Improving the Robustness of Urban Electricity Networks
IRENE

D1.1 – IRENE Scenarios and Baseline Model

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Author(s): Tony Clarke, Edward Lambert, Michael Deavis-Marks (Ethos)
Andrea Ceccarelli, Tommaso Zoppi (University of Florence)
Oliver Jung (FTW)
Michael Chai, Yue Chen (Queen Mary University of London)
Alexandr Vasenev, Lorena Montoya (University of Twente)

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EXECUTIVE SUMMARY

This is the first deliverable of IRENE WP1 and it provides the basis for the following project deliverables and the upcoming tasks. The aim of this document is to serve as a first description of scenarios that are considered and further on analysed by IRENE.

For several reasons electricity grids undergo currently a period of significant changes. Due to the introduction of enhanced communication and control facilities, new grid applications become possible. This leads not only to increased efficiency in the transmission and distribution grids but also to improved grid resilience by being more flexible in the way the distribution grid is configured and being able to flexible balance supply and demand.

The downside of this trend is the increased exposure to cyber-attacks that have the potential to cause even long-term power outages. Using distributed generation from photovoltaics or combined heat and power plants in urban environments bares the potential to supply at least the most critical urban infrastructure by operating the grid in island mode and setting up micro-grids to provide electricity to the most vulnerable citizens.

This document tries to capture the different aspects that influence the development of the electricity grids. To do so, four different scenarios for the evolution of urban electricity grids have been identified and the political, economic, social, and technical aspects that are closely associated are illustrated. The initial idea for the scenarios was to discriminate scenarios into categories of grid smartness (low/high) and degree of regulation (regulated/free market) making up the four different scenarios. Finally, a baseline model has been defined that assumes the wide spread use of smart grid components that are the enablers for different smart grid functionalities.

1 INTRODUCTION

In order to get a common understanding the environment IRENE is acting in the definition of a baseline model is an important first step. Finding this model required several iterations and discussions about the proper definition of scenarios and the approach to follow. Moreover, being the first project deliverable, D1.1 plays acts also a document for finding a common terminology.

1.1 PURPOSE

The purpose of the document is to present a baseline model for the evolving smart grid with specific relevance to a city's ability to respond in an energy supply crisis. This model forms the context for all other aspects of the IRENE project:

- Understanding the threats, risks and mitigations for a city's energy supply system
- Developing a "collaborative framework" and associated modelling tools that will explore the ways and means by which the many city actors could effectively engage and respond in an unfolding supply incident
- Evaluating this collaborative framework and its supporting tools for their effectiveness

The next section sets out the approach adopted in developing the baseline model.

1.2 APPROACH

In order to develop the baseline model we began by exploring the of the energy supply system from a city's perspective. The chosen tool for this was the development of a series of city based energy supply scenarios. These scenarios describe *possible* futures that cities may face in addressing their energy resilience needs, they are not forecasts. In developing these scenarios the intent was to push the boundaries as a means to help clarify:

- The key actors and their roles in a city's resilience capability
- Any key variables
- Common themes of critical interest to those actors involved in delivering a resilience response

The Insights and learning from this scenario development then formed the basis for establishing a plausible baseline model for a future city based smart grid, with a 5-10 years horizon. The scenarios were framed from the perspective of a city and its ability to act in a crisis situation; i.e. where there is a prolonged disruption to the city's energy supply to the extent that it threatens the welfare of its citizens.

We do not attempt to quantify how long the disruption will last

In developing these scenarios we considered two broad parameters that will constrain or enable a city to prepare for and act in an energy supply crisis:

- The "smartness" of the city's infrastructure
- The regulatory and policy framework

A city's "smartness" is a function of how advanced the grid infrastructure is and the degree to which it can be used to actively respond in a supply crisis, e.g. through islanding and quarantining.

The regulatory and policy framework for energy provision will constrain a city's freedom to act. At one extreme this will limit all action to a regional Distribution Network Operator (DNO) giving the city authorities a tightly constrained scope in terms of their energy resilience response. At the other extreme is a regime that gives a city, in principle, complete freedom to prepare for and respond in a crisis situation.

In summary this offers four scenarios from a city's perspective:

Table 1: Set of scenarios

	Low smart	**High smart**
Regulated	1. No change	2. Constrained response
Free market	3. Best endeavours	4. Freedom to act

The next section starts by clarifying some key underlying assumptions and context relevant to all the scenarios. The final section draws out the conclusions and formulates a model based on these scenarios.

1.3 CONTEXT

This section identifies a range of factors that are collectively driving the evolution of the energy landscape within which EU cities must operate. These include:

- The central role (currently) of DNOs as natural monopoly suppliers
- The emerging reality that current DNO business models are seen as increasingly under threat, demonstrated by recent credit downgrades of European utility companies [1]
- The current regulatory frameworks and its incentives – in many EU states these are not aligned with the rapid pace of development of new distributed electricity technologies and tend to favour the incumbent operators (both generators and DNOs)
- Game changing technologies that are becoming increasing pervasive, i.e. smart meters, electric vehicles (EV), distributed generation (DG), heat pumps (HP), photo voltaic (PV) and storage. Implementation across cities and countries remains uncoordinated and largely driven by economic and political pressures rather than longer term planning for energy resilience
- A cities' role in energy resilience planning, i.e. addressing the welfare of its citizens - in some EU states they have limited scope to act (other than by building a cooperative framework)
- The financing of the smart grid - cities may be reluctant to, and in some EU states prevented from, make investments that expose them to higher levels of debt; collaboration between cities may alleviate such exposure
- Taking control of energy resilience may provide cities with additional revenue streams
- The emergence of the Internet of Things and Big Data - offering the opportunity for

cities to coordinate best practices in smart grid technology and energy resilience and so accelerate successful implementation

- The long term demand profile will be influenced by some major trends
  - Increasing energy efficiency
  - Reducing DG costs (e.g. PV)
  - Increasing number of households
  - The move to a low carbon economy
  - New types of load (e.g. EV, HP)
  - Increasing load due to climate change (e.g. the increasing use of air conditioning in response to warming)
  - The development of energy storage
  - Increasing urbanisation
  - Aging populations
  - Human activity/societal events

Together these factors indicate the complexity of the energy landscape as a diverse collection of actors and emerging technologies co-evolve.

2 The Smart Grid

The section considers the current thinking on the smart grid:

- Smart Grid definition
- Smart Grid functionalities
- Smart Grid components

Each is explored in the following sub-sections.

2.1 Smart Grid Definition

The Smart Grid as defined by the European Commission is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety [2].

The main drivers for are the goals defined by the international community to mitigate climate change. This requires the fundamental change of the generation, distributed and consumption of energy. The main changes to be considered when reaching the goal are:

- Integration of renewables and energy storage
- Increased energy efficiency
- Increased electrification of transport (electric vehicles, electric buses, etc.)

This requires in particular the significant changes in the distribution networks and in system operation. While large windfarms will be connected to the transmission network, small scale renewable generation (e.g., small wind turbines, photovoltaic panels, CHP) and storage (e.g., in batteries, flywheels or super-capacitors or in plug-in hybrid electric vehicles) will be found in the medium and low voltage grid affecting the way distribution networks are managed.

Currently standard development organizations as CEN/CENELEC/ETSI, NIST and IEC are creating the first standards to ensure interoperability between the different components of the smart grid.

2.2 Smart Grid functionalities

Although components of the currently installed electricity grids offer smartness to some degree, all parts need to be updated to support the new functionalities. The following components are crucial for the smart grid can be considered to be the key enablers for smart grid functionality. Annex 1 shows the fundamental applications of the smart grid that build the bases for further enhanced applications like **Microgrids** or **Demand Response**. The figure also presents the interdependencies between the different functionalities, e.g. Energy Storage and Distributed Generation are required to build a Microgrid.

2.2.1 Demand Response

One of the major drivers behind the introduction of the Smart Gird is the demand response functionality. Demand response comprises the technologies and incentives that can be used to balance power supply and demand on one hand side and to balance of reactive power supply and demand on the other hand side. This means either shaping energy load profiles by requesting changes a) in use or b) generation. It is important to note that Demand Response as it is defined today is always voluntarily. The motivation of customers to participate in demand response programs can be

- Price-based, by time varying prices depending e.g. on time of day with increased prices during peak demand hours, or
- Incentive-based through giving customers incentives for reducing their load.

Demand response is considered to be one of the most complex smart grid applications. Non-automated mechanisms like phone calls are still in use e.g. in the generation domain. However, there are also automated mechanisms in use [7]. The implementation of demand response mechanisms using smart grid technology to send pricing or shedding signals will be an enabler for:

- The large scale integration of renewables and distributed generation, and
- For shifting of peak consumption.

Generation of renewable energy from wind generators or photo voltaic is barely predictable because of changing weather conditions. Thus there will be an increased need for demand response in order to balance supply and demand. Applying more reliable forecasting mechanisms for demand and supply will leverage the integration of renewables.

Shedding loads during peak demand can decrease the necessity for building new power plants. While peak demand emerges only a few time a year utilities have to build power plants and lines to meet these demands.

Load shedding is also mechanisms in case of congestion where not sufficient energy is available to meet the demands of all customers caused e.g. by faults in the transmission grid. The imbalance leads to a drop in frequency and grid instability. In order to prevent black out and to preserve the grid’s stability the load needs to be reduced by shedding.

In order for demand response mechanisms to work smart appliances or smart plugs are needed in the customer premises. The smart metering system is enabler for communication with Advanced Metering Infrastructure (AMI) components and home gateways that interacts with the smart grid components in the building [9].

2.2.2 Smart appliances

Smart appliances are controllable and capable of deciding when to consume power. This can be used to reduce peak loads which have a major impact on electricity generation costs. Moreover, this functionality can be used for load shedding in case of congestion, e.g. when there is not enough energy available from renewables or in case of faults in the grid.

2.2.3 Microgrid operation

In order to meet the European goals on carbon reduction the massive use of renewable energy sources is required. In particular in urban areas with dense housing to the advent of distributed energy generation from combined heat and power (CHP) plants or renewable resources like photo voltaic as well as large scale power storage systems is expected. This will also require significant changes in the operation of the distribution grid and changes in system operation with impact on the transmission grid.

The implementation of distributed generation and power storage will enable some areas to run as a microgrid supplying consumers also when disconnected from the centralized urban grid. Microgrids incorporate generation capabilities for meeting local demands and feeding unused energy to the central grid. The time period the microgrid can be operated disconnected depends on how generation and consumption can be balanced.

The smart grid acts as an enabler for these changes in the way that it offers the platform to control generation and consumption in the grid of increased flexibility. Moreover, with the increased generation from renewable resources the ability of utilities to manage also customer demand is fundamental. The microgrid is controlled by its own core for energy management that is not only able to control distributed generation but also able to manage smart appliances in the microgrid.

2.2.4 Improved grid operation

The enhanced possibilities for monitoring and control of power flows and voltages in the smart grid will also improve automated fault identification and ease grid reconfiguration after faults and thus reduce outage times. The advanced metering infrastructure will enable utilities to gather more detailed information of the distribution grid down to the low voltage level. Information gathering and control mechanisms can further on be used for dynamic protection and automation schemes.

2.2.5 Advanced Metering Infrastructure (AMI)

The AMI infrastructure features two-way communications between consumers and utilities for power measurements, and fault detection. The smart meter can also acts as a gateway to the smart appliances. The AMI consist of a smart meter in the customer premises and a Meter Data Management System operated by the utility.

2.2.6 Smart substations

Smart substations are enabled for monitoring and control of critical and non-critical operational data such as power factor performance, breaker, transformer and battery status, security, etc.

2.2.7 Smart distribution

A smart distribution grid can be divided into two subsystems: Distribution Automation (DA) and the Distribution Management System.

The aim of **Distribution Automation (DA)** is to respond in real-time and in an automated manner to status changes caused by loads, generation, or failures in the distribution system. This requires Intelligent Electronic Devices (IED) and advanced information technology (IT) development to enable automated decision making and the reporting critical information to the utility control center. Thus, real-time data acquisition and communication networks are key enablers for the implementation the smart distribution grids.

A **Distribution Management System (DMS)** is a collection of applications designed to monitor & control the entire distribution network efficiently and reliably. It acts as a decision support system to assist the control room and field operating personnel with the monitoring and control of the electric distribution system.

2.3 SMART GRID COMPONENTS

Annex A shows the different subsystems that make up an energy grid. Most of the mentioned subsystems already exist in the present legacy grid but numerous components will be introduced by the smart grid. The list of smart gird components can be found in Annex A of this document. IEC SG3 has developed a comprehensive set of components that will be part of the future smart grid. As IRENE is mainly focusing on the urban distribution subsystem only the relevant components from the distribution and consumption domain are depicted. The transmission and generation domain are not considered in this version of the scenario description. It needs to be considered later if this view is sufficient for the analysis or it needs to be extended.

In addition to the already mentioned functionalities the different models of consumption are considered. The industrial system represents a large enterprise that is running its own energy management system. The main difference between the industrial and the Home automation subsystem is the existence of a Process Automation System in the Industrial subsystem. The role of the Process Automation Subsystem is to control and monitor industrial production plants.

3 THE SCENARIOS

This section begins by considering:

- The overall context within which the scenarios were developed
- A description of "smart grid", highlighting key features and capabilities

This broadly establishes the key factors, features and trends that underpin the scenario development. We then move on to describe each of the four scenarios introduced above. Their features are explored using a PEST (political, economic, social, technical) framework.

3.1 SCENARIO 1 - NO CHANGE (LOW SMART & REGULATED)

This represents the status quo. While there are differences between EU members the current state of smart grid technologies is broadly similar. Ownership, operation and market concentration of the distribution grid though varies significantly across the EU with at one extreme Ireland with a single DNO with 100% distribution share through to Germany with approximately 800. While these represent different "departure points" the trends discussed in the previous section point to similar journeys across the EU.

3.2 SCENARIO 2 - CONSTRAINED RESPONSE (HIGH SMART & REGULATED)

Political:

- Coordinated city lobbying, in those EU states where there is a small number of DNOs, persuades the regulator(s) to address city energy resilience concerns by licensing city based independent DNOs, increasing competition for connections
- Legal constraints on micro-grids implementation are broadly overcome (e.g. way leaves for infrastructure installation)
- The regulators continues to create incentives for DNOs to innovate and play a full role in delivering a sustainable energy sector that provides value for money for consumers
- As extreme weather events increase, due to global warming, Cities come under pressure from their citizens and businesses to have an increasingly effective energy resilience response

Economic:

- Regulatory price controls promote DNO investment in delivering a sustainable energy sector and its enabling technology and infrastructure (smart grid)
- Energy demand continues a steady rise in line with economic growth, new house building and new consumer demand (EV, HP)
- This demand profile is sufficient to ensure that DNOs will achieve their anticipated return on their investment
- The demand profile is sufficient to attract the necessary investment capital
- This coupled with the reducing cost of distributed generation and storage encourages investment in city based micro-grids and power generation
- Cities across the EU increasingly own and operate their own DNOs to support their own micro-grids and power generation providing new revenue streams (and increasing competition within the distribution sector)

Social:

- Increasing urbanisation and an aging populations puts increasing pressure on a wide range of city services

- As the city finds it increasingly difficult to respond community action groups emerge that amongst other things begin to create community energy schemes (local generation, micro-grids, etc.)
- Where the city has the infrastructure they respond by providing coordination services to facilitate these initiatives (e.g. providing connection services through the cities' DNOs)

Technical:

- The investment in infrastructure results in highly interconnected grid capable of islanding and quarantining at a fine grained level
- A range of Energy Service Companies emerge that specialise in load balancing and storage solutions for micro-grids

3.3 Scenario 3 - Best endeavours (Low Smart & Free Market)

Political:

- There is an increasing pressure towards market liberalisation
- The political response is increasing deregulate the energy distribution and supply markets encouraging competition
- Independent DNOs and energy service companies proliferate
- Pricing for all distribution services is left increasingly to the market
- Cities must work hard to create the necessary collaborative frameworks to support their resilience planning

Economic:

- The cost of micro generating and storage keeps falling, energy efficiency improves and de-industrialisation (e.g. business/industry relocating offshore) continues resulting in a slow growth in demand for the foreseeable future
- The adoption of cheaper micro generating coupled with a slow growth in demand results in the amount of electricity to be distributed over the distribution grid falling
- The unit price of the electricity (£/kWh) rises to cover fixed distribution costs
- Energy customers (domestic and business) have an incentive to increase micro generation, improve efficiency
- The incumbent energy companies fail to innovate or adapt their business models and a vicious circle is established that results in the end of the regional distribution natural monopoly
- Inward investment to the city suffers as businesses find it increasingly difficult to guarantee a high quality value for money energy supply

Social:

- The increasingly fragmented market exposes the most vulnerable citizens to further difficulties in negotiating a fair price for their supply with possible social unrest resulting

Technical:

- The lack of a sufficiently smart infrastructure proves to be a disincentive for sharing of energy resources and results in highly fragmented energy distribution and supply sector with multiple ad-hoc solutions

3.4 Scenario 4 - Freedom to act (High Smart & Free Market)

Political:

- There is an increasing pressure towards market liberalisation
- While there is pressure to deregulate and increase competition government signals a clear intention to achieve this in stages responding to the market as it evolves
- As the natural distribution monopoly gradually dissolves, due to an increasingly smart grid and pricing pressures, regulation is reduced but leaving in place connectivity standards
- The move towards devolution continues and cities and their economic regions gain increasing control over their priorities and spending
- Cities are free, in principle, to become significant actors in both energy generation and supply giving them a high degree of control over their resilience planning

Economic:

- The cost of micro generating and storage keeps falling, energy efficiency improves and de-industrialisation continues (business/industry relocating offshore)
- EV and HP take up does not offset the falling demand
- The reduced demand results in the amount of electricity to be distributed over the distribution grid falling
- The unit price of the electricity (£/kWh) rises to cover fixed distribution costs
- Energy customers (domestic and business) have the incentive to increase micro generation, improve efficiency and continue de-industrialisation
- The finance sector increasingly adapts to the emerging market realities and moves its investments from the DNOs to the emerging eco-system of energy service companies further eroding the DNOs natural monopoly
- Cities become natural "units of investment" and increasingly develop their own energy infrastructure over which they have complete control
- The ability to respond flexibly to demand encourages urbanisation and inward investment

Social:

- The city can increasingly support vulnerable citizens
- Centralised city data leads to data privacy concerns

Technical:

- Over time an increasing sophisticated smart grid evolves enabling extensive control over quarantining and islanding in a crisis response

4 CONCLUSIONS

The scenarios deliberately explore the extremes of the two chosen parameters; the "smartness" of the city's infrastructure and the degree of policy regulation. The project though needs to develop a "baseline model" for a smart grid infrastructure as a basis for exploring the other project objectives.

Before developing this model we reflect on the following:

- The unknowns
- The likely response of a typical city given the unfolding technical and policy landscape, and
- The likely response of the DNOs

The final sub-section draws together the insights and proposes the baseline model.

4.1 THE UNKNOWNS

The key unknown in establishing this model:

- investment appetite (in smart technologies)
- technical maturity (of smart technology)
- regulatory response to the evolving market realities
- the degree to which cities will invest in smart grid technologies

Investment appetite – we think this a key theme as the market evidence is that the financial sector are no longer supporting the large scale utilities [1]. Over the last six years the value of Europe's top 20 utilities has halved. This suggests that the financial sector is increasingly aware that the existing utility business model is threatened by new disruptive smart technologies. As a consequence they are adjusting their investments accordingly.

Technical maturity – all aspects of smart technology are rapidly evolving. This ranges from the year on year fall in the price of PV and storage, the growing acceptance of EV and home micro-generation through to the increasingly pervasive Internet of Things (IoT) and big data. There is no sign that this trend will slow.

Regulatory response – while broadly technology agnostic many EU governments, in trying to balance the need for security of supply, the drive to decarbonise and ensuring affordability, tend towards support for the incumbent larger utilities which in turn tends to maintain the status quo. With exceptions (e.g. Germany) they are not yet recognising the disruptive nature of the evolving smart grid technologies. Given the level of lobbying and the emerging market reality touched on above we feel that while government policy will respond albeit in "catch up" mode.

The cities' role – there is a broad trend that places cities at the heart of economic regeneration and prosperity. Cities have the scale and financial base to enable them to become key players in the energy sector. The pace of this trend varies across the EU. For example, the city of Munich has already invested €900m in renewables and has plans to invest €9bn so that in can supply the entire city by 2020. Where Munich leads other UE cities will surely follow.

4.2 CITY LIKELY RESPONSE

Given the previous observation we anticipate that cities across the EU will proactively respond to the evolving energy landscape, albeit at different rates. We believe that cities will:

- Investigate, and increasingly adopt, city owned energy assets, providing both security of supply for citizens and additional revenue streams for the city
- Seek energy infrastructure investment through capital investments and/or public-private partnerships
- Instigate and promote community energy schemes, possibly in partnership with external investors

4.3 DNO LIKELY RESPONSE

The DNOs are *currently* the key actors in urban power distribution. With the steady move towards grid parity[1] and the themes discussed above we believe that DNOs will:

- Increasingly recognise that the business model based on selling volume (kWH) is not sustainable
- Adapt by selling value added services, e.g. load balancing, flow management and "energy insurance" (for when the sun is not shinning and/or the wind is not blowing) while differentiating around "local supply" and the provision of "green energy"

4.4 THE BASELINE MODEL

Drawing these threads together we plan to adopt a baseline model with a 10 year horizon having the following characteristics:

- Consumers – significant use of home energy efficiency measures (the impact of demand side response techniques) and alternative energy technologies with consumers increasingly becoming prosumers
- Cities – widespread use of distribution technologies and generation through a combination of municipally owned and community projects but security of supply and addressing the de-carbonisation agenda remaining a state responsibility
- Regulators (government) – policy in ongoing catch-up mode with market realities (further incentivising distributed generation and new distribution technologies)
- DNOs – remain an important actor in the city energy distribution but with increasing emphasis on value added services
- New actors – new energy services companies offering supply, aggregation and distribution services
- Smart technology components – wide spread use, although not ubiquitous, of local storage, PV, HPs and EVs, IoT, big data and ICT driven distribution technologies, providing a degree local capability for load shedding, balancing, islanding and quarantining

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[1] Grid parity - broadly the point at which the price of alternative energy is the same as that provided by the DNOs

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6 ABBREVIATIONS

AMI	Advanced Metering Infrastructure
CPH	Combined Heat and Power
DA	Distribution Automation
DER	Distributed Energy Resource
DG	Distributed Generation
DMS	Distribution Management System
DNO	Distribution Network Operator
DRMS	Demand Response Management System
EMS	Energy Management System
EV	Electric Vehicle
HAN	Home Automation Network
HP	Heat Pump
IED	Intelligent Electronic Device
LNAP	Local Network Access Point
MDMS	Meter Data Management System
NIC	Network Interface Controller
OMS	Outage Management System
PEV	Plug-In Electric Vehicle
PV	Photovoltaic
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition

A THE SMART GRID PYRAMID

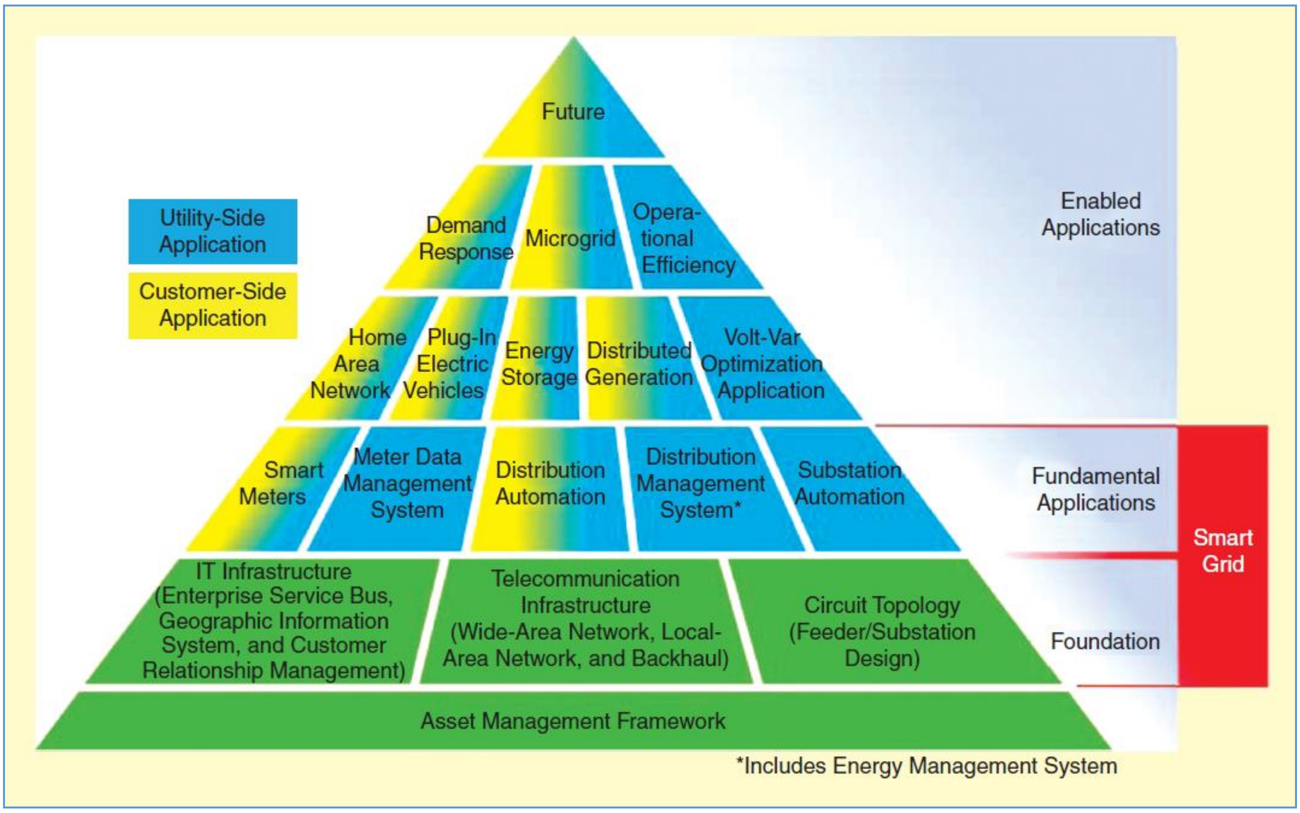

Figure 1: The Smart Grid Pyramid [5]

B Mapping of Smart Grid Components

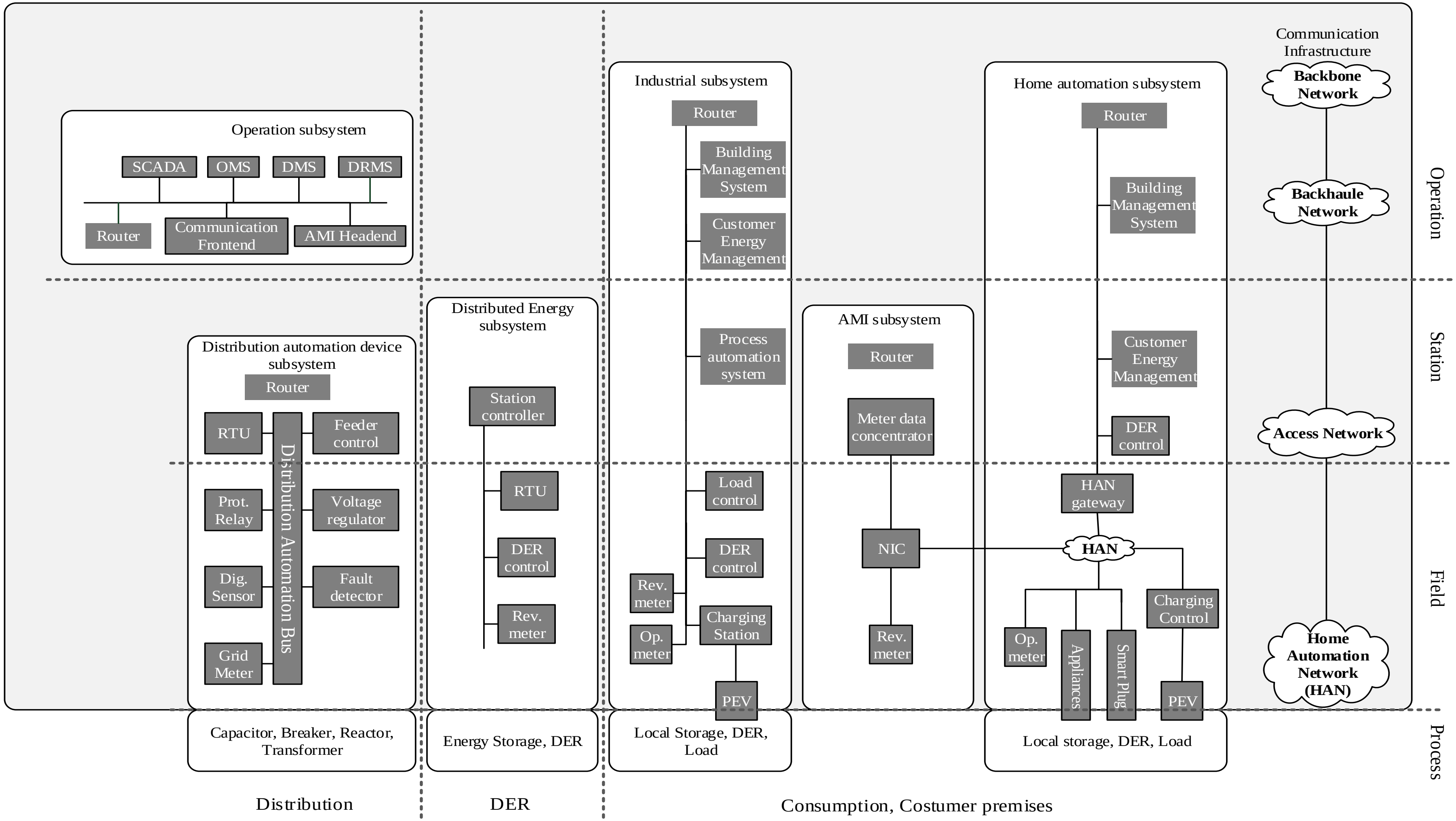

Figure 2: Mapping of Smart Grid Components [10]

C LIST OF KEY SMART GRID COMPONENTS

Table 2: Smart Grid Components [10]

Component	Description
AMI Head End	A system which acts as back-end for the metering communication and controls and monitors the communication to the meter devices. The collected meter information is provided for other system like meter data management
Appliances	Appliances within buildings which are providing an interface to influence their consumption behavior
Billing	Application which creates the energy bill information based on received metering information
Building Management System	A system consisting of several decentralized controllers and a centralized management system to monitor and control the heating, ventilation, air conditioning, light and other facilities within a building.
Cap Bank Controller	Device or application which controls the reactive power generation of a controllable capacitor bank, typically to maintain the voltage at a certain node in the grid
Capacitor	Two-terminal device characterized essentially by its capacitance
Charging Control	Controls the charging of one car at a residential customer side according to set points received from the customer‘s energy management
Charging Station	Single or multiple power outlets specially designed to charge the battery of cars. Typically including also facilities meter the energy consumption and to authenticate the owner of the car to be charged for settlement reasons.
Communication Front End	Application or system providing communication with the substations to monitor and control the grid
Demand Response Management System	(abbr. DRMS) Demand Response Management System; a system or an application which maintains the control of many load devices to curtail their energy consumption in response to energy shortages or high energy prices. A DMS may have interfaces to other DMS.
DER Control	Control of a DER the allows the adjustment of its active or reactive power output according to a received set point
Digital Sensors	Sensors for voltage, current, etc. with a digital interface that allows connecting the sensor directly to the substation integration bus
Distributed Energy Resource	(abbr. DER) Distributed Energy Resource; a small unit which generates energy and which is connected to the distribution grid. Loads which could modify their consumption according to external set points are often also considered as DER
Distribution Management System (application server)	(abbr. DMS) Application server of a Distribution Management System which hosts applications to monitor and control a distribution grid from a centralized location, typically the control center. A DMS typically has interfaces to other systems, like an GIS or an OMS
Energy Storage	An electrical energy storage which is installed within the distribution grid or DER site and operated either by a utility or energy producer
Fault Detector	Special devices typically mounted on distribution lines to detect whether a high current caused by a network failure has passed the supervised distribution line.
Feeder controller	Distributed Automation within a distribution feeder controlling typically voltage profile and providing fault restoration logic

Component	Description
HAN Gateway	A specialized gateway device or application which establishes the communication between external systems and the Home Automation Network (HAN) devices
Load	Energy consuming devices at customer site which might become subject for energy management
Load controller	Control the energy consumption of a load according to an received set point without jeopardizing the desired process of the load
Local Network Access Point	(abbr. LNAP) (Functional) Specialized Network Interface controller between the Local Network (within the private area) and the AMI system
Local Storage	An electrical energy storage which is installed behind the meter point an operated by the energy consumer/produce and not by the utility
Meter Data Concentrator	Device or application typically in a substation which establishes the communication to smart meters to collect the metered information and send it in concentrated form to an AMI head end
Meter Data Management System	(abbr. MDMS) Meter Data Management System is a system or an application which maintains all information to be able to calculate the energy bill for a customer based on the meter data retrieved from AMI head end(s). The energy bill information is typically forwarded to consumer relationship and billing systems
Network Interface Controller	(abbr. NIC) ―A network interface controller (also known as a network interface card, network adapter, LAN adapter and by similar terms) is a computer hardware component that connects a computer to a computer network.‖ (source: Wikipedia)
Operation Meter	Device which monitors the energy consumption for operational and control reasons. The meter values are not used for commercial purposes
Outage Management System	(abbr. OMS) System or application which intends to help a network operator to handle outage in optimizing the fix depending on many criteria (number of customer minutes lost, number of affected customer, capability of the network, …)
Plug-In Electric Vehicles (PEV)	(abbr. PEV) A vehicle with an electric drive (as only drive or in combination with a fuel engine) and a battery which can be charged at a charging station.
Protection Relay	Devices or application which monitors voltage and current at the terminals of grid devices to detect failures of this equipment and than issuing tripping commands to circuit breaker to avoid further damages.
Radio	Synonym for wireless communication
Reactor	(also named inductor) Two-terminal device characterized essentially by its inductance
Recloser	Special switch for distribution feeder typically combined with some automation logic to execute automated restoration after a failure in the corresponding feeder.
Registration	Application within an energy market system which handles the user registration for the market and monitors its transaction at the market.
Remote Terminal Unit	(abbr. RTU) A remote terminal unit is a microprocessor-controlled electronic device that interfaces objects in the physical world to a distributed control system or SCADA by transmitting telemetry data to the system, and by using messages from the supervisory
Revenue Meter	Device which measures the energy consumption within predefined cycles. The metered energy consumption is used to determine the energy bill

Component	Description
Router	TCP/IP communication device which typically interconnects an internal network with the public network infrastructure.
Smart Plug	Synonym for a load switch which can be controlled by the customer energy management via the home automation network
Substation Integration Bus	Intercommunication system for all intelligent electronic devices (IED) within a substation
Supervisory Control And Data Acquisition (abbr. SCADA).	Supervisory Control And Data Acquisition system provides the basic functionality for implementing EMS or DMS, especially provides the communication with the substations to monitor and control the grid
Transformer	Electric energy converter without moving parts that changes voltages and currents associated with electric energy without change of frequency
Voltage Regulator	(abbr. VR) Device or application within the substation automation or a power plant to control the voltage at busbar(s) within the substation

D MIGRATION TO THE BASELINE MODEL

The four scenarios and political, social, technical and economic aspects that are influencing the evolution of the electricity grids were presented in Section 3. In this Annex we highlight the technological aspects that characterize the evolution of the electricity grids and need to be taken into account during further analyses done by the project.

D.1 EVOLUTIONARY FEATURES

This is a list of the most relevant actions that a city could take in the future to update, improve and reorganize its existing grid infrastructure. The evolution stories presented in the rest of this annex are based on these features.

1. **Reduce carbon intensity.** In [13] the authors observe that under current policies and trends, global energy demand is predicted to increase by 40% from 2010 to 2030 and carbon dioxide emissions are expected to rise in tandem.
2. **Standardize different types of Smart Grid** in a specific city. In [11] we can see that the China energy distribution system is split into two grids: State Grid (80% services) and Southern Grid (20% services). We can imagine that in a lot of cases the heterogeneity of these systems can generate some kind of problems that a city administration wishes to avoid.
3. Utilization of **Combined Heat and Power (CHP) techniques**. In [13] the authors point out that with traditional coal-fired plants, only 30-35% of the fuel consumed is converted into electricity. In combined heat and power plants, which use a variety of fuels and share the heat they produce with nearby buildings, efficiency can reach 85%.
4. Encouragements to adopt **Electric Vehicles (EVs).**
5. Incentives to citizens, factories and companies to **adopt renewable energy sources**: Solar Power, Wind, Tides, ...
6. Utilization of **advanced Metering Tools** (complex Smart Meters, Smartphones, …)
7. **Growing number of citizens**.
8. **Decentralization of the energy production.**
9. **Increasing number of sensors** distributed in a specific or in a wider area.
10. **Changing grid maintaining strategy**. We imagine that some portions of the entire grid have higher criticality than others, so for example build some resilient (i.e., self healing) sub-grids may be a necessity.
11. Changes about **data collection and analysis policies**.
12. Incentives to the **electrification of Heating Systems**

13. **Improved Load Balancing strategies.** In [5] we can see an observation that nearly 90% of all power outages and disturbances have their roots in the distribution network, so that aspect should assume a critical relevance in our context.

14. Adoption of an **Automated Metering Infrastructure (two ways)** that manages the communication channels between the supplier and the consumer and allows the grid administrator to apply some optimization (i.e., Demand Side Response) and load balancing techniques.

15. Creating specific **micro-grids** with specific requirements and functionalities.

16. **New energy storage or distribution points.**

17. Adoption of some kind of **protection from natural disasters.**

18. Adoption of some kind of **protection from external attacks.**

19. **Growing support of Internet of Things**

20. New **availability of energy service companies** that want to operate in our city.

21. **Promotion of community projects** aimed to improve distribution, connection and reaction technologies.

D.2 NO CHANGE (LOW SMART / REGULATED)

This is the starting scenario that is further away from the objective traced by the Baseline Model: the smartness is limited to few elements and DNOs own most of the energy resilience response permissions, giving the city a limited constrained scope. We suppose the following evolution story for that situation.

D.2.1 Continuous supply of energy problem

Based on recent warnings about the continuity of the electricity erogation coming both from some factories and the hospital, the city's authorities decide that they must face up that problem.

- City takes few **storage points** located near by the key buildings, **creating small micro-grids** with specific objectives.
- A **basic metering structure** is built for the communications between the key buildings and the energy supplier
- The city receives some collaboration proposals from other energy service companies and decides to give the consumer the possibility to choose from all available companies. The competition rises and the quality of the offered services is continuously improving.

D.2.2 Terrorist attacks countermeasures

Due to the recent increase of terrorist attacks, city authorities want to adopt some kind of protection against that type of risks

- The existing limited grid is extended with the introduction of **new sensors** that send the observed data to the monitoring center.

- To support this change, the existing energy erogation system acquires a lot of “smart” characteristics, especially due to the adoption of **two way communication channels** that allows the grid administrator to take appropriate countermeasures to face up the detected problems.
- A **basic data collection and analysis system** is developed.

D.2.3 Incentive to micro-generation

Thanks to the optimization of the energy distribution through the key buildings of the city a good part of the fees collected by the city can be used to incentives the citizens to become micro-producers adopting PV panels or wind micro-stations where possible.

- Some micro-energy production sources are now connected to the grid, that must evolve with the introduction of hardware and software components that help the city to manage the **distributed energy production**.
- Citizens adoption of **advanced metering tools** to continuously check the state and the efficiency of the introduced “smart home” features
- The amount of the data collected by the city becomes very huge and requires to develop some **big data algorithms** to analyse properly all the received information.

D.2.4 Utilization of renewable energy sources

Due to the exit from the economic crisis, some state fees are used to proclaim community projects with the aim to modify the primary energy sources to reach better efficiency and reduce carbon emissions.

- Adoption of renewable primary energy sources (wind farm, PV stations, tides exploitation, ...) and reduction of carbon dioxin emissions
- Incentivising of community projects
- Where possible, adoption of Combined Heat and Power techniques
- Recommend the citizens to buy Electric Vehicles, which are less expensive than the classical ones.

D.2.5 Integration and optimization of software techniques

Integration of the new sources in the existing grid, that now can use sophisticated DSR, load balancing and islanding techniques with an higher level of security in some key areas, where specific micro-grids were built.

The recently gained smartness of the city allows the grid operating centre to develop advanced load balancing policies and optimize the location of the storage elements with respect to the needs of a specific part of the grid and the proximity to primary energy sources.

#	Scenario Update	Evolutionary Features
-	Starting Scenario	-
1	Continuous supply of energy problem	10,15,16,20
2	Terrorist attacks countermeasures	9,11,14,18
3	Incentive to micro-generation	5,6,8,11,13
4	Utilization of renewable energy sources	1,3,4,5,21
5	Integration and optimization of software techniques	13,16,19
	Final	1,3,4,5,6,8,9,10,11,13,14,15,16,18,19,20,21
	Unused	2,7,12,17

D.3 CONSTRAINED RESPONSE (HIGH SMART / REGULATED)

This scenario describes cities that have a wide distribution of smart technologies although they have strong constraints regarding the freedom to act in case of detected problems. The grid is highly interconnected and capable of islanding and quarantining at a fine grained level. Specialized companies, encouraged by the reduced cost of micro generating and storage of energy, give the city load balancing and storage solutions for micro-grids. The energy demand rises according to the economic growth attracting the necessary investment capital. A possible evolution is shown below:

D.3.6 Defences against natural disasters

Due to the relevance given to the ability of limiting the effects of natural disasters, a huge amount of sensors is distributed throughout the grid and self-healing micro-grids are built in the points that are more exposed to these risks.

- **New sensors** are inserted in the grid
  Specialized **Self-Healing micro-grids** are built to improve the **defences against natural disasters**

D.3.7 Advanced data analysis and DSR techniques.

The higher smartness of the grid gives the opportunity (through the support of community projects too) to improve the efficiency of the energy distribution using advanced data mining techniques with a growing support coming by Internet of Things, that provides additional key information to the data centre.

- **Community projects** aimed to develop very efficient algorithms are provided in addition to internal works with the objective to optimize the existing reaction system
- **Support of Internet of Things** to get some useful data for the tuning of statistical energy utilization prediction algorithms and so on. **Metering dispositives are upgraded** to read data coming from IoT

3.2.1 Break up grid action constraints

The excellence reached with respect to the structure of the electricity grid encourages the city authorities to relax some of the regulations which are limiting the freedom of the city to respond in a crisis situation. Advanced load balancing techniques that involves the entire grid (not specific for each micro-grid) are built giving the city the possibility to balance the load among wider areas.

- Wider **load balancing techniques** that allows the city to balance the load among the entire grid are developed. An excellence level is reached and the grid now has the highest level of smartness allowed by the actual technologies.

- Due to the relaxing of some supply and freedom to act constraints, new distribution technologies and new energy providers enter the grid

D.3.8 Adoption of renewable primary energy sources

An environmental movement forces the city to proclaim some community projects aimed both to accelerate the decarbonisation and adopt electrification of heat pumps and vehicles.

- Usage of citizen fees aimed to **reduce carbon dioxin emissions,** promote and incentivise the usage of **renewable energies**.
- A significant number of citizens adopt **EVs**
- All the **heating systems, included the factory ones, are updated** to use electricity instead of other energy sources

#	Scenario Update	Evolutionary Features
-	Starting Scenario	7,8,13,14,15,16,17
1	Defenses against natural disasters	9,10,17
2	Advanced data analysis and DSR techniques	6,11,19,21
3	Break up grid action constraints	2,13
4	Adoption of renewable primary energy sources	1,4,5,12
	Final	1,2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,19,21
	Unused	3,18,20

D.4 BEST ENDEAVOURS (LOW SMART / FREE MARKET)

This context describes cities that use electric grid with a very limited number of smart functionalities; the smartness' lack proves to be a distinctive for sharing energy resources and results in highly fragmented energy distribution and supply sector with multiple ad-hoc solutions. Also the market is fragmented due to the proliferating of independent DNOs and energy services that price their functionalities without a uniformed regulation by the city authorities. This generates an high social unrest due to the fragmentation of the market that exposes some citizens to further difficulties in negotiating a fair price for their supply. Incentives about micro generation are useless because the low smartness of the grid limits the benefits of becoming prosumers. We can imagine the following evolution:

D.4.9 Market standardization

The market is standardized a little to guarantee a simply energy erogation service with reduced costs, resulting in an higher satisfaction of the users, that grow in number. Other companies remain on the market to allow users to take advantage of higher quality services by paying additional money. The money saved in this way are used by the citizens to adopt micro generating facilities like PV panels. The energy sharing remains limited due to the structure of the grid.

- Some **functionalities are standardized** to build the skeleton of the future city grid and basic metering components are installed
- **Rise of the number of the citizens**
- Citizens are encouraged to become producers essentially through the installation of PV panels to **distribute the production**

D.4.10 Improved smartness of the city

Citizens want to become energy prosumers, so the grid is updated with the insertion of the basic smart functionalities that must be supported by an adequate architecture that allows to manage the new metering infrastructure.

- **Merging of the existing micro-grids** into a unique city grid with shared functionalities.
- A **two way communication infrastructure** is built to support the new metering facilities
- **Storage points** and **more complex smart metering elements** are inserted in the grid for managing and balance the available energy through the grid

D.4.11 Updating of primary energy sources and applying decarbonisation

Most of the citizens are now prosumers, so the fees used as incentives to micro-generation are now destinated to update the outdated primary energy sources of the city, that is far away from the sea and the lakes and is not well positioned with respect to the wind activity. To incentivise the decarbonization, a lot of charging stations for EVs are installed in some points through the grid.

- **Adoption of PV centrals**, transofmation of older ones in new energy sources that uses some **combined heat and power (CHP) techniques** with the aim to improve the efficiency and consequently reduce the carbon needed to produce the same amount of electricity.
- Installation of charging points and facilities to **reduce the dioxin emissions.** To reach this goal, the city authorities recommend to adopt at least one of **EVs** and **electrified Heating Systems** for each family

D.4.12 Protection against external attacks

Due to the recent conflicts between states near the city, the area around the context in exam is labelled as “danger zone”, so huge investments in security are needed.

- New sensors are added to the grid to detect malicious activities
- The most important parts of the grid are covered by specialized micro-grids with higher resilience capabilities. Depending on the specific component, some redundance is installed to improve system dependability.
- Community projects (that also involve the DNOs) aimed to develop advanced data analysis, islanding and quarantining techniques are promoted

#	Scenario Update	Evolutionary Features
-	Starting Scenario	8,20
1	Market standardization	2,7,8
2	Improved smartness of the city	2,6,14,16
3	Updating of primary energy sources and applying decarbonization	1,2,3,4,5,12
4	Protection against external attacks	9,10,11,13,15,18,21
	Final	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,18,20,21
	Unused	17,19

The matching characteristics between baseline model features and each scenario are expressed as <scenario update description> → <detail bullet index>

Baseline Model Characteristics	No Change	Constrained Response	Best Endeavours
Consumers – significant use of home energy efficiency measures (the impact of demand side response techniques) and alternative energy technologies with consumers increasingly becoming prosumers	Incentive to micro-generation → 1,2 **(i.e. bullet 1,2 of the "No Change" scenario update labeled as "Incentive to micro-generation")**	Starting Scenario Advanced data analysis and DSR techniques - 1	Improved smartness of the city → 2 Protection against external attacks → 1
Cities – widespread use of distribution technologies and generation through a combination of municipally owned and community projects but security of supply and addressing the decarbonization agenda remaining a state responsibility	Utilization of renewable energy sources → 1,2	Advanced data analysis and DSR techniques → 1 Adoption of renewable primary energy sources → 1,3	Updating of primary energy sources and applying decarbonization → 1,2 Protection against external attacks → 3
Regulators (government) – policy in ongoing catch-up mode with market realities (further incentivising distributed generation and new distribution technologies)	Incentive to micro-generation → 1	Starting Scenario	Market standardization → 3 Improved smartness of the city → 1
DNOs – remain an important actor in the city energy distribution but with increasing emphasis on value added services	Continuous supply of energy problem → 3	Break up grid action constraints → 1,2	Starting Scenario Protection against external attacks → 3
New actors – new energy services companies offering supply, aggregation and distribution services	Continuous supply of energy problem → 3	Break up grid action constraints → 2	Starting Scenario
Smart technology components – widespread use, although not ubiquitous, of local storage, PV, HPs and EVs, IoT, big data and ICT driven distribution technol-	Continuous supply of energy problem → 2 Terrorist attacks	Advanced data analysis and DSR techniques →	Improved smartness of the city → 2,3 Updating of

Baseline Model Characteristics	No Change	Constrained Response	Best Endeavours
ogies (providing a degree local capability for load balancing, islanding and quarantining)	countermeasures → 2 Utilization of renewable energy sources → 3,4 Integration and optimization of software techniques → 1	2 Break up grid action constraints → 1 Adoption of renewable primary energy sources → 2	primary energy sources and applying decarbonization → 2 Protection against external attacks → 2

E COLLABORATIVE FRAMEWORK REQUIREMENTS

E.1 FRAMEWORK

The Collaborative Framework is the key output of an energy resilience planning process. The Framework will clarify the:

- Response Group(s), i.e. those temporary organisations that will come together to carry out the response in the case of an event that impacts the city's energy supply
- Policies that will guide this group(s) in their decision making and clarify where authority and responsibility lies
- Agreements that are in place between key city stakeholders that clarify acceptable actions in helping to create a resilient response (these will underpin many of the policies)

E.2 PLANNING

The energy resilience Collaborative Framework **planning system** will:

- Define the city's smart grid topology and capabilities
  - Distributed Energy Resources (generation and storage)
  - Microgrids
  - ICT control mechanisms
  - Smart appliances
  - etc

- Rank critical services and enabling infrastructure
  - Critical services, supporting infrastructure and their energy related enablers
  - Demand usage/trends
  - City demographics (stakeholders) & service needs
  - Service criticality measures

- Clarify possible threats to the city's energy infrastructure, their impacts and mitigation options
  - Incidents
  - Impacts
  - Stakeholders
  - Mitigation options

- Define candidate improvements to the city's distribution/smart grid infrastructure to enhance resilience

- Establish the stakeholder groups to review mitigation options and agree responses
  - Criticality
  - Demand
  - Availability
  - Incentives (to cooperate)

    - Agreements

- Develop the policies needed to guide the actions taken by the response group(s)

E.3 TOOL

This planning system will be enabled by a **decision support tool**. This will enable planners to model (potentially) amongst others:

- The existing energy infrastructure (topology – both physical and ICT)
- Critical infrastructure and their energy availability and demand
- Islanding opportunities
- Social impacts
- etc

The tools will allow the planners to study the effects of changes so as to help provide an optimum response during an incident. Such changes could include, amongst others:

- Loss of infrastructure components in an energy disruption incident (based on known threats)
- Changes in the configuration of energy related resource configuration in response to such incidents
- New/changed/proposed criticality assessments
- Changed energy demand for critical infrastructure
- New distributed energy resources and/or smart grid components
- New micro-grids
- Changes to the “stakeholder configuration” (new players, new owners, revised policies, etc)
- New/changed response mechanisms, eg new ICT capabilities (smart grid), etc

F COLLABORATIVE FRAMEWORK

F.1 CORE ASSUMPTIONS

The project will address the issue from a city perspective (boroughs, wider, local economic area) and engage with the Resilience committee of a city (local gov resilience handbook).

1. The scope is limited to city boundaries and local hinterland
2. The study is focused on areas where cities can take action regardless of the wide variety of legislative and structural environments.
3. There will be more local power generation and more effective storage in the cities in the future.
4. There is a trend to the sharing (collaborative) economy and this is likely to increase and impact the area of energy resilience
5. There will be a roll out of micro / smart grids that allows sharing of energy
6. There will be a disruption to the historic national generation, transmission, distribution model
7. There will be many more actors in power gen and distribution.

F.2 DEFINITION OF COLLABORATIVE FRAMEWORK

A collaborative framework enables the range of stakeholders with central interests in an operative system to play critical and interdependent roles with a maximum of effectiveness and efficiency without introducing dynamics that distract or detract from the system's fundamental mission.

Thus, it contains and enacts sets of referential knowledge, expertise, capabilities and constraints that support effective exchanges, interaction and responses between the various stakeholders.

In the case of the IRENE project, the purpose of the collaborative framework is to support the stakeholders in:

a) maintaining systems' resilience readiness across the conditions set out in accepted scenarios.
b) enacting necessary redundancies in the event of outages in ways that minimize stress on existing systems and result in consistent achievement of targeted system performance.

I - Stakeholders

- Government / regulatory agencies
- Regional governments
- Municipal governments
- Energy providers
- Energy infrastructure servicers
- Citizens / homeowners / landlords

- Businesses
- Researchers

II- Role of Stakeholders

- **National Government** (regulation within national energy policy framework – varies country to country relative to general regulation philosophy, funding of fundamental research). The national government of each country in the scope of the IRENE project has a fundamental central role as in setting standards and regulating the provision of electricity to the citizenry of the country. As such, it must be seen as a key stakeholder prepared to take critical positions on resource availability, environment conditions (both physical and social), etc.
- **Regional Government** (county governance of region-specific energy issues). Primary concern is the coordination of responses with national authorities/stakeholders and adjacent regional governance in the case of widespread energy load problems.
- **Local Government** (local authorities). The role of local government is typically to understand, clarify, monitor and advocate for citizen concerns, as well as coordinate and facilitate specific local responses to preparedness. However, with this project focused primarily on cities' role in a rapidly changing energy supply / delivery landscape (***see core project assumptions***) it is assumed that the primary collaborations necessary in an emergent event will be between those who monitor and oversee energy provision and distribution at the local level.
- **Private Sector** (Local & Regional Business). National grid – maintenance of grid functionality to standards determined by national (and international) regulation. Development of additional capital investment and major infrastructure as population increases and as new means and methods of generating and distributing energy arise / emerge.
- **Energy suppliers.** Energy suppliers are bound by both energy markets and governmental regulatory frameworks. The delivery of energy services is paramount at all times, in all conditions and all energy suppliers must be capable of working independently and with each other in all conditions.
- **Infrastructure servicers.** Infrastructure service enterprises are typically bound by long-term contracts and service standards that guarantee quality and timeliness of services. Such arrangements must be reviewed and coordinated in any multiple-stakeholder collaborative framework.
- **Citizen & Business Advocacy Associations.** Given the core assumptions (above) of much greater decentralisation, the widespread presence of sensors in networks, the use of predictive algorithms, and the probability of energy generation and provision / distribution in close(r) proximity to citizens, it is wise to consider the implementation and use of citizens as 'first responders' and ongoing monitors of electrical services resiliency.] There are a range of emerging web services and mobile device applications that are enabling crowd-sourcing and the engagement with / use of sense-making practices. It is suggested that the exploration of such possibilities can be a significant boon to general system resilience as well as a means of building acceptance of changes in the consumption and stewarding of electrical energy.
- Technical Expertise (University Expertise, Consulting Expertise)
- Facilitation Expertise. Workshops to design, develop and implement a collaboration

framework will need to be supported by seasoned facilitators. The use by multiple stakeholders / task force of an online collaboration platform that holds the content that comprises a robust collaboration framework is likely to require the support of a community management / moderator role who will act as a steward and 'project manager'. It may be useful for this responsibility to be shared amongst stakeholders, with rotation of representative from the stakeholder group on (for example) a quarterly or bi-annual basis.

III - Central Elements of the Collaborative Framework

- Interdisciplinary Collaboration. Interdisciplinary in the IRENE project context means the pertinent / relevant intersection core disciplines (bodies of knowledge, expertise and capabilities necessary to build, maintain, operate and optimise the balancing of electrical load distribution across various jurisdictions that are or will be interdependent.
- Disciplines involved. The disciplines pertinent to the IRENE project include electrical engineering, civil engineering, mechanical engineering, statistics, finance, computer science, public administration, learning and talent development, and general management.
- Common ground of disciplines involved. The common ground for the involvement of disciplines and cross-disciplinary collaboration is the sharing of pertinent knowledge and ongoing discussion of roles and responsibilities that has tangible impact upon rapid or real-time response to emergent issues or crisis.
- Divergent ground of disciplines involved. The divergent ground for the involvement of disciplines and cross-disciplinary collaboration is the ongoing need for deepening, validating and clarifying the use of discipline-specific knowledge, expertise and capabilities essential to the effective function of electricity load distribution and balancing under conditions of system stress.
- **Trans-disciplinary Collaboration.** Trans-disciplinary in the IRENE project context means the pertinent / relevant cross-organization and cross-disciplinary silos application of knowledge, expertise and capabilities necessary to build, maintain, operate and optimise the balancing of electrical load distribution across various jurisdictions that are or will be interdependent.
- **Disciplines involved.** The disciplines pertinent to the IRENE project include electrical engineering, civil engineering, mechanical engineering, statistics, finance, computer science, public administration, learning and talent development, and general management.

IV - Policy Infrastructure

- regulatory policies (*to be aggregated & reviewed for commonality / overlap*)
- delivery responsibility policies (*to be aggregated & reviewed for commonality / overlap*)
- pricing policies (*to be aggregated & reviewed for commonality / overlap*)
- system security policies **(***to be aggregated & reviewed for commonality / overlap*)

V - Key Elements and Dynamics of Collaboration

A key aspect of a collaborative framework is that it identifies and describes for common understanding the key points of resiliency dependence, as well as separate and overlapping roles and responsibilities in the case of system failure or disruption.

Each of the above policy areas must be examined critically to identify possible vulnerabilities to collaboration in the even of an emergent situation. A task force consisting of representatives from the key stakeholders should be tasked with a comprehensive policy review in order to identify any unnecessary regulatory or operational redundancies and/or …

Such a task force could operate as an exploratory team in (for example) the relatively new but rapidly-spreading format known as a Living Lab, wherein various scenarios involving increasing amounts of bottom-up energy provision, effectiveness of predictive and control-oriented algorithms, network sensing capabilities and other emergent means of assessing, gauging, planning and monitoring a city's and region's energy system can be explored, tested, refined and communicated.

Once the IRENE project scenarios for testing resilience are finalised, a multiple-stakeholder (or representative) task force should review all pertinent areas of

- regulatory policy
- service delivery policy
- pricing policy
- system security / maintenance policy

to ensure relevance to each jurisdiction and eliminate unnecessary redundancy / overlap.

The resulting compilation should be published into a state-of-the-art information system platform designed to operate in such a fashion that all users have

- easy access to the common material.
- the ability to annotate the content with relevant updates and additional pertinent content
- the ability to exchange information via real-time chat, telepresence, uploading and download files

The content chosen to populate the resilience collaboration platform should be reviewed and tested regularly in order to ensure that it remains pertinent as energy sourcing, distribution and delivery capabilities evolve.

There now exist a range of collaborative platforms with significant functionality with respect to

- integration of all major forms of social computing to support collaborative working
- ease-of-use characteristics based on 20 years of evolution in the consumer-driven 'social tools ' arena
- classification, archiving and retrievability of pertinent content
- ease of uploading, downloading, sharing and using
- effective telepresence capabilities.

Once the stage is reached where

- the roles of key stakeholders are clear and agreed,
- pertinent domains of expertise are defined and agreed,

- the appropriate policy content has been reviewed and 'cleaned' with regard to overlaps / redundancy etc.,
- other necessary supportive content has been identified and curated

the choice of collaborative platform should be made and the Living Lab format (or some other similar experimental format) should be instituted as a pilot project to identify and flesh out what remains in order to provide resilient capabilities across the stakeholder systems.

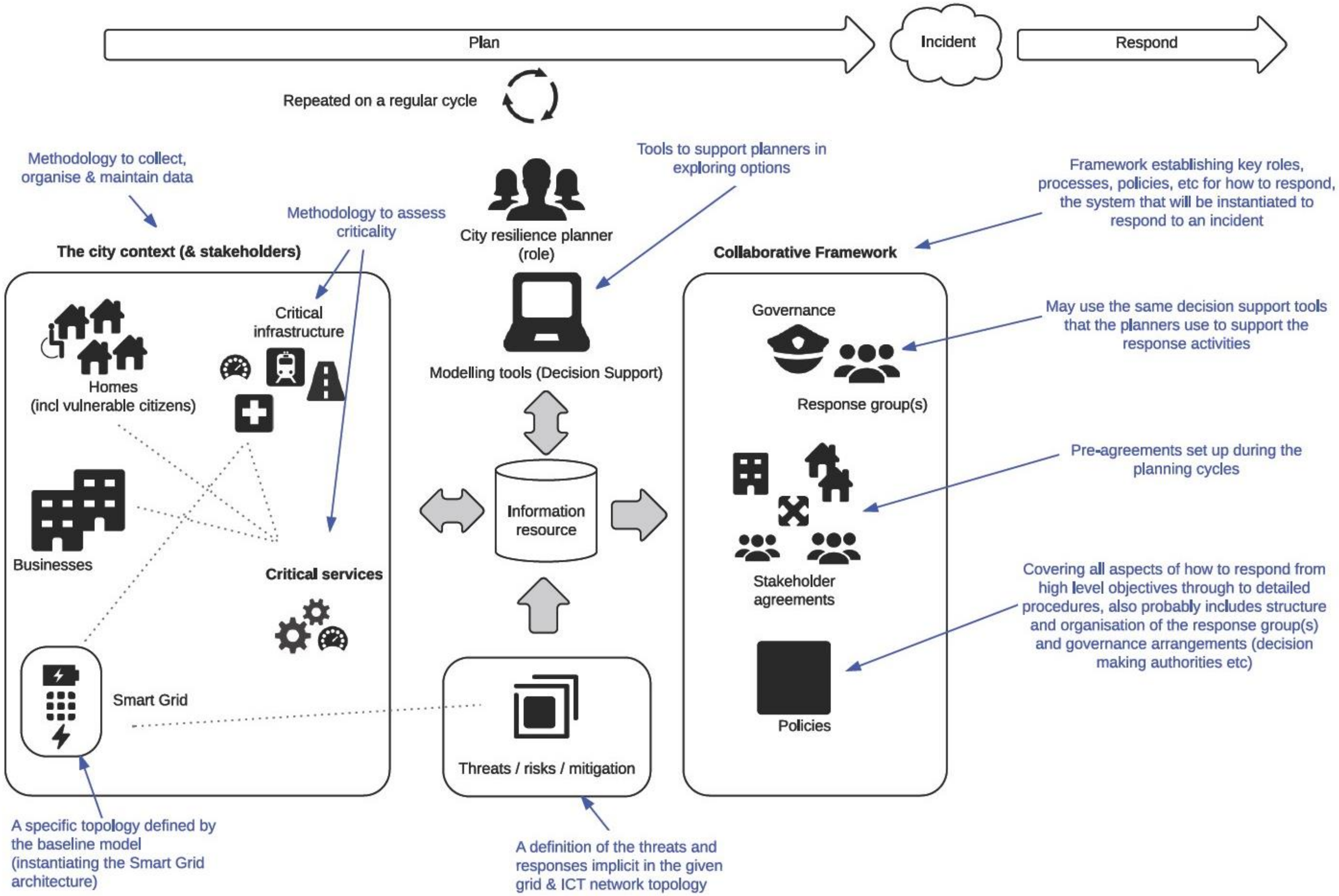

Figure 3: The Collaborative Framework

G IRENE - CITY ENERGY RESILIANCE QUESTIONNAIRE

A wide range of responses. 40% from DNO / DSOs so may not have a balanced perspective with regards to city energy resilience.

Considering each question separately:

Q3. Concern regarding city preparedness.

An even split "slightly/moderately/very concerned" re threats to power supply. No pronounced opinion on how prepared cities expect to be against such threats now or in 5 years.

There was a consensus that smart city management will increase significantly in next 5 years.

Respondents noted energy supply as "very" regulated with only a slight reduction in this regulation expected in 5 years time.

Q4. Plans in place to address energy resilience.

Most respondents noted "detailed plans" or "outline plans" in place to address critical services with consideration given to vulnerable citizens. Such plans promote cooperation between city stakeholders although there was little consideration given to the sharing and exploitation of open data. Community based energy groups were also not considered a significant part of such plans.

Q5. The impacts of a blackout.

Impacts were viewed mainly as severe or very severe to the emergency services, water supply, and healthcare, slightly less severe in the short term to sewage and wastewater treatment infrastructure, internet / mobile connectivity and transport infrastructure.

Q6. The impacts of a brownout (reduced voltage, typically <1hr duration).

As expected, overall impacts were considered lower. With regard to emergency services, still a significant proportion of responses classified impacts as "very severe".

Q7. Distributed Generation capabilities

77% respondents claimed to have some DG capability, yet 64% have no direct control over allocation of DG resources. There also seems little (18% of responses) confirmation of any micro grid capability.

Q8/9/10. Risks to supply from environmental events, accidental, malicious events.

Greatest environmental risks from wind and fire related events. Solar flare issues seen as of least concern. Accidental risks, i.e. human error and mechanical failure seen broadly as of equal concern.