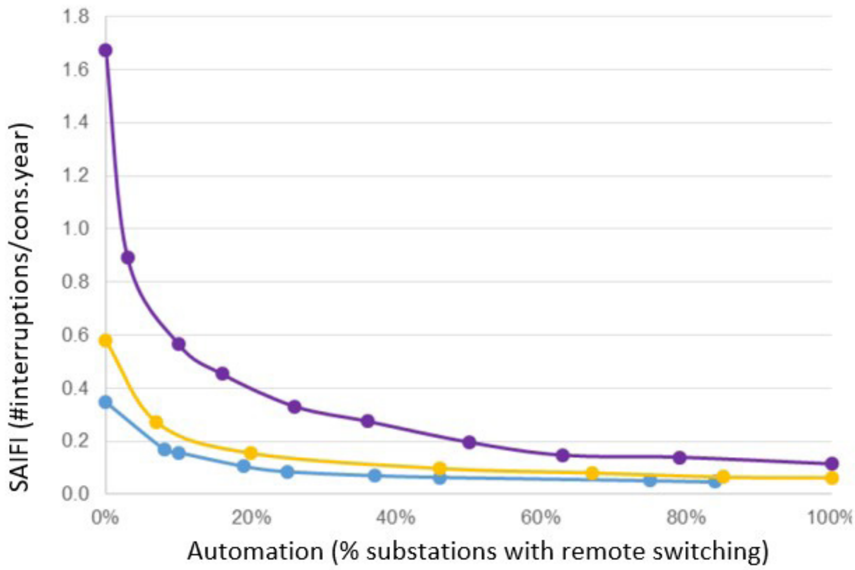


Figure 20 : SAIFI values for different automation levels in 3 MV urban networks. Source: [29]

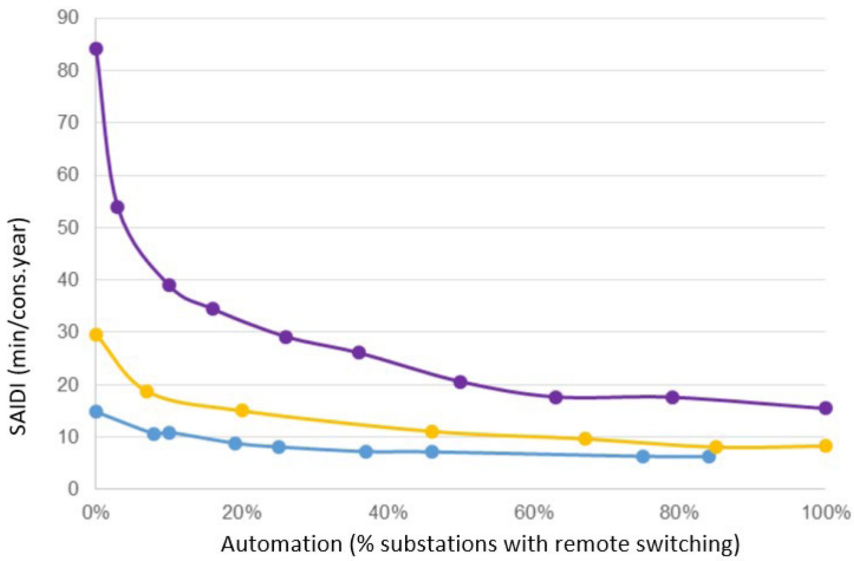


Figure 21 : SAIDI values for different automation levels in 3 MV urban networks. Source: [29]

Use case focused on DG hosting capacity:

This use case employs automation to optimise configuration of the network according to the state of the system. Therefore, a functional SRA focuses on the increased network hosting capacity (NHC) achieved by implementation of automation. NHC is computed for all possible configurations of the grid enabled by an autonomous switching system to determine optimal configuration.

Regarding **input data,** seven representative MV networks in different distribution areas (urban, sub-urban and rural) and at different voltage levels (10 and 20 kV) were considered.

The selected sensitivity parameters in the simulation were based on low demand (10% of contracted power or the maximum demand of each consumer) and concentrated DG at maximum production. Sensitivity to DG location was studied, considering DG at the beginning, the middle and the end of the main trunk of an MV feeder, and the end of ramifications where applicable. Additionally, different voltage limits were considered as limits for network hosting capacity (3, 5, 7 and 10% of nominal voltage). In line with scalability in density, different degrees of automation were contemplated to assess the effect of having a wider range of possible configurations of the improvement in network hosting capacity.

The **KPIs and additional metrics** that were used to evaluate the different SRA analysis scenarios were network hosting capacity, energy losses, quality of service indicators (line voltage profiles, overload avoided), disconnection of DG units avoided and the number of switching operations.

In GRID4EU the following lessons learned and SRA rules were obtained from Demo 1 – Decentralised grid operation in MV networks [29]:

- **Network hosting capacity in MV networks:** This can be increased by reconfiguration. The results show increases of up to 65% of initial network hosting capacity for degrees of automation below 20%. Reconfiguration can bring DG closer to the primary substation, so voltage rises are mitigated or a larger share of the DG production is consumed locally. The improvement in network hosting capacity achieved with reconfiguration is higher for overvoltages than for overloading lines caused by concentrated DG.

- **The effect of network topology:** Automation is usually designed with the main purpose of fault management, so localisation of switching modules may not be optimised to improve hosting capacity. In addition, existing switching modules can suffer from premature ageing due to more frequent usage. Furthermore, higher degrees of automation may not improve hosting capacity since the configurations allowed may not be aligned with the distribution of load and DG.

Non-technical SRA

Regulatory framework

Use cases focused on reliability improvement: Regarding reliability improvement use cases, the following main regulatory topics were identified [29]:

- DSO revenue regulation: General regulatory framework and cost benchmarking approach.

- DSO reliability incentives: Implemented or not, type of scheme and impact of DER are considered.

- DSO incentives for innovation: Specific incentives implemented and design of incentives.

In overall **revenue regulation**, use cases, the ultimate aim of which is to improve reliability, are heavily influenced by the existence and design of continuity of supply incentives for DSOs. An absence of such incentives or an inappropriate design, e.g. scarcely demanding reference values, wide deadbands or tight caps/floors, may act as barriers to the replicability and scalability of these smart grid solutions.

Different design elements in **reliability incentives** can deeply affect the extent to which DSOs are incentivised to implement use cases to improve continuity of supply. Discontinuities such as deadbands and caps may act as barriers to further reliability improvements. General rules cannot be applicable since the most adequate option depends on many factors. Therefore, on a case-by-case basis regulators should evaluate whether a further reduction in interruption levels is desired and in the case of an affirmative answer whether existing regulatory incentives are enough to achieve them.

Use case focused on DG hosting capacity:

In this use case, the following main regulatory topics were identified [29]:

- Network charges for DER: type and design of connection charges, UoS (use of system) charges for DG and design of UoS charges for DG.
- DSO revenue regulation: the general regulatory framework, a cost benchmarking approach and treatment of DER-driven network investments.
- DSO incentives for innovation: specific incentives implemented and design of incentives.

Distribution costs are recovered through **network charges** that are paid by distribution network users. These network charges comprise both connection charges, a one-off payment made at the time of grid connection, and use-of-system (UoS) charges, which are periodic payments to defray network costs normally included in overall tariffs. According to the analysis in GRID4EU, the Germany Demo 1 – Decentralised grid operation in MV use case is potentially affected by connection charge design. Connection charges may cover only the direct costs of connection to the nearby distribution grid (shallow connection charges) or also the full cost of reinforcing the grid to accommodate the additional DG capacity (deep connection charges).

Concerning the other main regulatory topics mentioned, the same conclusions presented in Section 4.1.2.4 for the LV Supervision and Control use case in GRID4EU are valid.

Stakeholders' perspectives

GRID4EU identifies the most relevant stakeholder groups for each use case. In particular, for MV grid automation and reconfiguration, there are the following relations between the two groups of use cases analysed and the stakeholder group. In [29], a discussion on the expectations and behaviour of these stakeholders is presented.

- Reliability improvement: DG/storage (indirectly), regulators, manufacturers, software/ICT providers, operators, etc.
- Increase in DG hosting capacity: consumers (indirectly), DG/storage (indirectly), regulators, manufacturers, software/ICT providers, etc.

Furthermore, of particular interest is the role of operators in MV grid automation and reconfiguration use cases. As was previously stated, the response time of the control system depends on its architecture and whether the control system is autonomous or supervised. In the latter case, the operator takes some time to confirm or modify the switching actions proposed by the automated control system [35]. For instance, in the German demo the failure management process relies on the work of experienced operation teams and SCADA engineers [36]. With the installation of an autonomous switching system, these working groups receive tools for more efficient and quicker failure management compared to the process without autonomous switching (baseline scenario).

4.2.2.4 EU SRA CONCLUSIONS

Currently, most of the projects that are being funded by the European Commission include an SRA following the BRIDGE methodology to generate valuable insights on how the solutions would perform in different contexts. Therefore, this study provides an overview of the main lessons learned from SRA applied to EU projects focused on demand response, LV monitoring/control and MV automation use cases. Taken together, the SRA assessment suggests the following general remarks on the EU projects reviewed.

Technical SRA

The functional analyses, from a methodology perspective, followed the same basic steps for every use case: data collection (e.g. grid characteristics, load profiles, etc.) to build the simulation, definition of sensitivity parameters to generate scenarios, definition of KPIs and analysis of results in a quantitative, qualitative or mixed way.

For DR use cases, the key factor to consider is whether direct human interaction is involved (e.g. HEMS, price and environmental signals, etc.) or not (e.g. direct controllable loads). Furthermore, to keep engagement in DR schemes, incentives should be designed considering demand seasonality, household comfort, the type of consumer and consumer sensitivity to price and environmental signals.

In unbalanced LV networks, implementation of smart metering, DR schemes and a moderate penetration level of solar PV can contribute to monitoring and controlling losses that also affect voltages. For direct control of voltages and higher network hosting capacity, installation and control of OLTC transformers using data from smart meters may be a better option than active and reactive power control of solar PV, although its deployment may be more limited.

For MV grid automation and reconfiguration use cases, as the SRA assessment reports, implementation of network automation in urban and sub-urban areas provides benefits in terms of reliability for automation levels up to 20-40%. Adding more automation further improves reliability but to a much lesser extent. Moreover, the impact of network reconfiguration on hosting capacity greatly depends on the structure of the distribution network and the location and characteristics of the DG connected. Therefore, the effect of reconfiguration in these solutions is greater in the case of overvoltages than overloading of lines caused by concentrated DG.

Regarding ICT, the results of EU demos are usually difficult to extrapolate. The ICT part of a smart grid solution is usually developed ad hoc for the demonstrator according to the actual needs and existing infrastructure. For demand response in households with HEMS, the use of wireless communication protocols such as Zigbee and Wi-Fi to communicate with controllable loads and the smart meter, as in InteGrid, constitute a possible solution. However, the low data rate and short range of Zigbee may be a barrier in some cases. For the ICT part of LV grid monitoring and control solutions, the implementation of functionalities in the cloud instead of a dedicated device could be studied to increase reliability. For smart metering through PRIME, if it is expected to participate in real-time operation the protocol should be updated to the latest version (v1.4) to improve performance.

Non-technical SRA

The main regulatory topics highlighted to provide flexibility through DR are the regulated charges and retail tariffs implemented. This is because they can constitute a barrier or an incentive in these use cases. In addition, this is in line with one of the main concerns of stakeholders, who consider that insufficient compensation is the main factor limiting the implementation of DR.

For implementation of smart grid solutions in LV and MV networks, regulation of DSO revenue and different types of incentives (e.g. for innovation and grid reliability) should be evaluated to ensure that regulation will not hamper implementation. For LV solutions, regulation of smart metering (deployment, functionalities, management and data access) must also be considered since multiple solutions rely on it. The perspectives of the regulator, manufacturers and technology providers regarding these issues may also provide valuable information for solution deployment.

Moreover, the experience of operators is relevant in MV grid automation and reconfiguration use cases. As was discussed earlier, in the case of GRID4EU the need for validation by the operator in the control centre adds a certain response time in the execution of switching actions. Hence, it is recommended to use the experience and knowledge available to develop and implement reconfiguration solutions.

4.3 INDIA CBA AND SRA ANALYSIS

4.3.1 INDIA COST-BENEFIT ANALYSIS

CBA is one of the most important tools to assess the financial viability of a project and to figure out alternative investment options to maximise profit. For smart grid pilot projects, CBA will provide outputs on the benefits and assess whether the benefits exceed the cost and provide profitable investments for utilities and other stakeholders.

To carry out a CBA of smart grid pilot projects, the report followed the European Commission Joint Research Centre (JRC) guidelines to perform a CBA of the smart grid projects. The recommendations mentioned in the JRC CBA guideline help to identify, quantify and monetise the project impacts and the benefits that are accrued in a project. Moreover, recommendations are also provided to analyse non quantifiable impacts. The JRC assessment framework consists of the seven steps below.

4.3.1.1 LV GRID MONITORING AND CONTROL CBA

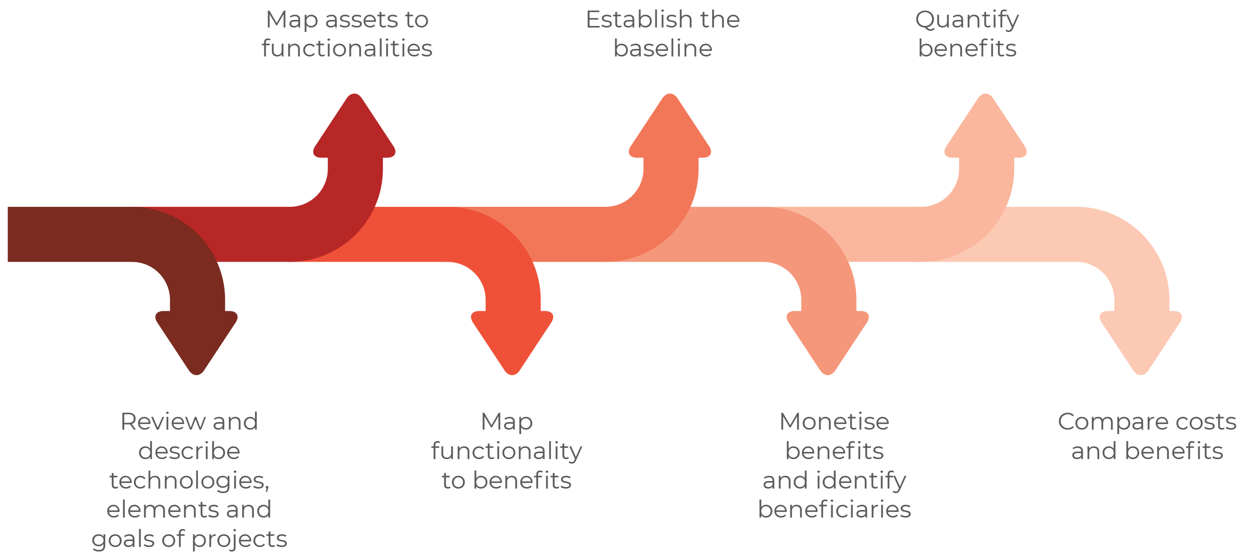
The CBA methodology for low voltage grid monitoring and control has been applied to two smart grid pilot projects, namely the Uttar Gujarat Vij Company Limited (UGVCL) smart grid pilot project and the Tripura State Electricity Company Limited (TSECL) smart grid pilot project. Each of the smart grid projects involves smart grid applications like advanced metering infrastructure, peak load management, an outage management system and transformer monitoring. The total cost of the projects and year-on-year benefits realised by these smart grid projects are explained in the following sections.

4.3.1.1.1 UGVCL CBA

The UGVCL smart grid pilot project is based at Naroda, Ahmedabad, where AMI, peak load management (PLM) and an outage management system (OMS) have been implemented with the objectives of reducing T&D losses, meter reading costs, peak power costs, the transformer failure rate and enhancing billing and collection efficiency and thereby helping to save electricity. The project serves 23,700 customers in the Naroda area and the total cost of the project is approximately INR 232 million, of which 50% (approx. INR 116 million) has been paid by the Government of India as a grant.

The smart grid pilot project involves implementation of AMI with RF mesh technology and also involves implementation of peak load management and outage management system applications. Implementation of these applications was carried out to ensure a reduction in AT&C losses, peak shaving, better load management, reduced connect/disconnect cost, reduced meter reading cost, increased network reliability and better asset management etc.

UGVCL has observed various benefits from the implementation of these functionalities, including reduction of AT&C losses by 3% as compared to approximately 1.5% and SAIDI values reduced by 61% compared to 18% in four years without implementation of these functionalities. The detailed benefits from the implementation of AMI, PLM and OMS are given below:



AT&C Losses	2015-16	2017-18	2018-19	2019-20	2020-21
Energy input MUs	42.05	54.05	62.88	79.60	83.44
AT&C loss - without S.G	7.43%	7.06%	6.71%	6.37%	6.05%
AT&C loss - with S.G	7.43%	5.81%	5.67%	6.17%	4.88%
Energy loss (MU) - without S.G	3.12	3.82	4.22	5.07	5.05
Energy loss (MU) - with S.G	3.12	3.14	3.57	4.91	4.07
Unit rate (INR)	2.79	2.93	2.93	2.93	2.93
Loss (INR) - without S.G	8716839	11178299	12354244	14857315	14795347
Loss (INR) - with S.G	8716839	9201094	10446317	14390168	11930585
Savings (INR)		1977206	1907927	467147	2864762
Peak Load Management					
Units consumed (MU)	42.05	54.05	62.88	79.60	83.44
Frequency below 49.5 Hz (as per CEA Data)	8%	7.6%	7.2%	6.9%	6.5%
Units consumed in above slot (MU)	3.36	4.11	4.54	5.46	5.44
Reduction by demand response		5%	5%	5%	5%
Units reduced	0	0.21	0.23	0.27	0.27
Rate/unit in the frequency band (INR)	13	13.65	14.33	15.05	15.80
Savings (INR)		2803574	3253432	4108234	2864762
Reliability Index					
SAIDI - Naroda (minutes) - without SG	217	206	196	186	177
SAIDI - Naroda (minutes) - with SG	217	84	92	108	85
Units consumed - Naroda (Mus)	42.05	54.05	62.88	79.60	83.44
Units lost due to interruption (Mus) - Naroda without SG	1.736	2.118	2.345	2.817	2.81
Units lost due to interruption (Mus) - Naroda with SG	1.736	0.864	1.101	1.636	1.349
Units saved due to improved reliability (Mus)	0	1.254	1.244	1.181	1.461
Per unit saving (INR)	2.79	2.93	2.93	2.93	2.93
Savings (INR)	0	3674220	3644920	3460330	4280730

Source: UGVCL

Table 26: Detailed benefits from the implementation of AMI, PLM and OMS

In addition to the above benefits, which have led to considerable cost savings, other benefits like a reduction in the transformer failure rate, a reduction in the cost of collection etc. have also contributed to cost savings. The financial CBA was based on the cost-benefit ratio and payback period of the project. Based on the project's savings mentioned below and considering INR 6000 as the present day meter cost per node for 23,700 customers, the total cost will be INR 142,200,000.

Therefore, the payback period of the project with PLM will be 142,200,000/13,832,598 = 10.3 years whereas if we calculate the payback period without PLM benefits it will be 13.9 years. This suggests that implementing the PLM application has helped enhance the benefits of the project by reducing the peak power cost and better load management.

4.3.1.1.2 TSECL CBA

Implementation of the smart grid pilot project in Agartala, Tripura has been carried out by TSECL, the Tripura state power utility. The pilot project involves implementation of a control centre along with installation and commissioning of complete AMI, including smart meters, data concentrator units, a head end system, meter data management and hardware and software for the control centre, etc. along with a peak load management system. It is one of the successful AMI projects with PLC-based communication for the AMI system. Moreover, a geographical information system has been integrated in the AMI system for better asset management and the billing and collection system has also been integrated with the AMI system to enhance billing and collection efficiency and reduce commercial losses.

The pilot project covers 46,071 consumers and the total cost of the project stands at approximately INR 634 million, of which 50% (INR 317 million approx.) has been paid by the Government of India as a grant. The project area, i.e. Electrical Division 1 Agartala, is covered under the R-APDRP Scheme for IT implementation and system strengthening. Peak load management functionality has been implemented for both residential and industrial customers with the AMI system.

The project involves implementation of 42,831 single phase smart meters and 2,459 three phase smart meters for 46,071 residential and industrial customers with the objectives of ensuring better asset management, reducing AT&C losses, better load management, improved billing and collection efficiency and enhanced customer satisfaction.

Particulars	2017-18	2018-19	2019-20	2020-21
Meter Reading Cost	1944000	1944000	1944000	1944000
Cost of collection	136080	155520	174960	194400
Connect/disconnect cost	2190000	2250000	2332500	3343800
AT&C losses	1977205.753	1907927	467146.9	2864761.9
Peak load management	2803574	3253432	4108234	4295654
Transformer failure	0	0	39000	0
Reliability index	3674220	3644920	3460330	4280730
	12725079.25	13155798	12526170	16923346
Total saving in 4 years (INR)				55330394
Total saving per year (INR)				13832598

Source: UGVCL

Table 27: UGVCL Cost-Benefit Analysis

With the commissioning of this smart grid project, TSECL accrued various benefits in terms of reducing T&D losses which have led to energy savings of approximately 31 MUs in four years from the date of commissioning. Similarly, billing has been improved and it has provided a benefit of (approx.) INR 82 million in four years. The benefits that have been accrued due to AMI implementation are detailed below.

In addition to the above cost and energy savings, a considerable amount of energy saving has been contributed by peak load management. The financial CBA is based on the cost-benefit ratio and the payback period of the project. Based on the project savings mentioned above and considering INR 634 million as the cost of the project, the payback period of the project is INR 634 million/INR 36.46 million = 17.38 years.

2016-17 (Base Year)	Benefits due to reduced losses, in millions (INR)	Benefits due to efficient billing, in millions (INR)	Benefits due to remote management of meters, in millions (INR)	Total Energy savings (MU)
2017-18	10.10	6.92	4.94	2.65
2018-19	16.38	28.42	1.36	6.68
2019-20	19.99	44.62	5.45	9.76
2020-21	4.07	1.60	1.99	11.90
Total	50.54	81.56	13.74	30.99
Transformer failure	145.84			
Reliability index	36.46			

Table 28: UGVCL Cost-Benefit Analysis

Source: TSECLL

4.3.2 SCALABILITY AND REPLICABILITY ANALYSIS (SRA)

This section introduces the key ideas of scalability and replicability and existing methods for evaluating the scalability and replicability of smart grid pilot projects. The scalability of a system can be defined as its ability to increase in size, scope or range, whereas the replicability of a system refers to the ability to be duplicated in another location or time. The primary objective of SRA is to understand whether a certain use case, system or service can be performed at different locations and/or under different technical and non-technical conditions. SRA must take into account two fundamental concepts: scalability and replicability.

Scalability: Scalability refers to expanding the particular region where the smart grid solution is deployed, expanding the scope of the deployment to include more consumers and other stakeholders or increasing the degree of deployment to include more network elements or larger volumes of energy produced or demand. There are two types of scalability analysis which can be performed.

Scalability in size: Implementation of the use case is assessed for a larger area, including a larger number of network elements and network users.

Scalability in density: The scope of the use case is expanded in terms of the degree of implementation of the smart grid solution (e.g. a greater number of consumers involved, a larger volume of participating distributed energy resources and a larger number of smart grid elements in the system).

Replicability. The replicability part of the analysis tries to determine how regulatory, technical, environmental and social conditions affect the conclusions drawn on the use case with the objective of applying it in other regions, either national or international. For example, changing the network characteristics (e.g. topology) or its regulatory constraints (e.g. allowed voltage levels) according to a network representative of a country.

The process of scaling-up and replication of smart grid pilot project implementation is depicted in the figure 22.

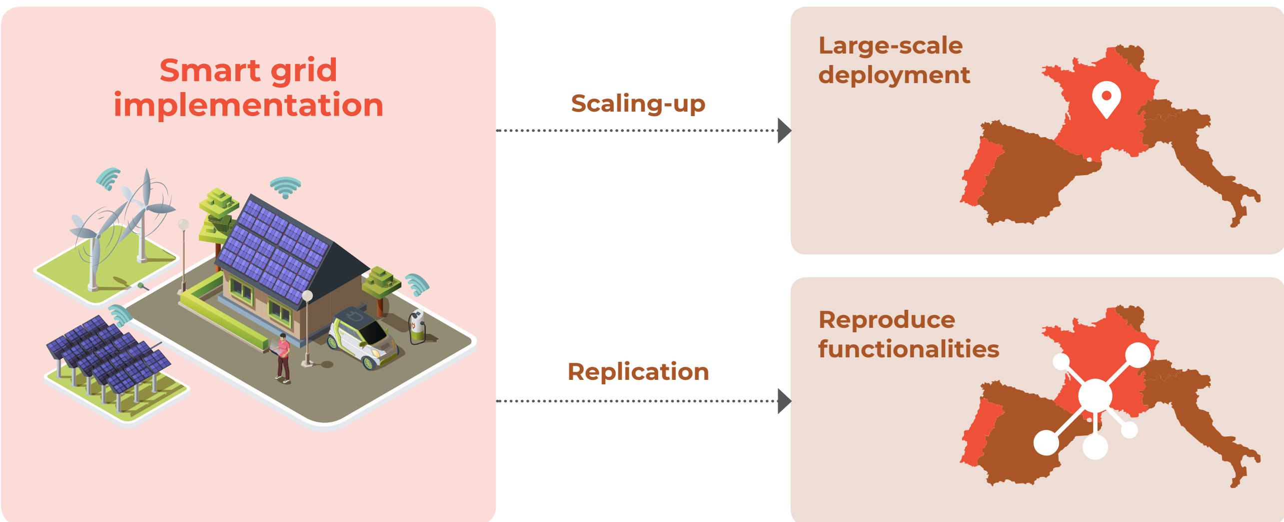


Figure 22: Scalability and Replicability of Smart Grid Pilot Project Implementation

4.3.2.1 LV GRID MONITORING AND CONTROL SRA

The scalability and replicability methodology for low voltage grid monitoring and control has been applied to two smart grid pilot projects, namely the Uttar Gujarat Vij Company Limited (UGVCL) smart grid pilot project and the Tripura State Electricity Company Limited (TSECL) smart grid pilot project. Each of the smart grid projects involve smart grid applications like advanced metering infrastructure, peak load management, an outage management system and transformer monitoring. The technical and non-technical SRAs of these smart grid projects are described in the following sections.

4.3.2.1.1 UGVCL and TSECL SRAs

Technical SRA

Through these pilot projects, UGVCL and TSECL are trying to control their rising AT&C losses and also help peak load management through installation of advanced metering infrastructure. They are pilot cases for both non-residential general purpose (NRGP) and low-tension maximum demand (LTMD) customers with the objective of shifting the peak period load to the regular/off-peak period to flatten the load curve with added incentives to consumers and no extra burden (preferably savings) on discoms. The table below summarises the key characteristics and takeaways from the various LV monitoring and control use cases.

In the analysis of the UGVCL and TSECL pilot projects, the objective was to evaluate the grid for implementation of AMI to detect faults and increase the number of new DER units connected. The **sensitivity parameters** were increase in peak load, loading of the network, type of communication infrastructure, reliability improvement and voltage, current and harmonic levels, which determine low voltage grid characteristics. The **KPI** objectives used were to decrease peak load consumption by 5% every year in the Naroda area, Gujarat and 10%

Project Demo	Scope	Sensitivity Parameters	KPIs	Main Lessons Learned
UGVCL, Gujarat	• AMI implementation • Peak load management • Outage management • Power quality	• Increase in peak load • Loading of the network • Phase balancing of the network • Type of communication infrastructure • Reliability improvement • Voltage, current and harmonic levels	• Decrease in peak load consumption • Decrease in AT&C losses • Voltage levels • Reliability index • Phase balance	• Transformer failure rates depend on AMI implementation of the network • Time of use (ToU) pricing can help peak load management • Power quality management ensures a better network voltage level
TSECL, Tripura	• AMI implementation • Peak load management	• Increase in peak load • Load balancing of the network • Reliability improvement • Type of communication infrastructure	• Decrease in peak load consumption • Decrease in AT&C losses • Phase balance	• Transformer failure rates depend on AMI implementation of the network • Time of use (ToU) pricing can help peak load management

Table 29: Summary of the SRA of AMI use cases in UGVCL, Gujarat and TSECL, Tripura

in the Agartala area, Tripura and decrease AT&C losses by 4.8% in the Naroda area. The main results of the analysis are below.

These pilot projects use AMI voltage management capabilities to enhance the effectiveness of automated controls in voltage and reactive power management. Voltage management is the smart meter ability to measure voltage levels and certain power quality parameters which discoms can use to develop accurate voltage and current profiles across feeder lines throughout the network. Data on voltages can be used to diagnose customer voltage issues remotely and determine if the issue is related to the distribution system or is the result of factors inside customer premises.

An outage management system manages unscheduled distribution infrastructure like distribution transformers (DTs) and HT/LT feeders etc. It collects and coordinates information about outages, including customer calls and reports of the operator taking corrective actions through crew management and remote-control, enabling customer satisfaction, improved system availability and reliability.

ICT

The ICT architecture that supports smart grid functions is typically designed ad hoc for the use case and the discoms which will deploy it, taking into account the communication technologies available in order to ensure interoperability with other discoms' systems. The following technologies are used in the implementation of AMI technology.

RF mesh technology employs the unlicensed RF spectrum using mesh topology. Smart meters play the role of transmitters/receivers and communicate with each other. Data are collected by concentrators with the help of repeaters. The frequencies used are usually located around 900 MHz or 2.4GHz. This technology enables wireless communication and is a core function of automatic meter reading (AMR). It is mainly used as a way to measure power consumption and collect data from energy consumers. Paired with PLC, it provides better accuracy and coverage and, just like PLC, it requires modules to be installed on meters.

Power line carrier (PLC) technology consists in using power lines as data transmission supports. AMI applications are usually based on low data rate technologies (few hundreds of kilobits/ sec max). The technology allows bi-directional communication between the meter and a concentrator, usually located in a transformer.

Non-Technical SRA

Regulatory framework

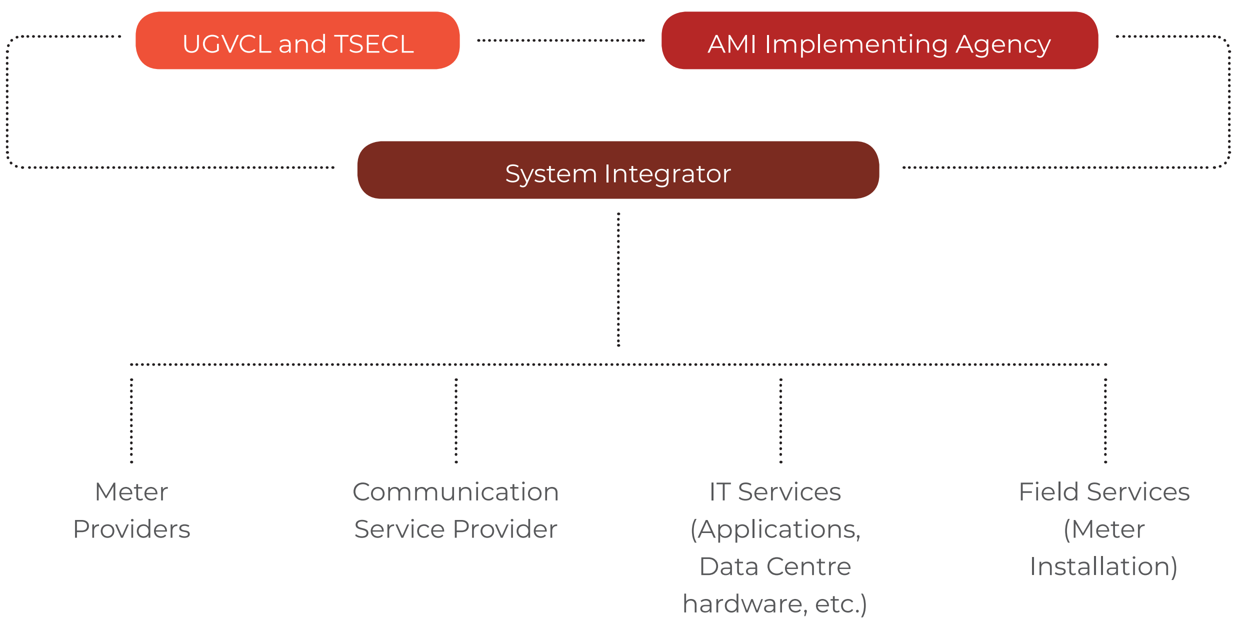
The regulatory framework must be appropriate for discoms to be willing to invest in LV grid supervision and control systems in order to improve the supply continuity and reliability of the network. The main regulatory topics involved in both the smart grid pilot projects are:

- How discom revenue is regulated.
- Electric vehicle and charging infrastructure. Plans for a roll-out of EVs.

Some LV grid monitoring and control solutions require the use of EVs to operate. AMI services can support the integration of electric vehicle charging and evaluated customer charging patterns with various rate options to help UGVCL and TSECL anticipate how increased adoption of electric vehicles might affect peak and non-peak demand in the future. Smart meters can be used to offer customers ToU rates for EVs to provide financial incentives for customers to charge vehicles during off-peak periods. The meters also provide valuable data for EV manufacturers and utilities on customer charging patterns, and to assess the grid impacts of different types of chargers, including standard (120 V) and alternative chargers (240 and 480 V). AMI implementation can contribute to advanced concepts like vehicle-to-grid applications in which UGVCL and TSECL can have access to EV storage capacity to meet system needs.

Stakeholders' perspectives

Consumers and DER owners/providers are indirect stakeholders in both LV grid monitoring and control use cases. They are more interested in the results than how they are done. Therefore, apart from discoms, the most relevant and direct stakeholders are the regulator, manufacturers and software/ICT providers. The diagram below shows a brief idea of a possible ecosystem with individual stakeholders and their responsibilities in AMI implementation.



4.4 KEY OBSERVATIONS AND A COMPARISON OF EU AND INDIAN CBA/SRA ANALYSIS

The tables below compares the key features of the use cases in the EU and India.

<table>
<tr><th rowspan="2">Use Case</th><th colspan="2">Cost-Benefit Analysis</th></tr>
<tr><th>European Use Case Application</th><th>Indian Use Case Application</th></tr>
<tr><td>Demand Response</td><td>Home Energy Management

Appliances are managed using a smart home management system. The costs associated with this are both CAPEX and OPEX heavy as equipment needs to be installed to monitor, communicate and manage.

The type of consumers and their tariff plans play an important role in determining the benefits. For instance, premium consumers benefited more as opposed to those with PV installed, as consumption was already happening at low-cost times. Consumers with dynamic prices saw more volatility and received no positive benefits.

Consumer habits determined the level of benefits received as the use of these systems need alterations in daily habits. Benefits were seen for single and double occupancy apartments as opposed to ones with families as the latter's use of appliances was more dispersed throughout the day and harder to optimise.

Engaging Consumers in Demand Side Management Programmes

The management of appliances is done manually following recommendations from the mobile application. The costs associated are relatively low compared to other investment-heavy applications, as in this case an e-agreement and a mobile application were all that was needed.

The benefits were positive as the consumers who engaged were aware, motivated and responsive.</td><td>N/A</td></tr>
</table>

<table>
<tr><th rowspan="2">Use Case</th><th colspan="2">Cost-Benefit Analysis</th></tr>
<tr><th>European Use Case Application</th><th>Indian Use Case Application</th></tr>
<tr><td>Demand Response</td><td>Aggregate and communicate multi-period behind-the-meter flexibility from LV prosumers

In the case where aggregated behind-the-meter flexibility was offered, the benefits came from selling on the secondary reserve market at the building level, with a potential to offer twice a day. The costs associated were minimal, as already existing equipment was used and any other equipment needed was offset at the aggregator level and hence not taken into account at the building level.

The overall benefits were profitable as adjustments at the building level were negligible and offset individual comfort levels.</td><td>N/A</td></tr>
<tr><td>LV/MV Automation, Supervision and Control</td><td>MV-grid automation and monitoring

Assets for fast fault detection and chronometric selectivity include smart switchgears at nodes, mutual low latency radio channels, electricity and environmental real-time measurement assets and two-channel data communication with the central information system

Remote control of the MV/LV grid

Assets to improve remote control include upgrading existing switchgears.

New management criteria for the MV grid

Assets to minimise electricity losses include development and implementation of algorithms and software for SCADA-based state estimation.

Overall observations

LV/MV monitoring and remote control are both CAPEX and OPEX heavy as they need significant investment in upgrading network infrastructure, which includes physical items that depreciate in value. In the case of grid management of MV grids, the main asset is software.</td><td>Uttar Gujarat Vij Company Limited (UGVCL)

The assets in this project include AMI with RF mesh technology, peak load management and outage management system applications to ensure reduced AT&C losses, peak shaving, better load management, reduced connect/disconnect cost, reduced meter reading cost, increased network reliability and better asset management.

The project saw a significant improvement in KPIs such as SAIFI and SAIDI over a period of 4 years. CBA analysis shows that for investments in this system upgrade the payback period was in fact shorter (by ~3.5 years) than without the system upgrade.</td></tr>
</table>

<table>
<tr><th rowspan="2">Use Case</th><th colspan="2">Cost-Benefit Analysis</th></tr>
<tr><th>European Use Case Application</th><th>Indian Use Case Application</th></tr>
<tr><td>LV/MV Automation, Supervision and Control</td><td>Distribution companies that invest in smart infrastructure and improve their security of supply will receive more benefits. However, when benefits were calculated at the test project level, all projects showed negative benefit. It should be noted that the CBA may not fully capture all the actual social benefits. On, performing a sensitivity analysis and scaling up these test projects, benefits became positive. This highlights the need to have a methodology to optimise investment in LV/MV upgrades.

CBA Methodology for smart LV/MV investment

The net cost of the system is the sum of investments in smart MV/LV substations and the cost of supply interruptions. The benefits are monetised using two different approaches: the cost of non-served energy for network users affected and the economic incentives granted to distribution companies to achieve satisfactory continuity of supply.

When considering KPIs such as SAIFI and SAIDI, it is found that in semi-urban areas the optimal degree of automation is 12% with regulatory incentives and 16% if non-served energy is monetised. And in the case of urban areas, these figures are 15% and 20% respectively.

Semi-urban areas gave distribution companies more incentives to reach a degree of automation beyond the optimal value as opposed to urban areas, due to the way regulatory payments are made.</td><td>Tripura State Electricity Company Limited (TSECL)

The assets in this project included a control centre along with complete AMI including smart meters, data concentrator units, a head end system, meter data management and hardware and software for the control centre and peak load management system.

The benefits were mostly due to AMI implementation and are close to 37 crore a year, with an overall payback period of ~18 years.</td></tr>
</table>

Table 30: Key CBA features by use case

Scalability and Replicability Analysis					
Use case	**Project demo**	**DR devices**	**Sensitivity parameters**	**KPIs**	**Main lessons learned**
Demand Response -EU	InterFLEX German demo	• Night storage heaters (NSH) • Heat pumps (HP)	• Penetration of NSH, HP and solar PV. • Seasonality	• % Increase in hosting capacity • % Flexibility power available • % Successful customer recruitment • % Technologies leveraged (active participation)	• Seasonality must be considered to design incentives. • DR from NSH is better than from HP to reduce network loading. • With 50% penetration of flexible loads, network violations were still detected
	InteGrid Portuguese demo	• HEMS	• Number/ location of HEMS • N° loads controlled by HEMS • RES penetration • Network size and R/X ratio • Presence of OLTC and storage control. • Availability of historical data	• Peak demand reduction ratio: 4% with PV panels • Ratio between min. and max. daily demand: 1% with solar PV • Electricity cost per kWh in DR • Amount of self-consumption: 57% on average, with HEMS	• HEMS is good for flexibility in resistive networks. • Location of the HEMS is important. It is better at the end of feeders for voltage control. • The quality level of historical data is not a barrier. • Real-time operation is not significantly affected by the n° of HEMS. • HEMS contribute to significant power loss reduction (maximum of 4.26%) in networks with high DER penetration.
	InteGrid Swedish demo	• HEMS	• Type of household • N° of HEMS • Type of signal • Response rate	• Peak load reduction: 5% on average. • Energy use reduction: 10% on average. • Self-awareness of household energy used (surveys)	• Single households are more flexible for DR. • Incentives can be based on the type of household. • Price signals are more reliable. However, environmental signals have more potential impact on load reduction. • Incentives require compatibility with household comfort.

Scalability and Replicability Analysis					
Use case	**Project demo**	**DR devices**	**Sensitivity parameters**	**KPIs**	**Main lessons learned**
LV Automation, Supervision, and Control - EU	GRID4EU Swedish demo	• Operational problems in LV networks. • Effects of different loads on phase unbalance that justify implementation of LV monitoring solutions (e.g. AMI)	• Type of network. • DER characteristics (size and location of DG). • Loading of the network. • Level of EV penetration.	• Loss factor. • N° buses experiencing over-voltages.	• The effects on power losses must be monitored in heavily-loaded unbalanced networks. • Implementation of EV slow-charging strategies and DR schemes may mitigate the effects on power losses of EV slow-charging infrastructure (loss factor ranging from 2 to 3.8). • Moderate levels of PV (50-75%) are better in terms of losses than very high or very low shares of PV.
	IGREEN grid Austrian demo	• Voltage control solutions (VoltVar control, VVC, Wide Area Control, WAC)	• Type of voltage control solution implemented. • Installed generation (solar PV)	• % Increase in network hosting capacity.	• There is high potential for voltage control solutions in voltage-constrained feeders in rural areas which are not overloaded. • The average increase in hosting capacity when WAC is implemented is higher (250%) than with VVC (16%), but its deployment is more limited (in less than 30% of the feeders. versus 70% for VVC). • The combined WAC and VVC solution resulted in an average increase of 340% in hosting capacity. • In a network with non-homogeneous penetration of PV, the hosting capacity provided by VVC might be enough for actual requirements.

Scalability and Replicability Analysis					
Use case	**Project demo**	**DR devices**	**Sensitivity parameters**	**KPIs**	**Main lessons learned**
LV Automation, Supervision and Control - India	UGVCL, Gujarat	• AMI implementation • Peak load management • Outage management • Power quality	• Increase in peak load • Loading of the network • Phase balancing of the network • Type of communication infrastructure • Reliability improvement • Voltage, current and harmonic levels	• Decrease in peak load consumption • Decrease in AT&C losses • Voltage levels • Reliability index • Phase balance	• Transformer failure rates depend on AMI implementation in the network • Time of use (ToU) pricing can help peak load management • Power quality management ensures a better voltage level of the network
	TSECL, Tripura	• AMI implementation • Peak load management	• Increase in peak load • Load balancing of the network • Reliability improvement • Type of communication infrastructure	• Decrease in peak load consumption • Decrease in AT&C losses • Phase balance	• Transformer failure rates depend on AMI implementation in the network • Time of use (ToU) pricing can help peak load management
MV Automation, Supervision and Control - EU	GRID4EU: Reliability improvement use cases	• Solutions aiming to improve grid reliability through network automation and reconfiguration.	• Network length. • Network failure rate. • Type of automation solution. • Degree of implementation of monitoring and control.	• Fault awareness, localisation and isolation time. • Reliability indices: SAIDI, ASIDI, SAIFI, ASIFI. • Number of switching operations.	• There is a saturation effect around a degree of automation of 20-40%, according to the SAIFI and SAIDI indices obtained for different shares of telecontrol for urban and sub-urban networks. • The architecture of the automation control system impacts on the time required for the system to perform reconfiguration. Therefore, the time response of the system has an impact on both SAIDI and SAIFI. • The use of SAIFI and SAIDI will prioritise reliability improvement in areas with a higher number of consumers, while ASIFI and ASIDI will prioritise reliability improvement in areas with greater demand.

Scalability and Replicability Analysis					
Use case	**Project demo**	**DR devices**	**Sensitivity parameters**	**KPIs**	**Main lessons learned**
	GRID4EU: Increase in DG hosting capacity use case	• Increase network hosting capacity (NHC) achieved by implementing automation and reconfiguration.	• Based on low demand and concentrated DG at maximum production. • Sensitivity to DG location. • Different voltage limits. • Different degrees of automation.	• % Increase in network hosting capacity. • Energy losses. • Quality of service indicators (line voltage profiles, overload avoided). • Number of switching operations.	• NHC can be increased by reconfiguration. Results show increases of up to 65% of initial network hosting capacity for degrees of automation below 20%. • Higher degrees of automation may not improve hosting capacity since the configurations allowed may not be aligned with the distribution of load and DG.

Table 31: Key SRA features by use

The following observations were made as outcomes of the platform's third workshop:

- Indian project implementation has more than one use case in projects, as opposed to European projects, which implement only one use case per project. This skews measurement and calculation of benefits.
- Data availability is a key issue in Indian projects, due to which CBA methodology cannot be fully implemented.
- Data reporting and transparency are lacking, due to which many active projects were not assessed due to data use restrictions.
- Appraisal of pilot projects in the case of Europe provides necessary inputs for large-scale initiative appraisal. The outcomes of corresponding financial and economic CBAs highlight the profitability of initiatives and its sensitivity to uncertainties in the future scenario.

4.4.1 INSIGHTS ON SPECIFIC KEY ISSUES IDENTIFIED CONCERNING CBA AND SRA ANALYSIS

The aim of the EU-India High Level Platform on smart grids' fourth workshop was to gain insights on specific key issues identified concerning CBA and SRA conducted on the three shortlisted use cases. The issues were divided according to our fundamental framework consisting of four pillars, namely technology, finance, policy and regulation, and social acceptance.

Technology

Question 1

In the context of technology, two crucial dimensions to be kept in mind regarding smart grid implementation in India are variation in socio-economic spread and the level of infrastructure, which contrast with the current situation in Europe. There is significant variation in socio-economic development across different regions of India in terms of indicators such as per capita income and the human development index. The same holds true with regard to electricity infrastructure development. Therefore, deciding on the level of automation across different geographical and demographic areas in India is a major challenge. Therefore, the first question discussed was as follows:

Modernisation of the grid – what should the optimal level of automation be?

Insights : To decide on the optimal level of automation, it is important to first ascertain what is actionable and available for the discom to have a positive business case and customer willingness to participate in the process at the required level of involvement. For their part, utilities need to build a vision based on local needs.

Question 2

Another challenge expected when deploying innovative smart grid solutions is development of a deployment strategy. Smart grid solutions deployed will have a range of innovative technologies. While some of these technologies can be implemented in isolation or greenfielded, others may have interdependencies and significant minimum requirements. Therefore, the first strategically important decision to make is whether to deploy several technologies in parallel or in an incremental linear fashion. Both approaches have pros and cons in terms of factors such as deployment time and implementation complexity and indeed depend on the system where deployment is to take place. Therefore, a pertinent question to discuss is as follows:

How do we choose between a linear and a parallel technology deployment strategy?

Insights: Basic technology will build on other basic technology. Therefore, mostly linear development can be expected, while innovative pilot tests will occur in parallel. It is important to expose utilities to innovative technologies, which then can be customised according to local needs across India. Experts expect a 3-5 year timeline for technology development.

Finance

In our study we observe that in many cases the CBAs are negative at the pilot level but there is potential to make projects net positive when implemented at a larger scale due to economies of scale. Therefore, to understand the value of such projects, two possible approaches can be applied:

simulations of large-scale applications based on results from pilots; and direct application and measurement at a larger scale. Indeed, the answer will lie somewhere in the middle. This leads to the following question:

How do we evaluate benefits from scaling up in the case of India?

Insights: It is important to focus on resolving issues for which the solution is applied for reasons beyond just monetary considerations. Therefore, a broad set of KPIs should be defined and compared across various projects. To evaluate benefits and translate from pilots to large-scale deployment, data sharing is crucial as lesson sharing is key to avoid negative duplication. In this context, an open access data platform to evaluate projects across India with an observatory needs to be developed, therefore providing a common template to share data. Furthermore, implementation in states that are lagging behind could possibly result in higher benefits, but a key constraint here could be a lack of skilled staff, which will entail investment in capacity building.

Policy and Regulation

Given that smart grid projects are generally dispersed and ad-hoc, it is important to understand possible ways to incentivise distribution companies to invest in smart grids, keeping in mind long-term benefits. Various kinds of regulatory approaches discussed widely in the literature can be applied but finding the right balance is crucial. Therefore, a key question to discuss from the policy and regulatory perspective is as follows: **What should the regulatory approach applied to ensure structured scaling up of smart grids in India be?**

Insights: It is important to assess the trade-off between societal benefits and discom benefits to ensure equitable distribution of benefits from smart grid solution deployment. Furthermore, local regulation should work with a long-term vision for discoms to make long-term investments. Regulators should move away from one-off projects to a KPI-driven planning approach to smart grid solution deployment.

Social acceptance

For any project with a visible direct impact on consumers to succeed, it is crucial to have buy-in by relevant customers. This is crucial to ensure participation by these customers and ensure a sustainable positive impact of innovative smart grid projects. This is even more crucial when upfront costs are involved. Consumers need to be sensitised to the long-term benefits of such an investment. Therefore, a discussion question put forward to the experts was as follows:

How can we get customer buy-in to innovative projects in terms of participation and willingness to pay any upfront costs that may be involved?

Insights: The key insight from the experts was the need to provide customers with incentives to participate in such innovative smart grid projects. These incentives can come in various direct and indirect forms. On the other hand, it is important to help de-risk such projects by providing service providers with long term contracts. Furthermore, using open standards will lead to better solutions by accelerating participation and deployment.

5
Conclusions

5 CONCLUSIONS

Implementation of innovative smart grid projects will enable India to reach its ambitious sustainability goals. However, a multitude of challenges in rolling out these novel solutions on a nationwide scale continue to persist. The purpose of this research was to develop a handbook containing insights and tools that will aid implementation of innovative smart grid projects in India. Therefore, this handbook provides its readers with the following:

5.1 SETTING THE RIGHT CONTEXT FOR REPLICATING SMART GRID PROJECTS IN INDIA

To ensure the development of effective actionable research, the first step in this study consisted of setting the right context by understanding from the panel of experts the key needs and specificities to replicate smart grid projects in India. There are four key dimensions: technology, finance, social acceptance, and regulation and policy. These were used in the first expert workshop. The key observations from the workshop are listed in the next section.

Technology

- In a country setup such as India where diverse socio-economic geographies exist, one size will not fit all. Smart grid technological solutions need to be implemented bottom-up according to consumer profiles and distribution company affordability.
- Distribution companies which have implemented base technologies are able to scale up relatively quickly.
- Given the scale and size of implementation in India, perhaps a phased approach to rolling out technology is advisable, and in some cases basic simple technological solutions may suffice.
- An integrated approach to planning smart grid rollout is needed, keeping in mind different layers such as technology, communications, data, monitoring etc.
- A collaborative approach involving different service providers will help roll out better integrated solutions.

Finance

- A clear smart grid implementation roadmap will indicate the scale of investment needed to see a real impact.
- A way to measure the impact of smart grid projects is needed, to understand the different added value at a given stakeholder level and the system level.
- Business model innovation combined with other policy initiatives and the use of other technologies (2nd life) should be accessed and pathways for utilisation should be established.
- The financial health of implementation organisations should first be made viable. Otherwise the value of smart grid investments may not be accurately measured.
- Along with public funding, private investments need to be brought in to bring efficiency and innovation.

Social Acceptance

- Build awareness of smart grid technologies at both the implementer end and the adopter end.
- Consumer-centric solutions are needed and consumers need to be engaged from development to implementation.

Policy and Regulation

- Long term planning and signals are needed to attract investors and businesses to the implementation of smart grids.
- Regulation should allow for data transparency, data sharing and data security to enable business innovation.
- Enabling standardisation across the layers of smart grids, including products, services and processes, is essential and in the long run will enable system-wide applications.
- Target based regulation is needed to kick start smart grid projects.
- Regulatory sandboxes will allow experimentation with innovative solutions and determining upscaling potential.
- Cost benefit analysis of various projects will help evaluate solutions and determine the future course of action.
- Regulation should address the health of distribution companies, which is a major deterrent in the uptake of smart grid solutions.
- Going beyond the energy sector and looking at sector integration (or coupling) would allow cross-sector benefits technically, economically and socially.

5.2 A FRAMEWORK FOR SELECTING USE CASES BASED ON THEIR RELEVANCE TO INDIA.

To achieve success in the rollout of smart grid solutions, it is important to choose the appropriate solutions that are relevant to the needs of the Indian power system. This handbook has presented a framework for selecting solutions by first identifying and prioritising the aims and benefits of these solutions (or use cases) and then quantifying their impact, as was discussed in chapter 2. Furthermore, the framework has been applied to case studies from India and Europe to provide the users of this handbook with hands-on experience and to aid in the selection of use cases for further development of this report. Based on the analysis and insights from the discussions in workshop 2, the following three use cases were selected.

Use case 1: Demand response/consumption optimisation	
Technologies	• Smart meters, in-home display, mobile apps, HEMS/BMS/EMS, load automation, smart appliances/plugs, ZigBEE/wifi/Ethernet
Functions	• Load automation/management in response to tariff/price signals and/or active power set-points
KPIs	• Bill reduction (€), drop in energy consumption (kWh), peak load reduction (kW), user acceptance/engagement/satisfaction (%)
Pros	• Largest market potential with respect to other use cases. Has a market dimension whereas the others are more tech-focused. • Drives energy efficiency • Strong business case for residential consumers in high rise residential projects. • The demand curve has more peaks, which warrants more ramping up capability. Therefore, demand response will help flatten the curve. • The same assets if done with use case 2
Cons	• Residential consumers may not be interested because of low tariffs/lower savings for those who can afford these technologies, so the focus should be on large consumers. • Previously piloted projects did not provide sufficient benefits to be attractive to consumers
Use Case 2: LV supervision and control	
Technologies	• AMI (smart meters, PLC/GPRS/mobile communications, LV supervisor (secondary substation) software
Functions	• Loss reduction, phase balancing, improvement of connectivity model, state estimation
KPIs	• Loss reduction, PQ indicators, OPEX reduction, communications performance
Pros	• Provides increased consumer satisfaction due to reduced disruptions, which also reduces losses for discoms • Application should focus on last mile connection • Scalability and replicability should focus on revenue for utilities • Solutions should factor in the geographical context and consider applicable use cases in rural and urban communities
Cons	• The existing regulatory framework has not evolved to encourage utilities to invest enough
Use Case 3: MV grid automation and reconfiguration	
Technologies	• Fault detectors, telecontrol (breaker primary SS, switch secondary SS), OMS, RF/GPRS/other
Functions	• Monitoring and automation to reduce the frequency and duration of network outages
KPIs	• SAIDI/SAIFI reduction, restoration time, OPEX reduction (crews, vehicles)
Pros	• Very easily applicable in all discoms • Industry islanding should be explored
Cons	• Utilities have not been actively investing in MV grids

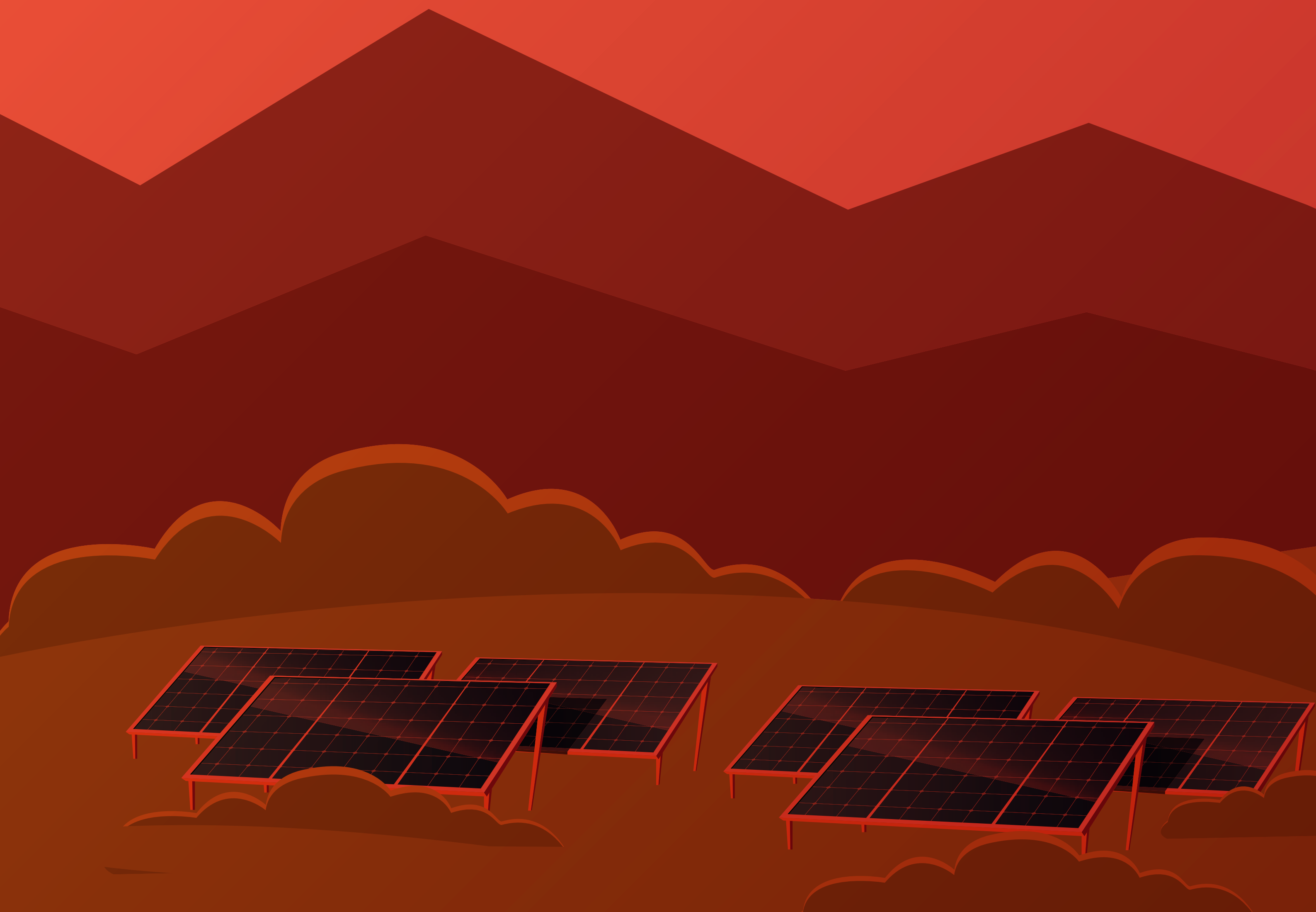
5.3 SRA AND CBA TOOLS TO ASSESS SMART GRID USE CASES

The report has presented a CBA (based on the EC JRC) and SRA toolbox consisting of several dimensions that can be used to assess smart grid use cases. These frameworks were discussed in detail in Chapter 3. As in the previous step in this research, the CBA and SRA tools presented were applied to the use cases identified in Chapter 2 to provide readers of this report with a hands-on experience of analysis done by applying these tools and insights into the scalability, replicability, the costs and the benefits of implementing these use cases in India.

The combination of CBA with SRA allows extrapolation of the results obtained from pilot projects and ex-ante understanding of the financial and social viability of large-scale initiatives. A summary of key insights from the analysis conducted using CBA and SRA and the discussions in workshop 3 is presented below.

The insights were discussed in detail in Chapter 3.

- CBA of demand response use cases aids the definition of business cases to obtain flexibility from third party providers. The existence of a monetary incentive fosters participation by electricity customers in demand side response programmes. In all the cases, clear benefits were observed. These vary according to the type of investment, type of consumers, consumer behaviour and tariff structure. Initiatives concerning MV and LV grid automation, supervision and control involve an upgrade of network infrastructure, which produces benefits for the DSO investing and connected customers because of increased security of supply. However, how much a DSO should invest would require implementing a CBA analysis to determine the optimal level of investment in a given network.



- From a technical SRA perspective, in unbalanced LV networks, for direct control of voltages and higher network hosting capacity installation and control of OLTC transformers using data from smart meters may be a better option than active and reactive power control of solar PV, although its deployment may be more limited. For use cases of MV grid automation and reconfiguration, implementation of network automation in urban and sub-urban areas provides benefits in terms of reliability for automation levels up to 20-40%, with limited benefit beyond this point. Moreover, the effect of network reconfiguration on hosting capacity in these solutions is higher in the case of overvoltages than overloading of lines caused by concentrated DG. Regarding ICT, results of EU demos are usually difficult to extrapolate. The ICT part of a smart grid solution is usually developed ad hoc for the demonstrator, according to the actual needs and existing infrastructure. For demand response, Zigbee to communicate with controllable loads is a possible solution (as in InterGrid). For the ICT part of LV grid monitoring and control solutions, implementation of functionalities in the cloud instead of a dedicated device could be studied to increase reliability.

- From the non-technical SRA perspective, the key issues in providing flexibility through DR are implementation of regulated charges and retail tariffs, as insufficient compensation can be the main limiting factor in implementation of DR. For implementation of smart grid solutions in LV and MV networks, regulation of DSO revenue and different types of incentives should be evaluated to ensure that regulation will not hamper implementation. For LV solutions, regulation of smart metering (deployment, functionalities, management and data access) must also be considered since multiple solutions rely on it. Moreover, the experience of operators is relevant in MV grid automation and reconfiguration use cases.

5.4 RECOMMENDATIONS ON KEY ISSUES IDENTIFIED IN THIS STUDY

This section summarises the experts' recommendations on specific key issues identified in this study and discussed during the workshops.

5.4.1 Technology

To decide the optimal level of automation it is important to first ascertain what is actionable and available to have a positive business case for the discom and the customer willingness to participate in the process at the required level of involvement. For their part, utilities need to build a vision based on local needs both at a centralised and decentralised level.

Basic technology can build on other basic technology. Therefore, a mostly linear development can be expected, while innovative pilot tests will occur in parallel. It is important to expose utilities to innovative technologies, which then can be customised according to local needs across India. Experts expect a 3-5 year timeline for technology development.

5.4.2 Finance

It is important to focus on resolving issues with solutions which goes beyond just monetary considerations. Therefore, a broad set of KPIs should be defined and compared across various projects. To evaluate benefits and translate from pilot to large-scale deployment, data sharing is crucial as lesson sharing is key to avoid negative duplication. In this context, an open access data platform to evaluate projects across India with an observatory needs to be developed. Therefore, a common template should be provided to share data. Furthermore, implementation in states that are lagging behind can possibly result in higher benefits, but a key constraint here could be a lack of skilled staff, which entails investment in capacity building.

5.4.3 POLICY AND REGULATION

It is important to assess the trade-off between societal level benefits and discom benefits to ensure equitable distribution of benefits from smart grid solution deployment. Furthermore, local regulation should work with a long-term vision for discoms to make long-term investments. Regulators should also move away from one-off projects to a KPI-driven planning approach to smart grid solution deployment.

5.4.4 SOCIAL ACCEPTANCE

The key insight from the experts was that customers need to be provided with incentives to participate in such innovative smart grid projects. These incentives can come in various direct and indirect forms. On the other hand, it is important to help de-risk such projects by providing service providers with long term contracts. Furthermore, using open standards will lead to better solutions by accelerating participation and deployment.

5.5 THE WAY FORWARD

It is important to ensure continuity of this platform in order to take forward the work conducted in the first stage to maximise benefits from this initiative. Accordingly, the following key recommendations are a way forward for the next stage and the evolution of this smart grid platform.

- A national level smart grid observatory should be established to monitor development and implementation of smart grid projects across India and to support knowledge and experience sharing to enable effective roll-out of smart grid solutions across the country.
- The smart grid platform should be extended to selected states to support implementation of smart grid projects while taking into account state-specific constraints.
- The smart grid platform should be extended to further study and develop solutions based on the experts' recommendations on specific key issues identified in this study and discussed in the fourth workshop.

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Appendix I
Overview of SRA and CBA in EU projects

Table 32 : Overview of SRA and CBA in EU projects

Project Name	SRA	CBA	Reference Name	Reference	Use Cases		
					Demand response/ consumption optimisation	LV supervision and control (including AMI)	MV grid automation and reconfiguration
InterFLEX	X		D3.8 Scalability and replicability analysis (SRA) of all use cases	[36]	UC2-German Demo: Demand response (DR) UC3-German Demo: Ancillary services/DR UC1-Netherlands Demo: Improve grid flexibility using smart storage units UC2-Netherlands Demo: Improved grid flexibility using electric vehicles UC3-Netherlands Demo: Usability of an integrated flex market		
SmartNet		X	D4.3 Cost-benefit analysis of the selected national cases	[37]	Pilots: Denmark, Italy, Spain		
GRID4EU	X		gD3.5 Scalability and replicability rules gD3.2 & gD3.3 Technical SRA gD3.1 Methodology for the definition of scaling up and replication rules and cost-benefit analysis	[38]	Demo 6 - Maximise PV production in LV	Demo 2 - LV network monitoring and control Demo 5 - Failure management in LV	Demo 1 Germany - Load control in MV Demo 1 Germany - Failure management in MV Demo 3 Spain-Automatic grid recovery Demo 5 Czech Republic - Failure management in MV
GRID4EU		X	gD3.1 Methodology for the definition of scaling up and replication rules and cost-benefit analysis	[38]	Only the methodology of cost-benefit analysis is available.		

Project Name	SRA	CBA	Reference Name	Reference	Use Cases		
					Demand response/ consumption optimisation	LV supervision and control (including AMI)	MV grid automation and reconfiguration
FutureFlow	X		D6.2 Barriers to scaling up and replication of the most promising field test results	[39]	Use case 2 - DR/DG integration within each of the four control zones independently		
SuSTAINABLE	X		D8.1 Definition of scalability and replicability of the SuSTAINABLE concept SuSTAINABLE concept	[40]	SF5: VPP (Virtual Power Plant) as a support for DSO/ TSO in Germany and Greece including DR resources		
		X	D7.1 Cost and benefit analysis in the SusSTAINABLE demos		CBA by demo countries		
EcoGrid EU	X		D7.4 EcoGrid EU Replication Roadmap	[41]	EcoGrid demo		
CLNR		X	Customer-Led Network Revolution, Cost-Benefit Analysis	[42]	Demand Response evaluated		
IGREENGrid	X	X	D5.1 Technical and economic evaluation of replicability and scalability of solutions to increase DER	[33]		LV Voltage Monitoring (AMI) LV Distributed Voltage Control	
InteGrid		X	D7.4 CBA regulatory analysis and business models	[43]	SW HLUC09 (Home Energy Management), SW HLUC11 (Engage consumers in demand side management programmes), PT HLUC08 (Manage internal process flexibility to optimise energy consumption), PT HLUC09 (Home Energy Management), PT HLUC10 (Aggregation and communication multi-period behind-the-meter flexibility from LV meters)	SL HLUC12 (Aggregate geographically distributed third-party resources to offer ancillary services to TSO and DSO), PT HLUC02 (Distributed monitoring and control of LV network using available flexibility), PT HLUC02* (Potential benefits and impact of the LVSE)	

Project Name	SRA	CBA	Reference Name	Reference	Use Cases		
					Demand response/ consumption optimisation	LV supervision and control (including AMI)	MV grid automation and reconfiguration
			D8.1_Technical scalability and replicability of the InteGrid smart grid functionalities; D8.2_Economic and regulatory scalability and replicability of the InteGrid smart grid functionalities; D8.3_ Replication Roadmap		SW HLUC11 (Engage consumers in demand side management programmes), PT HLUC08 (Manage internal process flexibility to optimise energy consumption), PT HLUC10 (Aggregation and communication multi-period behind-the-meter flexibility from LV meters, considered in Cluster 4), PT HLUC11 (Engage consumers in Demand Side Management programmes)	Cluster 2 Flexibility management for optimised LV network operation (HLUC02, HLUC06, HLUC09), Cluster 3 Large customer cVPP (HLUC05, HLUC06, HLUC12)	
ADDRESS		X	D5.3 Key economic factors influencing the adoption of the ADDRESS smart grids architecture; WP5-T5 1-Evaluation of AD benefit, D1.2 Scenario Descriptions	[44]	Active Demand. 4 scenarios (described in D1.2) Scenario 1: Southern City, Scenario 2: Southern Countryside, Scenario 3: Northern Suburban Village, Scenario 4: Mid-Latitude High-Rise community. The documents also review previous estimates of the costs and benefits of active demand		
GOFLEX		X	D7.4_Report on Demonstration Results Evaluation - Use Case 1; D8.4_Report on Demonstration Results Evaluation - Use Case 2; D9.4_Report on Demonstration Results Evaluation - Use Case 3	[45]	UC 2 (Switzerland, flexibility, HEMS, FEMS, CEMS), UC 3 (Germany, HEMS, FEMS)		

Project Name	SRA	CBA	Reference Name	Reference	Use Cases		
					Demand response/ consumption optimisation	LV supervision and control (including AMI)	MV grid automation and reconfiguration
WiseGRID	X		D18.1 Scaling up and replication roadmap	[46]	BM7: Supply-demand balancing by means of implicit DR events (WiseHOME, WiseCORP)	BM2: Efficient monitoring and management of the distribution grid (WG COCKPIT)	
		X	D16.1 Impact assessment and CBA planning; D16.2 Socio-economic and technical impact assessment of WiseGRID integrated solution				
		X	D5.5 Cost/ benefit Assessment Methodology for Network Planning in the Presence of Local Storage				
SOGNO	X		D5.3 Evaluation of scalability and performance	[47]		State Estimation Power Quality Evaluation Power Control FLISR	Power Control FLISR

APPENDIX II: Innovative smart grid implementation with limited data

Case I: Tata Power Delhi Distribution Ltd. (TPDDL) – Battery Energy Storage Systems

TATA Power DDL in collaboration with AES and Mitsubishi Corporation commissioned the first of its kind 10MWh grid connected battery energy storage system in India.

System Configurations:

- No. of Cores: 4 (2.5MWh each core)
- No. of racks in each core: 37
- tems in each rack: 14 battery modules, 1 BMS, 1 node, 1 UPS and 1 inverter
- Battery: LG chem-lithium-ion polymer battery (NMC)
- Energy capacity of each battery: 6.5kWh
- Current carrying capacity: 126Ah
- Battery voltage: 51.8V DC
- Rack voltage: 725V DC
- Total energy capacity of each rack: 91kWh
- Inverter: Parker with 88kVA capacity
- Output of inverter: 415V AC, 126A, connected to LT board by 3ph. 50 sq.mm copper cable
- Isolation transformer: 415V/11kV, 2.5MVA each (Delta/Delta)
- LT switch board: 4 of 4000A each with 38 outputs in each panel
- LT cable from isolation DT to switch board: 5 runs of 1Cx 630Sq.mm
- 11kV switchboard: 4 11kV boards of ABB, 630A each with SEL protection relays

Business case for BESS in Power Distribution:

1. Peak load management

In FY 18-19, the peak load seen by TATA Power DDL was 1897MW. The figure below depicts the winter and summer TPDDL load curves. In general, the peak is between 3-3.15pm and 11.45 pm-12.15 am but the actual peak of solar generation does not coincide with the utility peak. It is pertinent to store the low-cost power from solar and use it during the peak period by using energy storage. The assets installed in the network are rated to meet the peak load and in the remaining periods the assets are under-loaded. During off peak hours the battery can be charged and during peak hours it can be discharged. The figure 23 depicts the benefits of storage in peak load management.

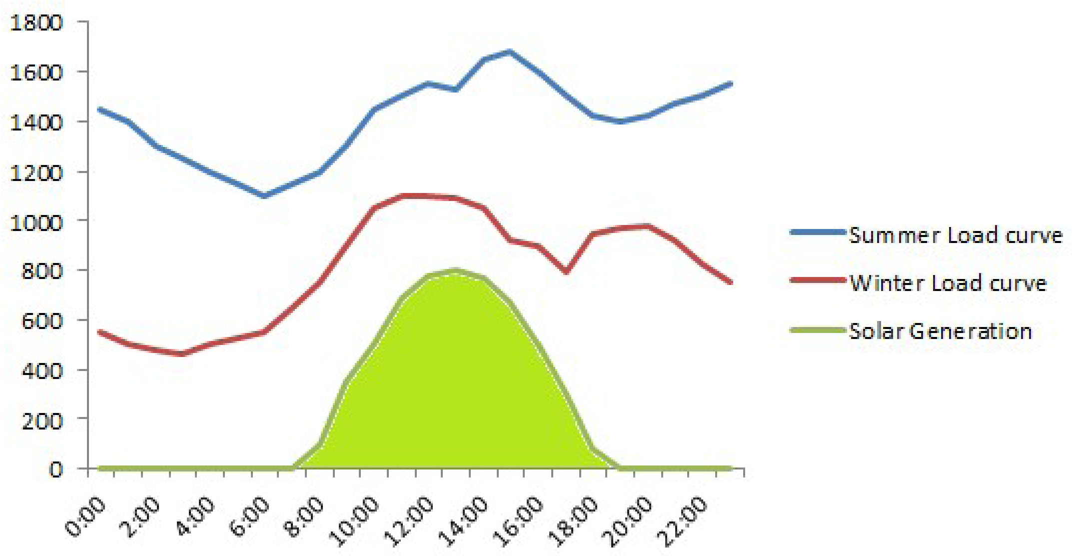

Figure 23: Winter and summer load curve of TPDDL

2. Deviation settlement mechanism (DSM) loss minimisation

A challenge for the power distribution utility is to maintain the power drawn schedule according to DSM regulation. Each state has its own deviation limit defined by the commission based on its peak load. Despite accurate forecasting there are various external factors contributing to deviation in the schedule due to sudden changes in temperature, humidity, rain etc. The only mechanism to manage the deviation is a battery energy storage system where the excess energy can be stored during under-drawn conditions.

TPDDL case study:

According to the regulation Delhi has to maintain the deviation band within ±150 MW. As TPDDL is in the Delhi region, the TPDDL deviation limit has been set at ±38MW. According to the DSM regulation, a penalty is to be paid when under-drawn energy is 38MW below the scheduled drawn. Battery energy storage can help minimise DSM loss as the cost of power during under-drawn conditions will be almost zero. It can be used for charging batteries and they can be discharged during peak load conditions. This not only uses the effective available power but also contributes to grid stability.

In FY 2018-19, ADSM penalties of around 2.32 crores were paid by TPDDL on account of underdrawn and overdrawn energy above 38MW. Roughly around 40% events occurred and in 12% of them there was underdrawn energy and in the remaining 28% overdrawn. This could have been managed effectively through implementation of BESS.

3. Reactive power management

Battery storage can be used for effective management of power quality as it uses power-conditioning electronics to convert the power output of the storage technology to the voltage and frequency of the grid. Battery energy storage can output both active and reactive power at the same time and has four-quadrant operation ability so it will play an important role in the power quality management of distribution networks. All the utilities have a capacitor bank installed to supply reactive power but during high voltage there is no provision to absorb reactive power. Here battery storage will play a vital role in helping the utility reduce penalties thereby improving its operation efficiency.

TPDDL case study:

In FY 2018-19, TPDDL injected around 396.67 MUs of reactive power into the grid when the voltage band was above 103% and overall there was no net drawn at voltages below 97%. A reactive penalty is charged at 0.14 paise per kVARh. From these data it is clear that the 98% penalty was on account of not absorbing reactive power from the grid. Battery storage would help the utility to absorb reactive power, especially in the winter season when the grid voltage rises due to low consumption of power at night time.

4. Renewable energy integration

TPDDL has an installed roof top solar (RTPV) capacity of 1.85MWp and Delhi has a potential of around 450MW roof top holding capacity. TPDDL proactively approaches consumers and helps them get RTPV in their buildings, and using the RESCO model the approach has benefitted by installing around 8.5MWp in consumer premises.

Case II: Tata Power Delhi Distribution Ltd. (TPDDL) – Advanced Distribution Management System

To ensure a reliable power supply and to provide the best to its customers, Tata Power DDL has implemented several world class technologies such as an advanced distribution management system (ADMS) which is designed to replace conventional SCADA-DMS and OMS. It has features like real time integration of smart meter data/distributed generation integration and a GIS single data model with integrated GIS for instant services, automated demand response (ADR), a smart streetlight management system and field force automation (FFA) which utilises real-time network information that spans from EHV to low voltage. Tata Power DDL is the first utility in the world to implement ADMS to such an extent with total integration of all the systems in the utility, i.e. GIS, SAP, MWM/FFA, AMI etc.

Apart from operational technologies, ADMS is also integrated with big data analytics for real time reports and analytics, a power manager portfolio for real time load forecasting and inter control centre communication protocol (ICCP) for real time data exchange with other control centres. The system also helps during times of outages by providing faster resolution of faults with more efficient and accurate results.

ADMS delivers increased productivity and efficiency with active network optimisation and control to enhance the reliability, safety and efficiency of power. Seamless integration of IT/OT gives benefits to both the utility and consumers and creates a utility of the future delivering smarter and sustainable power distribution through integration of technology. The ADMS will also help Tata Power DDL towards implementation of a smart grid, electric vehicle charging infrastructure, battery storage solutions and integration of RTPV by monitoring load patterns and availability of power supply.

To improve reliability parameters, Tata Power DDL has taken many conventional measures like augmentation of the existing network, segregation of long feeders, providing protective devices with proper coordination at optimised locations, adding sectionalising and load break switches at proper locations, improving lightening protection and introducing covered conductor and bird guard etc. In addition to these conventional methods, it is equally imperative to implement progressive technology that integrates the IT and OT systems. ADMS has therefore been adopted to make progress not only technologically but also to enhance reliability and consumer satisfaction.

- SCADA along with a grid sub-station automation system (GSAS) to monitor and control the sub-transmission network.
- DMS along with DA to supervise and control the 11kV distribution network.
- OMS for complaint handling, outage management and crew management.
- Customer information service (SAP-CIS). A unified juncture for consumer interaction and to convey necessary information.

Tata Power DDL strives to maintain its reliability parameters, but taking into consideration the growth of disruptive technologies like DERs including RTPV plants, microgrids and growth in EVs, it is bound to meet regulatory and customer requirements. To meet further expectations TPDDL has stepped towards smart grid technology like smart meters, ADR, BESS and FFA. These evolving technologies increase the volume of data to manage and visualise. Existing technologies like SCADA, DMS and OMS can handle and analyse limited data and are unable to respond to new relevant data coming from both grid sensors and consumers' smart meters effectively.

With new emerging technologies like smart grids, DERs, EVs etc. in place, it is equally important to enhance the capability of the existing network to integrate them. Therefore, a requirement arises for more advanced tools which are capable of organising and analysing huge volumes of proximate real-time complex data and integrating existing technologies in a unified platform for better network, outage and crew management. Reliability and consumer satisfaction will improve with reference to the above stated challenges through ADMS.

Key benefits to TPDDL

ADMS delivers increased reliability, productivity and efficiency through a single integrated operational platform, providing utilities with:

- A system which has a capability to assist the operator for back feeding affected areas from other supply sources for early restoration of customers' power. This improves reliability indices like SAIDI, MTTR etc.

- A reduction in verbal communications between crews/operator via integrated mobile apps for dispatch and switching productivity.

- An increase in renewables generation through adaptive network management
- Reducing the total cost of ownership through IT/OT convergence.

Benefits to consumers:

- Being an integrated system, faults at any level provide power outage information to affected customers along with the duration of restoration in real time through the TPDDL mobile APP, website, IVRS and call centre.

- Scheduled maintenance activity through ADMS facilitates informing affected customer in advance of the duration of non-availability of power by SMS.

- The system has a capability of predicting faults which will result in communicating to customers power non-availability and the estimated duration of restoration by SMS.

- The system provides real time information on faults to maintenance crews for early restoration of the power supply.

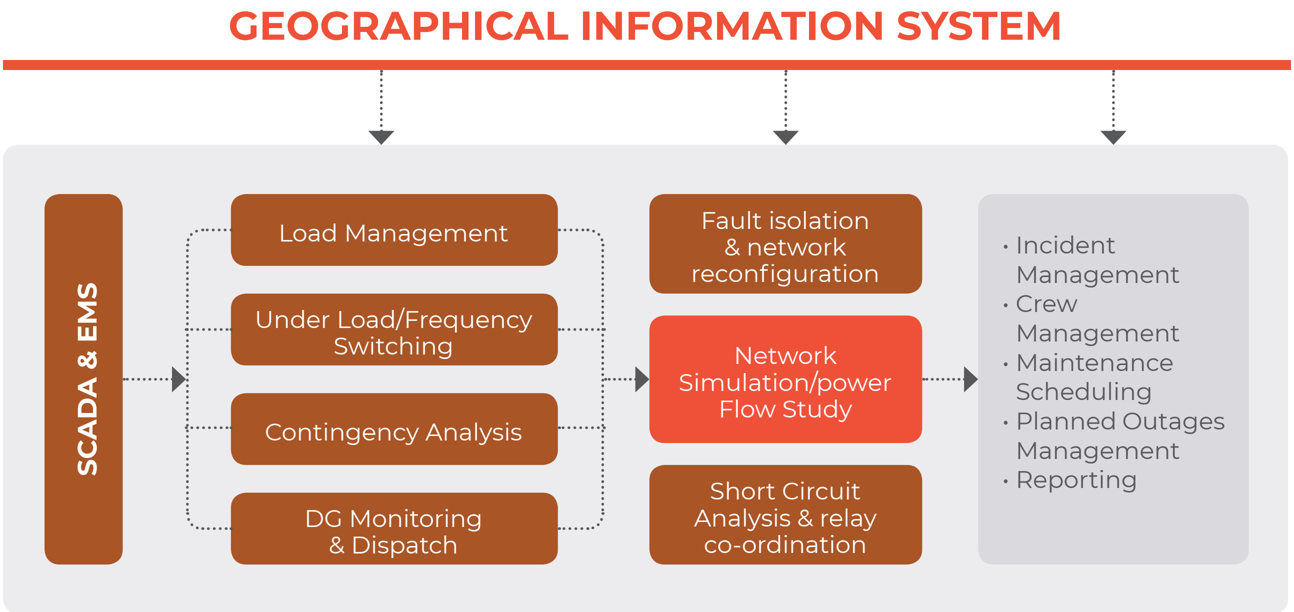

Figure 24 : Architecture of ADMS

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