Project document

Smart grids in Latin America and the Caribbean

Michele De Nigris
Manlio F. Coviello

Economic Commission for Latin America and the Caribbean (ECLAC)

The document was prepared by the ECLAC International Senior Consultant, Michele De Nigris, it was coordinated by Manlio F. Coviello, Chief of the Energy and Natural Resources Unit, of ECLAC, who also contributed substantially to the document's preparation.

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Table of contents

Index of figures

Index of maps

Index of boxes

Executive summary

Aim of the study:

The study aims at unveiling the potential of smart grids technology deployment in the Latin America and the Caribbean (LAC) Regions. Founding on a general discussion of the smart grids functionalities and on the description of the progressive evolution of an electricity system from the present state towards the full deployment of smart grids concept, the study puts the concept into the LAC context through the preliminary analysis of the present situation in six representative countries. Challenges and opportunities for the evolution of the local systems towards smart grids are pointed out, motivating policy makers to address the subject and understand its potential. Although acknowledging the wide difference between the network situations in the LAC region, the different drivers that may motivate the network development and the consequent variety of targets to be reached, a general Decalogue is proposed highlighting the most important implementation priorities to be considered. The instrumental role of CEPAL in this process is also put in evidence, at the light of the recent developments in the international smart grids community.

Definition:

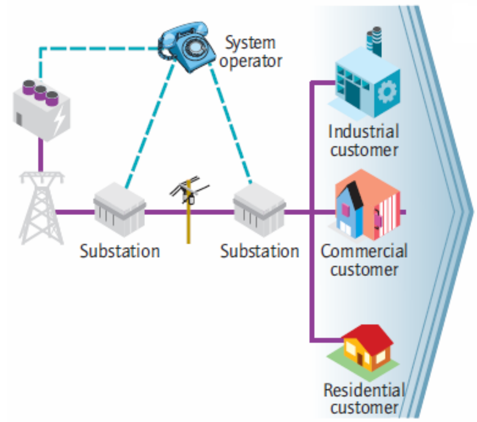
According to the Technology Roadmap on Smart Electricity grids recently published by the IEA[1], a smart grid is "an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability".

Functionalities:

Smart grids constitute therefore the progressive evolution of the electricity network form the situation represented in Figure 1 in which electricity produced in (large size) power plant (based on different types of primary energy: fossil, nuclear, hydro, geothermal etc.) flows unidirectionally, through the transmission and distribution systems, to final users (industrial, commercial, residential), towards the full-features deployment shown in Figure 2, where the smart grids potential is fully deployed.

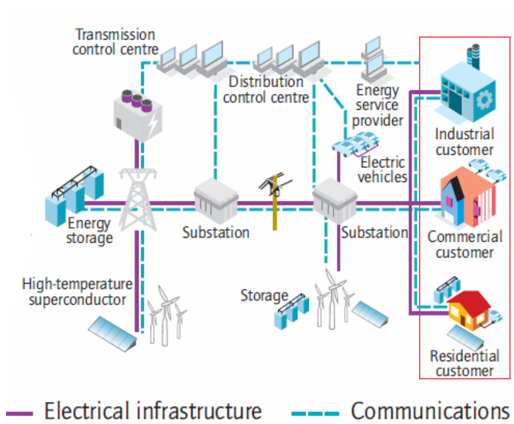
1 Technology roadmap Smart grids – IEA – downloadable from the website: www.iea.org

FIGURE 1
SCHEME OF THE ELECTRICITY SYSTEM BEFORE THE TRANSITION TO SMART GRIDS



Source: IEA.

FIGURE 2
SCHEME OF THE ELECTRICITY SYSTEM SHOWING A FULL DEPLOYMENT OF SMART GRIDS FEATURES AND TECHNOLOGIES



Source: IEA.

The electricity system integrating the smart grids technologies and functionalities is constituted by an additional information layer applied on top of the power system and by additional power equipment. The information layer enables the implementation of system automation and protection features enhancing the capacity to integrate large shares of variable renewable energy sources on the generation side and allowing the implementation of load flexibility measures such as the demand response on the user side. The smart grids system is capable of bi-directional power flows to and from the user who can now become an active player in the electricity market characterised by its high flexibility and efficiency, integrating also the contribution of user-side distributed generation. New technologies that characterise the smart grids are the advanced metering systems, allowing a bi-directional information flow, storage devices, used to mitigate the variability of generation and loads, power electronics (inverters, converters, rectifiers etc.) used to connect all types of generators and loads to the network, and electric vehicles, whose charging system is very deeply integrated into the smart grids control system.

The most important features facilitated by the evolution of the electricity system towards smart grids are the possibility to integrate very large shares of variable renewable energy sources, the large amount of flexibility of the load permitted by the demand response techniques, the reduced level of losses (technical and commercial), the superior power quality, the increased security of supply and reliability, the higher level of market transparency and the possibility to intelligently supply an extensive fleet of plug-in electric vehicles.

In order to enable the evolution of the electricity system of a country or region towards smart grids, several conditions must be met involving the structure of the system, the local legislation, regulation, market organisation, technological advancement, customer involvement, technical skills development etc.

One size does not fit all situations:

The evolutionary drivers, motivations and path followed by each region and country towards the implementation of smart grids is unique and must be respected. Each local situation is different in terms of energy mix, environment, legislation, regulation, market, customer response etc. The starting point in view of the evolution is also very scattered and will have a strong influence on the smart grids target reachable in a sound cost-benefits balance. As better discussed in the study each country and region must formulate its own ideal technology mix, which best suits the development drivers and targets foreseen. Also in the LAC regions, a very wide range of energy mix situations and market environments have been detected and a single common motivation for the evolution towards smart grids could not be found in the course of the study, apart from a main unifying idea: the urgent necessity to reduce system losses and increase the electricity system efficiency. Each LAC country shall therefore find its own ideal balance of technologies and develop its own smart grids roadmap, possibly following the general indications and the Decalogue proposed in the study.

The method followed:

With the consciousness that the general scope of the work was to start a process and to motivate local policy makers to address with the required level of completeness the local situation, it was decided to adopt a systematic approach involving six countries in the LAC regions, characterised by different conditions and showing a strong interest towards the subject. The countries considered in this study were Brazil, Uruguay, Chile (study 2010), Mexico, Jamaica and Panama (study 2011). The approach adopted consisted of the following five steps:

- Analysis of the most recent literature concerning the energy and electricity systems of the countries considered;
- Development of a questionnaire distributed by CEPAL to representatives of the different stakeholders of the electricity system, i.e: Government, Electricity (Energy) Regulator, local Electricity Industry (distribution system operators), R&D community, Academia and, when possible, local Electromechanical Industry;
- Discussions and interviews with major local stakeholders representatives generally based, but not restricted to the main points of the questionnaire;
- Elaboration of the information gathered in view of the understanding of the present situation of the electricity system and the drawing of the boundaries for the further analysis of the smart grids application potential;
- Setting up of recommendations based on the previous elaboration and taking into account the activities being developed internationally in this field.

The main findings

- The **generation** of electricity in most of the countries visited heavily relies on fossil fuels: Jamaica, Mexico, Panama and Chile are heavily dependent on fossil fuels (coal, oil and gas), while Uruguay depends on fossil fuels for about 30% of its production. For some of the countries (e.g. Jamaica and Panama) the burden of electricity supply is barely sustainable in situations of high fuel price volatility and motivates the government towards a diversification of the portfolio mix possibly with a high contribution from renewables. In several countries (e.g. Brazil and Uruguay), on the other hand, the conventional renewable energy potential (specifically hydro) is very well developed and expanding. Very large generation plants are connected to Ultra High Voltage lines on the transmission system. Although in most of the countries (except Jamaica and at a lesser extent Panama) the generation situation appears sustainable for the next few years, potential shortages are to be foreseen due to the very steady demand growth, typical of emerging countries. This fact call for immediate action in the development and integration of non conventional renewable energy sources that may play a very outstanding role in the future. However, the variability of this type of source implies the necessity of more network flexibility, i.e. the evolution towards smart grids.

- **Non conventional renewable energy sources** (essentially wind and biomass) are starting to be installed since nearly 10 years, with particular reference to Brazil (700 MW wind and 8000 MW biomass). Most plants are in the 5-10 MW range and are typically connected to the sub-transmission or transmission system. All countries visited have programs aimed at the expansion of the non conventional renewables and have inserted this priority in their fundamental energy strategic documents. The potential for this type of energy source appears to be wide and only partly known: although solar and wind potential charts exist in all main countries visited, the evaluation of the real potential still needs to be assessed. Moreover, the present regulation in all visited countries does not motivate the investment in such type of plants as no incentive, nor feed-in tariff scheme is applied (the generators are dispatched using the same rules as all other generators or have a certain level of dispatching priority, but no incentive). Grid codes for the operation of such variable sources are often very restrictive.
- **Distributed generation** (DG) is negligible up to now and the distribution systems can be considered as passive, i.e characterised by a single-direction power flow, from bulk generators, through the transmission and distribution network, down to the loads. Most countries declare to have extensive plans to develop DG, mostly based on wind, solar, biomass and mini-hydro. DG may be of interest to avoid the construction of new generation in remote areas, reduce distribution losses, enhance local consciousness towards energy aspects and conservation, thus contributing to social welfare and is useful in complement to conventional generation in view of enhancing the system reliability and quality of supply. However, in the present regulatory situation, this solution becomes attractive only for large electricity consumers having a Time of Use tariff, in order not to be forced to buy electricity during peak hours.
- **The transmission system** of all countries visited is characterised by adequate voltage ratings and performances, as a function of the local requirements. In Brazil part of the transmission system is operated at 765 kV (AC) and 500 kV (DC); in the Uruguay, Chile, Panama and Mexico, although the system voltage is not so high, being the distances between generation and load less extreme, the ratings are nonetheless very high (400-500 kV AC). Jamaica has the lowest transmission system voltages (138 kV), being the load, distances and the system requirements less stringent. Lacking precise information on the system management and operation (automation, monitoring, protection and control), there is no specific reason to consider any major inadequacy. Nevertheless the recent blackouts in Brazil (2008) and Chile (2009) indicate that some bottlenecks or structural weaknesses may subsist, needing more accurate evaluation, out of scope of this report.
- The **distribution system** of all countries shows a very wide range of situations: from the up-to-date underground infrastructure in large towns and new settlements, to the overhead mixed and “messy” situations in smaller towns, rural areas and neighbourhoods of large towns. These systems are typically old, weak and uncontrollable portions of the network requiring modernisation and refurbishment. In all the countries considered the distribution network is designed and operated as a passive system, as the presence of distributed generation is negligible. In general terms, for what concerns the smart grids technologies, we notice a very limited distribution system automation, with little observability and flexibility. SCADA systems, often developed in collaboration with local developers and suppliers, monitor and control remotely portions of the medium

voltage network only at the substation level, and never at the feeder or derivation level. All low voltage outage management operations are generated by telephone calls from the users. No on-line automatic reconfiguration system is in operation, especially on the low voltage distribution system, but advanced on-line and off-line elaboration is made of the data available from the supervision system and from historical manual meter reading data, demonstrating much operation intelligence, even without an AMI. In terms of power quality: the average number of interruptions per subscriber ranges around 10-12 hours, while the duration of interruptions per subscriber ranges from 10 to 18 hours, depending on the country. Higher values must be reported for Jamaica. The average monthly consumption ranges between 150 and 300 kWh/month, i.e. about half the consumption of the European householder and a quarter of that of American. The typical loads are constituted of lighting, food refrigeration, TV and partly cooking. Ambient heating is normally by natural gas and air conditioning is very seldom used in household application.

- **Metering equipment** are conventional electromechanical or electronic meters, with little or no communication features (local download of data from the reading operator), except for large users or auto-producers. Electronic meters allow the setting of multi-level Time of Use tariffs. Manual reading is carried out on a monthly base, the billing is monthly and based on real consumption data. The information reported in the electricity bill of the customer reports the monthly consumption trend of the past year, information on the user category, the daily electricity average cost and general advices for energy saving; electromechanical meters inhibit any possibility of indication about the most energy-intensive appliances and therefore offer very little energy saving potential value.
- **The present level of distribution losses** ranges from 6 to 24%. It is estimated that non-technical losses are in average 5 to 10%, with peaks as high as 40%. Electronic meters could help substantially in the reduction of non-technical losses, the application of better Time of Use tariffs and demand participation measures. The business cases for the implementation of an advanced metering system needs to be carefully evaluated taking into account the low cost of manual meter reading and considering the relatively low level of pro-capita consumption. Losses reduction and improvement on energy efficiency would partially cover the expected demand rise for the coming years without the necessity to increase the installed capacity. Several countries are adopting losses reduction measures in portions of the network showing the most critical trends, using technical (e.g. anti-damping connections and collective electronic meters), economical (pre-paid formulas), educational and social measures and actions.
- **The regulation**: transmission and distribution activities in the countries considered are regulated businesses: therefore operators are remunerated according to different cost recovery schemes, considering prudent investment, efficient administration of the company, efficient operation of the system etc. Each operator is given minimum technical performances for the delivery of the electricity service. No incentive is allowed in case of quality performances higher than the expected values, nor on the investments specifically made for innovating the system: this rises the problem for the setting of the business case for the evolution towards smart grids.
- The **human skills**: Latin America and the Caribbean region have top-level universities and academia. The electrical engineering studies do not yet address smart grid application. However the natural skill of local engineers to address problems and projects using a very pragmatic approach and setting up solutions characterised by a very practical approach, cheapness and reliability may be used also for the addressing of smart grids and for the applications in developing countries.

The way forward: the Decalogue for the smart grids perspectives

At the light of the results of the study carried out, a Decalogue for supporting the development and deployment of smart grids in the region has been elaborated. The Decalogue is illustrated in Figure and calls policy makers to take decisions and actions according to their respective responsibilities in the different fields of governmental and local political support, regulation, standardisation, network operation and development, education and customer involvement. LAC countries should start the path towards the local smart grids development with the elaboration of local roadmaps highlighting the objectives and the goals expected by the application of this set of technologies and carefully balancing the costs with the benefits of the smart grids applications. This approach is considered as the most rational by the international community and methods and tools are being developed to conduct roadmapping exercises and carry out cost benefits analysis. Smart grids technologies, system integration and business case must moreover be demonstrated in the specific LAC variegate situations. In line with the actions carried out in all regions pursuing the smart grids deployment, large scale demonstrators must be developed once the main strategic targets are defined by the roadmaps. In this effort, particular attention must be given to the regulatory aspects, which at present virtually inhibit any network development towards smart grids in the region. Finally, no actual capillary smart grids deployment will be possible without the conscious acceptance from the final user, who shall fully understand and adhere to the new system paradigm. This implies a wide effort in education, listening and building of consciousness and skills.

The role of CEPAL

Smart grids can be instrumental in enhancing the sustainability of the energy system in the region, contributing to the long term security of supply and to the global system competitiveness. LAC countries are characterized by system losses and electricity thefts that in some regions reach level beyond international benchmark. Smart grids can give an outstanding contribution in the increase of the system efficiency and in helping enhancing access to energy and electricity. CEPAL has taken a real leading role in the region, in assisting the LAC countries to start build up a consciousness about the smart grids potential and the directions to be taken to ignite the related technological deployment. Leveraging its favorable credibility as advisor to local governments, CEPAL can promote and coordinate a task force of LAC governments and stakeholders to foster the development of regional smart grids roadmapping efforts, contribute to the assessment of the present level of grid smartness using recognized benchmarking methods (presently under development within IEA-ISGAN), stimulate the debate among regulators and governments in view of the setting up of adequate legislation and regulation to pave the way to the deployment of these technologies (an initial effort in this direction is being envisaged in Panama), and take active part in the setting up of medium to large scale technological and market demonstrators that will test and prove the practical conditions for the deployment of smart grids in LAC region, characterized by an adequate standardization and replicability level.

FIGURE 3
THE DECALOGUE FOR THE SMART GRIDS DEVELOPMENT IN LATIN AMERICA AND THE CARIBBEAN REGION

Source: Author's elaboration.

I. Smart grids

A. Context, concept and general definition

Constantly rising aggregate demand for electricity (which is reflected in increased per capita energy use) and the major challenges of climate change are placing a heavy burden on the infrastructure of the world electricity grid. The current grid was designed and built mainly at a time when electricity was relatively cheap and abundant, and when the priority was to expand electrification.

Nowadays, however, the world is rapidly approaching a turning point towards a new phase in which the main drivers will be totally innovative concepts such as energy efficiency, the use of clean energy sources (renewables and low carbon emission technologies), distributed generation and the new role of consumers in determining their levels of energy use.

In this context, the process of making the current grid "smarter" is fundamental if the process of change is to be tackled successfully. As pointed out by the Major Economies Forum,2 this is because there are many factors that argue in favour of such an update.

In no particular order, these factors are as follows:

Technological factors:

- Completely obsolete transmission and distribution grid
- Reduction in the skilled workforce (50% of skilled technicians will reach retirement age over the next 5 to 10 years)
- Major capital investment worldwide for the development of new technology and improvements to current technology

Normative or regulatory factors:

- Willingness of many governments (for instance in the United Kingdom, United States, Brazil, Australia, Netherlands and Sweden)
- Development of distributed generation that encourages renewables
- Achievement of national security objectives (such as energy independence)
- Substantial improvements to market efficiency

2 "Technology Action Plan on Smart Grids", Report to the Major Economies Forum on Energy and Climate, 2009.

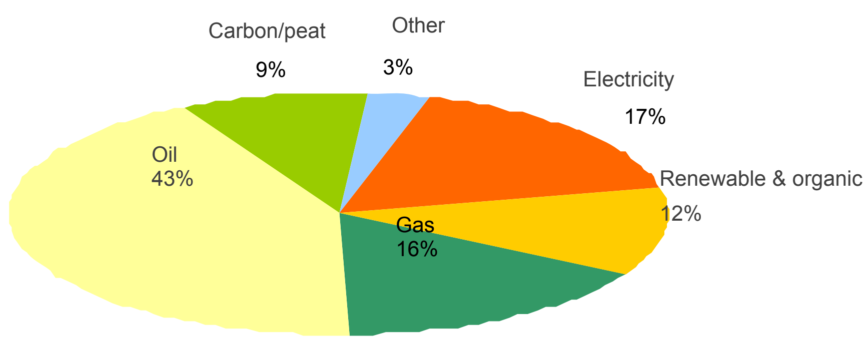
Economic factors:

- Improvements to reliability (including reduced frequency and duration of outages, and so forth)
- Reduction of direct and indirect labor costs (for example, meter readings and maintenance, company vehicles, insurance, repairs, and so on)
- Reduction of system losses (system planning and resource management, for instance)
- Income protection (through, inter alia, more accurate billing and the prevention/interception of theft and fraud)
- Emergence of new markets in the electricity sector

Environmental factors:

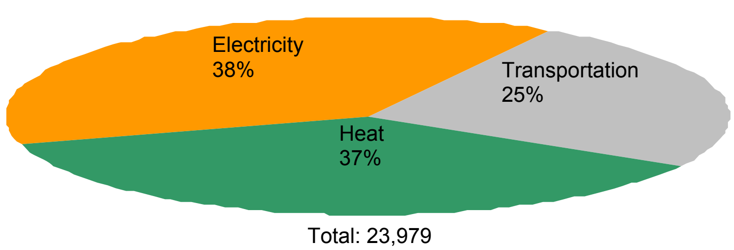
- Reducing carbon emissions:
  - Directly – Considering that, although electricity represents only 17% of total fuel consumption (figure 4), the sector is responsible for 38% of global greenhouse gas emissions (figure 5), due to the intensive use of fossil fuels
  - Indirectly – Thanks to the ever-increasing number of non-polluting electric vehicles
- Increasing renewable generation and incorporating it into the existing grid
- Improving energy efficiency

FIGURE 4
TOTAL ENERGY USE BY FUEL



Source: Key World Energy Statistics, IEA.

FIGURE 5
CO2 EMISSIONS BY SECTOR



Source: Mitigation of Climate Change, IPCC.

Social factors:

- Response to the demand for sustainability and integration of users in managing their energy use
- Covering the upward trend in constant energy demand
- Providing the customer with options for saving and storing energy.

Beyond the above-mentioned drivers that are pushing many governments to modernize their electricity grids, there are also some risks concerning the potential impacts of failing to take action.

According to the World Economic Forum,3 integrating energy supply from intermittent renewable sources and connecting and charging electric vehicles without a smart grid infrastructure could potentially undermine the stability of the entire energy system. Even relatively low levels of penetration by these technologies would suffice to cause instability and significantly increase the risk of outages. By acting now, governments would thus prevent the electric grid from soon becoming a bottleneck, as this would block the way to achieving a sustainable future of low carbon emissions.

B. Definition

Smart grid is not a one-dimensional concept, as the technology covers many aspects. Generally speaking, however, we can define a smart grid as "a wide range of solutions that optimize the value chain of electric power".

On a more detailed level, the Smart grids European Technology Platform (which gathers the sector's European stakeholders) has defined smart grids as "electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies"4.

In the United States there are two main definitions of smart grids, one from the Department of Energy (DOE) and one from the Electric Power Research Institute (EPRI).

- Department of Energy: "Grid 2030 is a fully automated power delivery network that monitors and controls every customer and node, ensuring a two-way flow of electricity and information between the power plant and the appliance, and all points in between".5 Smart grids use "digital technology to improve reliability, security, and efficiency of the electric system"[6].
- Electric Power Research Institute: "The term 'Smart Grid' refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage transmission network and the distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices"[7].

In a study carried out in conjunction with Accenture, the World Economic Forum identified the following seven key characteristics in a definition of a smart grid: "Self-healing and resilient (...)

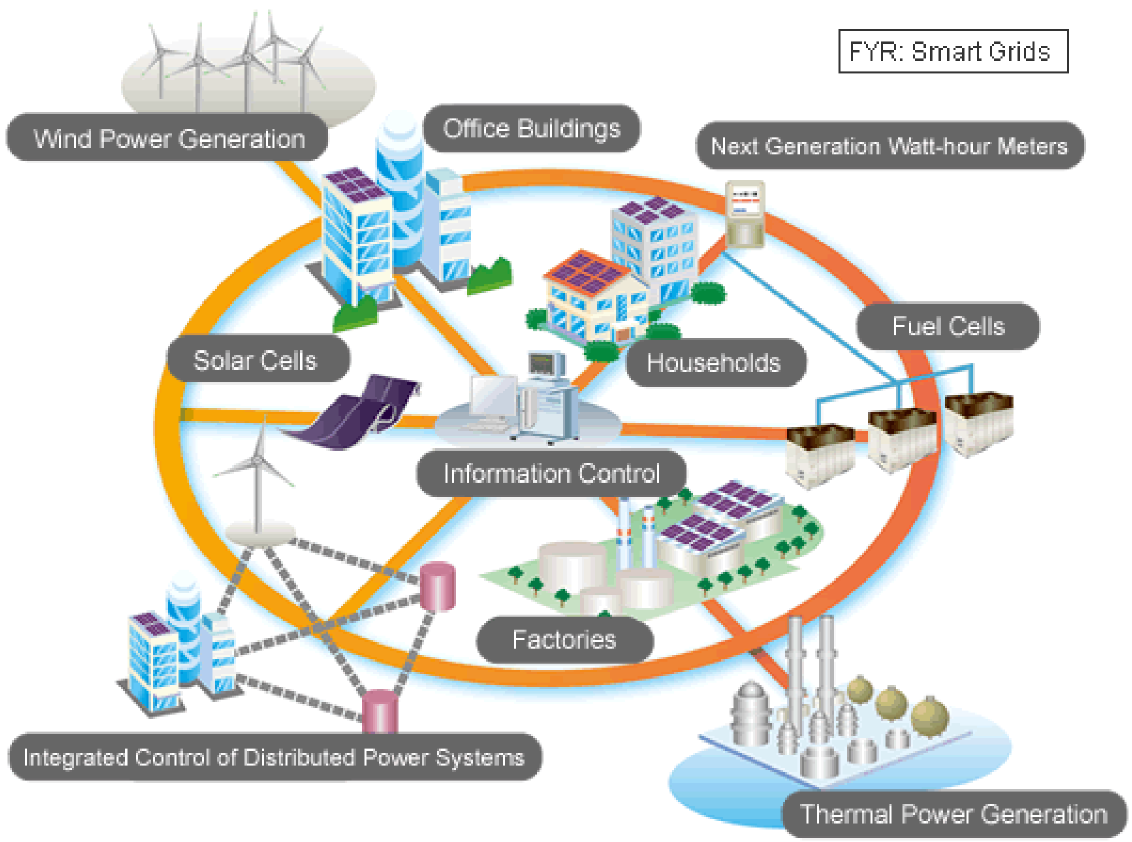
3 "Accelerating Smart Grid Investments", World Economic Forum, Accenture, 2009.
4 "Smart Grids", European Technology Platform, 2008.
5 "GRID 2030: A National Vision for Electricity's Second 100 Years", United States Department of Energy (DOE), Office of Electric Transmission and Distribution, 2003.
6 "Smart Grid: Enabler of the New Energy Economy", Electricity Advisory Committee, 2008.
7 "Report to NIST on the Smart Grid Interoperability Standards Roadmap", EPRI, 2009; in: "Technology Action Plan on Smart Grids", Report to the MEF on Energy and Climate, 2009.

Integration of advanced and low-carbon technologies (...) Enable demand response (...) Asset optimization and operational efficiency (...) Customer inclusion (...) Power quality (...) Market empowerment”[8].

In summary then, a smart grid is an update of the traditional electric grid, which functions by adding many networks and several power generation companies, with various operators that use different levels of communication and coordination. Basically, smart grids have the useful effect of increasing connectivity, automatization and coordination among providers, consumers and the grids themselves that are responsible for long-distance transmission and local distribution. A smart grid also includes a new control system that accurately monitors and measures all the electricity in the system. A smart grid can also incorporate new superconductor transmission lines to reduce energy losses and to integrate alternative non-traditional sources of renewable energy into the grid.

In conclusion, the concept of a smart grid cannot be summarized into a specific device, object or action, because it is more of an integral system vision, a series of actions (supported by an updated infrastructure) that will help to achieve specific aims based on each country’s energy policy priorities.

FIGURE 6
SMART GRID AND THE ACTORS INVOLVED



Source: European Technology Platform.

C. “One Size Does Not Fit All”

This is the key idea and main strength on which the entire vision of smart grids is based. The fact that many factors are involved has the effect of dividing the transition to smart grids into specific areas based on the weaknesses or aims of each electrical system. At the same time, the flexibility in

8 “Accelerating Smart Grid Investments”, World Economic Forum, Accenture, 2009.

terms of solutions makes it possible to adapt the system in accordance with each grid's requirements, in the light of the infrastructure legacy and the ambitions of the policymakers.

Multifunctionality: thanks to the use of information and communication technologies (ICTs) in the system, is what makes smart grids a universally applicable technology. In developed countries, the main reasons for adopting smart grids are the reduction of losses, system performance and resource optimization, the integration of renewables, energy efficiency and a rapid-response mechanism to demand. In developing countries, there are other, new factors. For instance, the quality and reliability of electricity supply are fundamental for supporting an expanding economy, and can be achieved relatively rapidly and sustainably by designing, planning and developing a modern electricity infrastructure that is forward-looking from the outset. Indeed, the vital transfer of technology and expertise must always take account of each country's specific geographical conditions and the technical characteristics of the grid to be modernized.

More specifically, in the case of obsolete and unstable grids, such as those in some parts of Latin America, in the first instance the updates will focus on reducing the system's technical losses and increasing its reliability in terms of outages. For strongly developing economies, including the Asian tigers, the priority will be safety of uninterrupted supply, the quality of the power supply and the management of consumption peaks. In developed countries with fully efficient grids (as in Northern Europe), efforts could be concentrated on reducing CO2 emissions through the integration of distributed generation and the use of electric vehicles on the road. In other, similar countries, work could be based around regulation, implementing policies aimed at raising user awareness about the new role involved in responsible energy use.

Generally speaking, and as suggested by the World Economic Forum9, each decision to implement a smart grid, at the local or national level, is based on the following two factors:

- Infrastructure legacy and technical characteristics of the grid: the condition of the current grid and the level of "smart" development are crucial variables when it comes to defining a modernization strategy;
- Primary drivers for implementation: the strategic objectives which the smart grid is designed to achieve will also vary in each instance, reflective of the region's challenges and ambitions.

It should be pointed out that the development of a smart grid should be in response to preventive planning and a detailed cost-benefit analysis of specific policies. The complex nature of an electric grid requires a gradual, target-oriented approach that can use the potential of new information and communication technologies (ICTs). All components of the electric grid will have their functionality altered and improved as part of a modernization process consisting of stages that, besides making the grid "smarter", will facilitate the achievement of many strategic objectives in the above-mentioned domains.

Historically, that process dates back to the 1980s, which saw the first attempts to set up an electronic system to control and measure energy use. Automatic meter reading was used to monitor the loads of large customers, then the advanced metering infrastructure was used in the 1990s to register variations in usage throughout the day, and nowadays smart meters are the first major step towards the introduction of ICTs. Smart meters monitor the grid in real time, work as an interactive device for the user and have opened new markets and opportunities in the electrical services sector.

At the beginning of 2000, the Italian project Telegestore was the first large network of smart meters (27 million) connected via low-voltage electrical grid and capable of sharing information with the central system. The most recent Broadband over Power Line (BPL) projects use wireless technology for projects such as the Wide Areas Measurement System in China.

[9] Ibid.

D. Systemic vision: functions of a smart grid

Today's grids are mainly based on electricity generation from large power plants connected to low-voltage transmission systems that use alternating power to provide the required energy to the low- and medium-voltage local distribution system. The transmission and distribution grid is usually managed by natural monopolies (with national or regional coverage), while monitored by the respective oversight authorities. In contrast, the electricity generation sector is increasingly competitive and open to participation by many actors (with obvious exceptions, such as Uruguay).

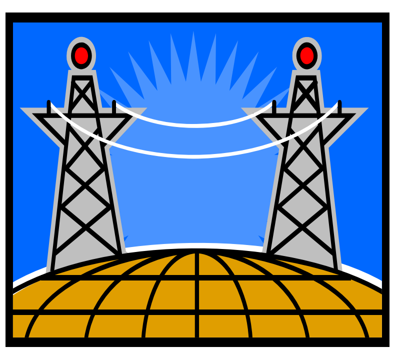
However, the general image remains one of a grid with a one-directional flow from power plants, via a transmission and distribution system, to the end user. In this context, energy supply and grid control are usually the responsibility of centralized facilities that can control several regions from the same place. Consumer participation is limited or non-existent, and there is practically no communication between the two ends.

The design and planning of the conventional grid have changed in accordance with the development of economies of scale, such that the prevailing model is one consisting of large electricity power plants concentrated in locations close to primary inputs for generation (such as coal basins or water resources, which are also useful for cooling). Conventional grids usually have regional or national coverage and capacity. Although any interconnections were originally developed for countries to provide each other with mutual support in emergency situations, they are now increasingly used for the commercialization of electricity among States.

Generally speaking, the existing grid infrastructure is a good starting point for tackling the challenges and opportunities arising from the modernization of the entire system. Nevertheless, as suggested by the European Technology Platform,[10] the change process should ideally be gradual and planned in advance, rather than uncoordinated and revolutionary. As a result, defining a long-term strategy becomes an essential means of approaching smart grids.

FIGURE 7
TRADITIONAL GRID VERSUS THE GRID OF THE FUTURE

Traditional grid:	Future grid:
Centralized control	Flexible, optimal and strategic expansion, maintenance and operation of the grid
Large electricity generation plants	Capillary distributed generation and small-scale generation in proximity to users
Limited border interconnections	User-specific quality, safety and reliability of supply, thanks to digital technology
Technically optimized for regional coverage	Flexible demand-side management and value added services for users



[10] "Smart Grids. Vision and Strategy for Europe's Electricity Networks of the Future", European Technology Platform, Research Directorate General, European Commission, 2006.

Obsolete technological vision (almost 100 years old)	Integration of distributed generation and coordinated management with large-scale power plants
Normative differences and differences in trade frameworks	Standardized legal framework to facilitate cross-border trade in energy and grid services

Source: Author's elaboration.

The comparison between the current and future system can be used as the basis for defining the functions that a grid must fulfill to be considered "smart". As stated above, these functions involve different system features and can be divided into four general aspects: technological, regulatory, economic and environmental.

None of these aspects should be considered in isolation from the others, as each is one aspect of the same modernization process that covers the entire grid and its actors: a systemic vision of the smart grid concept.

Technological aspects. These include all functions relating to the infrastructure of the electric grid and its communication system. This aspect is fundamental, given that the current grid is already obsolete, as in most cases it is around a century old. There is therefore a significant gap between the grid's technical capacities and growing energy use needs, as well as increasing difficulties in the management of the electricity flow.

In more detail, the aspects are as follows:

- Autonomous operation and self-healing capacities;
- Increased resistance and reliability in the event of natural and manmade disasters.

Regulatory aspects

This refers to all decisions taken by the relevant authorities, whose responsibilities are largely the result of technological progress, and which are responsible for regulating the electricity market and encouraging efficiency, in the delicate process of changing from centralized to distributed generation (as this in turn involves new business actors). Furthermore, replacing traditional meters with smart meters enables regulatory agencies to introduce policies (especially tariff policies) aimed at raising awareness of, motivating and directly involving users in the management of their own levels of energy use.

Economic aspects

This is clearly a fundamental perspective when it comes to making decisions on modernizing the electricity grid. According to an EPRI study[11] the combination of different factors to improve grid efficiency and reliability could lead to a 1.8 trillion dollar rise in annual income for utility companies by the year 2020. Furthermore, the introduction of smart technology in the United States alone is expected to reduce power supply interruptions to 49 billion dollars a year. Similarly, it is calculated that smart grids may reduce the required infrastructure investment in the United States grid by between 46 billion dollars and 117 billion dollars over the next 20 years[12]. Beyond the figures, it is worth pointing out that the use of more efficient technologies will considerably bring down fuel use, with the potential knock-on effect of lower fuel prices for all consumers at every level.

The main economic aspects that result from moving towards smart grids include the following:

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[11] "Electricity Sector Framework for the Future. Volume I: Achieving the 21st Century Transformation", Electric Power Research Institute – EPRI, 2003.

[12] Data from the Galvin Electricity Initiative, "The Case for Transformation", http://www.galvinpower.org.

- Optimized resources and operability of the electricity grid to achieve greater system efficiency;
- Better quality electricity to meet the economic challenges of the twenty-first century;
- Empowering new markets linked to the development of smart applications, smart meters and new means of communication and transport.

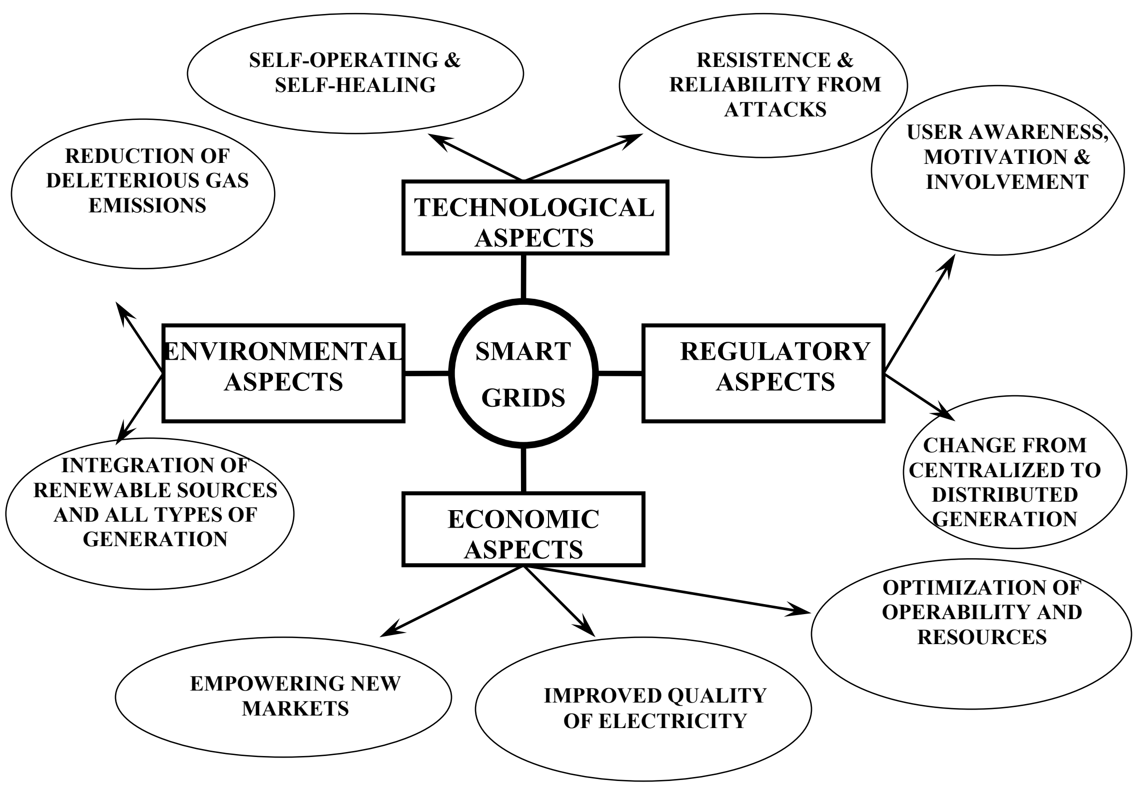
Environmental aspects

Countries throughout the world are introducing legislation to regulate greenhouse gas emissions, thus demonstrating the very high level of public awareness around global warming. In this context, the introduction and operation of smart grids have a major role to play, given that utility companies are under pressure from all sides to adopt business practices that take better care of the environment.

More specifically, these environmental aspects include the following:

- The reduction of deleterious and greenhouse gas emissions, thanks to increased energy efficiency and the future introduction of electric vehicles;
- The achievement of a high level of penetration by renewable and intermittent sources, which will have the effect of changing from centralized to distributed generation.

FIGURE 8
SYSTEMIC VISION OF SMART GRIDS



Source: Author's elaboration.

E. Technological aspects

1. Autonomous operation and self-healing capacities

In the context of a modern distribution grid, the capacity to operate autonomously and to self-heal involves an engineering design that makes it possible to isolate the system's problematic elements and, ideally, restore normal operations without the need for human intervention. Self-healing actions will reduce or even eliminate any interruption in the supply service to consumers. A study carried out for the United States Department of Energy and the National Energy Technology Laboratory13 clearly defines this function as the immune system of the modern electricity grid.

How? Generally speaking, a smart grid is continually assessing and monitoring itself in order to foresee potential problems, detect existing or emerging faults and, as a result, immediately put into motion the appropriate remedial responses.

From the introduction of smart meters that facilitate the transmission and storage of data practically in real time, through a network of advanced sensors installed at different levels of the system, it is possible to isolate a fault and alert the nearest devices responsible for restoring normal functioning. The network of sensors is also able to detect patterns that may predict system breakdowns, which results in real-time capacity to alleviate those conditions before the predicted event actually happens.

In terms of self-healing, the system's objective is to maintain the level of supply to the highest possible number of customers through the instantaneous distribution and transfer to alternating electricity sources. These sources may include connections with different feeders, as well as resources from distributed energy resources, such as energy storage devices or small electricity generators that run on renewable and non-renewable fuels. Another important tool in the grid's self-healing process is the direct management of energy demand (demand response (DR)), which makes it possible to adapt the level of load to the capacity generated in real time.

In this context, faults in stations and substations, circuit configuration changes, problems with energy and voltage quality and - more generally - any grid anomaly can be rapidly identified and corrected. High-risk areas, as well as individual components of equipment, can be remotely analysed with a view to acting immediately and preparing advanced models of analysis to show the load congestion and system threats.

The modern electricity grid will certainly know itself, its potential operating problems and the way to resolve them independently and automatically. They key to achieving this is the use of a wide range of information collected by the grid's smart devices, whose function is to facilitate the rapid analysis of those data and the subsequent remedial actions.

Aims and benefits: The general aim of the self-healing function is to limit the impact of negative events to the smallest possible area. Any type of action aimed at limiting the number and duration of outages, reducing the time taken to restore supply and reconfiguring the grid to ensure optimum reliability and service quality comes under the definition of self-healing, and has many benefits from various points of view:

- Reliability: Filling the gaps caused by frequent service interruptions will have a considerable effect in terms of increasing the reliability of the entire system, as well as economic benefits thanks to savings resulting from the avoidance of outages.
- Public safety: Increased control over the state of the system's infrastructure will provide more efficient public safety. For instance, a reconfiguration of the grid will make is possible to remotely and rapidly deactivate all exposed and fallen cables. Furthermore, reducing the

[13] "A Vision for the Modern Grid – Appendix A1", National Energy Technology Laboratory (NETL) for the United States DOE, 2007.

duration of outages will lessen the impact on patients receiving medical assistance that uses electricity, while reducing the frequency of outages will restrict the opportunities for carrying out criminal activities

- New income: The installation of instruments for distributed energy resources (DER) and demand response (DR) will create systems of peak shaving14 and reserve accumulation, of which the commercial exploitation in the energy market is expected to generate new revenue streams for owners.
- Quality: The modern grid will detect and correct in real time the quality of energy supplied, thus eliminating all losses relating to this aspect.
- Environment: The self-healing process will facilitate the integration of (centralized and distributed) renewable generation into the grid, which will in turn significantly bring down CO2 emissions. This will also reduce the environmental impact of outages and equipment faults, as well as decreasing the system's electrical losses.

Obstacles. The grid in its current state is concerned with preventing infrastructure damage, with the emphasis on the protection of resources in the wake of inevitable system failures. This perspective is diametrically opposed to the vision of the modern smart grid. The path to achieving the ideal system – able to detect and respond in real time to transmission and distribution problems in the grid using a prevention-based approach – is filled with obstacles of various kinds:

- Financial resources: Business cases for a supply grid with a self-healing function guarantee good results, and especially if the social benefits are included. However, regulatory authorities usually demand extensive and exhaustive evidence before authorizing major investment.
- Governmental support: Private industry may not have sufficient resources to develop new technologies without the help of any government programme to incentivize the research and development sector. Indeed, although the utilities sector is capital intensive, it has often been through difficult market times, with some companies presenting negative results.
- Incompatible infrastructure: The oldest equipment may have to be replaced if it proves impossible to update it to make it compatible with the requirements of the self-healing function. This may pose a problem for utility companies and regulators if there has to be a kind of "early retirement" for equipment that has not reached then end of its lifetime, as this would push up costs for users.
- Pace of technological development: Historically, the process of technological development in the electricity sector has not advanced very rapidly. As pointed out by the United States National Energy Technology Laboratory (NETL),15 there are some specific areas that would require more significant development and deployment, such as the high-speed integrated communication system, smart electronic devices, demand response (DR) systems that use tariffs in real time, a profitable and environmentally friendly distributed energy resource (DER) system, and so on.
- Policy and regulation: New construction projects tend to receive little consideration from the authorities. Unless the attractive yields for investment in self-healing functions are promoted, utility companies will remain reluctant to invest in new technologies.
- Cooperation: The challenge for many utility companies will be to achieve the mutual cooperation required for the installation of circuit nodes and the free exchange of information needed to implement a genuine smart grid.

[14] System that defines how to neutralize demand peaks by using energy stored during periods of low consumption.

[15] "A Vision for the Modern Grid – Appendix A1", National Energy Technology Laboratory (NETL) for United States DOE, 2007.

BOX 1
NEW YORK, UNITED STATES

Nowadays, many large cities have an obsolete electricity structure that is unsuited to current socio-economic needs.

Replacing this infrastructure with smart devices has many advantages from several different viewpoints. Particularly striking is the grid's capacity to prevent and avoid faults and to rapidly and automatically self-heal, thus minimizing the losses due to outages or technical failures.

Source: Author's elaboration.

2. Greater resistance and reliability in the event of natural disasters and man-made attacks

Another smart grid characteristic is greater resistance and reliability in the event of natural and man-made disasters, and this is closely linked with and facilitated by the self-healing function.

Thanks to the combination of increased control over infrastructure and capacity (provided by the introduction of ICTs into grid management) and the simultaneous handling of large data volumes using various means, the entire system achieves unprecedented levels of resistance and reliability.

How? The key to reducing the system's vulnerability to physical and cybernetic attacks lies in a wide range of solutions, beginning with grid design and coming into their own in terms of grid operability.

In this regard, the United States Department of Energy highlights the following three general characteristics:

- Identification of threats and vulnerabilities
- Grid protection

Incorporation of security risks in system planning.

More specifically, a distinction should be made between the threat of natural disasters and deliberate human attacks, which tend to be mostly cybernetic.

In the case of natural disasters, it is up to the self-healing function to guarantee at least a sufficient performance when faced with uncontrollable events, such as extreme meteorological conditions (floods, hurricanes and drought), earthquakes, tsunamis, solar magnetic storms, and so forth. In other words, incorporating data on environmental conditions provides a probability model able to assess grid status, provide improved interpretation capacity for operators and minimize the risk inherent in such disasters.

As for human cybernetic attacks, the smart grid's defence system deploys security protocols that contain elements of deterrent, prevention, detection, automatic response and mitigation to minimize the impact on the grid and its economic system.

On a more general level, the touchstone of increased grid resistance and reliability may consist in the smart monitoring of all components, and the capacity to handle a much larger volume of data than a conventional grid. This is in turn largely dependent on the use of digital devices at all levels that can ensure the two-way transmission of information and that can be operated remotely.

Aims and benefits. The general aims of increasing the grid's resistance and reliability are to reduce the number and duration of outages, and minimize the time it takes to restore the power supply in the event of a disaster. What is more, the introduction of security improvements indirectly optimizes many other aspects of the grid, such as its reliability, its computer and communications system and the decision-making process of operators.

While most of the general benefits are broadly similar to those listed under the self-healing function, in terms of human threats the same idea of an attack-resistant grid is in itself a strong deterrent for those individuals determined to carry out any disruptive action. In other words, a self-healing system that can automatically defend itself from external attacks on various levels is a far less attractive target than some others, especially if its recovery capacity minimizes the impact that these attacks can cause.

Obstacles. The current electricity grid is highly vulnerable to human attack and natural disasters. Achieving the ideal of a system capable of resisting such threats and of rapidly restoring supply involves overcoming the following obstacles:

- Technological: The traditional monitoring system16 is very weak and likely to fail when faced with flagrant errors that may relate to metering, parameters or topology. It is therefore vital to adopt new monitoring technology capable of overseeing various sectors of a modern grid, such as the Wide Area Monitoring System – WAMS.
- Information technology: The transition from an analogue electricity infrastructure to a digital one, and the exponential increase in data resulting from the introduction of smart meters, sensors and an advanced communication network, poses certain problems associated with the security of this structure. In other words, any device designed to reduce the vulnerability of the grid involves new and subsequent risks relating to information technology, especially in terms of the danger of organized hackers.
- In summary, a successful effort to reinforce a weak spot in the system could end up generating a risk factor in another aspect and opening a gap in a structure of strategic national importance.
- Normative: The introduction of smart meters and the launch of two-way transmission in the flow of information have opened the doors to a potential invasion of users' privacy. Data collected on energy use (and possibly generation) may be indicative of customers' behaviour and preferences. All of this information, which could be valuable to consumers and operators in terms of the efficient management of grid resources, could be the cause of normative problems if security measures and protocols are not properly respected.

BOX 2
NEW ORLEANS, UNITED STATES / HARBIN, CHINA

In these places, the implementation of a smart electricity grid involving the use of devices for advanced communication devices and other electrical functions, has involved creating a more dynamic and streamlined system to improve the grid's resistance and recovery capacity and ensure the availability of electricity supply.

The adoption of smart grids is therefore recommended in regions with a strong tendency to experience natural disasters, so as to minimize their negative effects. Alarm systems, self-healing mechanisms and active temperature control are very useful means of preventing outages and guaranteeing supply.

The cases of New Orleans and Harbin are very similar because both cities are exposed to severe meteorological conditions (floods and ice storms, respectively), which used to cause frequent outages.

Source: Author's elaboration.

[16] Based on Weighted Least Square – WLS.

F. Regulatory aspects

1. Raising awareness, motivating and involving users

A smart grid offers the opportunity to involve users by making them an active part of the electricity market. In a context where customer expectations are constantly rising, a smart grid infrastructure and its various instruments would help to educate consumers about optimally managing their energy use, which would have a major impact at the economic and environmental levels, mainly thanks to the lower cost of electricity supply.

How? Most of today's consumers are completely cut off from the volatility of tariffs in the electricity market. Customers buy energy at previously fixed prices that do not react to variations in the cost of generation. However, the reality of the electricity market is different, as the cost can vary widely even within one day.

Smart technology, with its next-generation meters, can provide users with information about their energy use, energy costs and environmental impact in real time. Informed users will be able to manage their energy use interactively, mainly according to the capacity of the electricity system to satisfy aggregate demand. Two- or three-rate tariffs will indicate prices to users, so that they may alter their habits, thus encouraging financial and energy savings (which benefits end users and the entire system alike).

Aims and benefits. These practices are part of a new policy area known as demand response (DR), of which the successful application is closely linked to the implementation of a new vision of an active role for users. Indeed, the natural evolution of this process will soon lead to the development and use of technological instruments such as thermostats, timers and systems that use ICTs to carry out operations remotely, thus creating a "smart household".

At the aggregate level, this type of management will confer great advantages in terms of economic convenience and efficient distribution of energy use loads. First, consumers will react to price indications and other incentives to reduce their electricity costs. Second, the ability to manage and smooth out peaks will bring significant benefits to grid operators and generators, since a mostly efficient use of electricity will reduce the need to build new plants by improving the use made of existing ones, thus reducing the environmental impact of electricity generation.

Obstacles. Raising awareness, motivating and involving users can be achieved through financial, technological, normative and especially cultural means. As stated previously, there is a marked difference between the current and the ideal situation. Concrete results will only be achieved by working on the following aspects:

- <u>Financial resources</u>: Whoever owns the metering instruments, be it the utility company or the user, is not always prepared to invest large sums of money to replace them. In some cases, the prospect of recovering the investment are not good enough to justify the change from electromechanical to digital meters.
- <u>Technological</u>: The devices that power demand response (DR) and distributed generation are still at the development stage, and the area of research and development will therefore continue to require significant resources.
- Furthermore, technological advances in metering, communication, data processing and resource distribution are being applied very gradually, which to some extent slows the pace of research.
- <u>Regulations</u>: The regulations in force and the efforts of regulatory institutions usually aim to protect consumers from the risks of competition, and this does not tend to dovetail with the new vision of the electricity market, and in particular does not motivate customers to take decisions about their level of energy use.

- Cultural: The market's transition from passive and protected users to well-informed proactive customers should be implemented in the same way as in other markets. However, the lack of education on electricity services makes it difficult for consumers to embrace the concept that the price of electricity should reflect its actual production and supply cost. This is directly reflected in users' decisions, which are not always based on purely economic criteria and are therefore not always the best decisions for the system as a whole.

2. Changing from centralized to distributed generation

Although this function will be analysed in more detail in the context of environmental aspects (see Integrating renewable sources and all types of generation), it is worth mentioning that such a radical transformation of the electricity system requires considerable involvement by the authorities, so that the regulatory framework can be adapted to the new market vision of electricity generation.

The current grid was designed and built to transport electricity from centralized generation plants to users using predetermined, predictable and constant loads. In most cases, this context has limited market access for smaller generators, and this has become a major obstacle.

The willingness of governments to increase the share of renewables in the energy mix, including by encouraging distributed generation, has opened the doors to the emergence of many new actors that, despite being small when considered individually, at the aggregate level represent considerable leverage in the electricity system.

Against this backdrop, the aim of regulators is to rethink the rules of the electricity market to provide stakeholders (including small generators involved in distribution) with the optimum conditions to continue operating. This is even more relevant in countries where it is a strategic priority to promote small-scale sources of renewable generation based on a more secure supply.

BOX 3
FLANDERS, BELGIUM

Environmental concerns, rising energy costs and the considerable reduction in the costs of renewable micro-generation are pushing consumers into a new role within the electricity market: prosumers.

Government incentives such as feed-in tariffs may bring about a rapid surge in the penetration of these technologies (photovoltaics (PV), small-scale wind turbines, micro-geothermal energy, biomass, fuel cells, and so on), and the distribution system could suffer from such a radical change in its functioning.

In Belgium, one utility company has decided to adapt the grid infrastructure to the rapid growth in distributed generation, which represents an average of 7% of total generation, in order to take full advantage of the resource potential.

Source: Author's elaboration.

G. Economic aspects

1. Optimizing operability and resources

One striking advantage of smart grids is that they optimize operability and resources throughout the electricity chain, namely from generation to the end user. In particular, the new way of managing the grid's operability and resources will be automatically adjusted to ensure the required functionality for the lowest possible cost. This is possible without necessarily having to exploit available resources to their maximum capacity, but rather by managing them efficiently to provide what is needed when it is needed[17].

How? There are two main ways in which smart grids provide a substantial advantage in the optimization of resources: by reducing the system's technical losses (thus increasing the load factor) and by lowering operating and maintenance costs.

Both aspects depend on the installation of control elements in the system, such as sensors distributed throughout the grid to assess infrastructure conditions almost in real time; common information models to manage and interpret the data and prevent faults; and the automatization of substations for the purposes of remotely monitoring, predicting and solving problems in the electricity supply.

As grid conditions do not feature these systems at present, operators are unaware of the general state of the infrastructure when they do not see it during routine maintenance operations. This way of operating leads to technical losses and wasted resources, owing to a very limited knowledge about the state of the grid.

In summary, if utility companies are to reap the above-mentioned benefits they must face three types of challenge: obtaining information about the state of the grid almost in real time; devising a communication system to collect the information; and effectively processing and managing the information using next-generation software.

Aims and benefits. The benefits of optimizing resources and operational efficiency are key to the smart grid vision. The impact of this modernization is generally reflected in different aspects of the grid, including its reliability, security and efficiency.

On a more detailed level, as stated above the main factors in the optimization of resources involve a reduction in losses and lower operating and maintenance costs. Indeed, having up-to-date knowledge on the infrastructure conditions in the grid makes it possible to take the level of system use closer to its maximum capacity (thus reducing intrinsic technical losses and increasing the load factor), while also facilitating the management of and reducing the costs of maintenance operations (as faults are clearly and accurately identified and even predicted). This enables technicians to develop a working method known as preventive maintenance, which means working on the grid infrastructure when alert signals are received, which occurs just before the fault has a chance to cause avoidable losses to the company.

Furthermore, processing this information using patterns of behaviour for elements of the grid has the impressive advantage of drastically reducing the risk of outages by efficiently controlling wear and tear, as well as the overloading of equipment (especially as far as transformers are concerned).

In conclusion, there are obvious economic benefits for enterprises, in terms of improved use of existing infrastructure without the need to increase load capacity to respond to an upward trend in demand, as well as lower operating and maintenance costs thanks to the more efficient and precise management of resources. It should be remembered that users will also benefit from the improved supply service, in the form of fewer outages and better-quality electricity.

Obstacles. There are three types of obstacle to the large-scale implementation of all technological elements and applications needed to optimize operability and existing resources:

- Financial resources: The number of sensors needed and the creation of an appropriate communication system call for the investment of significant financial resources that can make for business cases with limited profitability, if the optimization of operability and resources are considered in isolation. The situation is different if the sensors and communication system are used for many purposes, such as the development of a self-healing function (see 2.1) and improvements to the quality of the energy supply.
- Incompatible Infrastructure: Some of the older elements of the electricity grid may not be compatible with the sensors that facilitate the optimization of resources and, in some

[17] "A Vision for the Modern Grid", National Energy Technology Laboratory (NETL) for the United States DOE, 2007.

cases, installing them may not be very profitable, thereby weakening the business case even more.

- Resistance to change: It is not easy to impose a change in maintenance practices that are deeply entrenched within a company's working procedures. Furthermore, this type of innovation can involve practical problems relating to the development of accurate predictive models, and also the training of maintenance staff.

2. Improving the quality of electricity

This is a fundamental aspect of modernizing the electricity grid, which in most cases was designed and built in the early 1900s and therefore cannot guarantee the quality of supply required by twenty-first century society.

How? When users think about energy quality, they refer to an electricity supply free from interruptions and disruptions. To achieve this and minimize all phenomena that lower the quality of electricity, such as voltage drops, harmonics caused by non-linear loads, surges and unbalances, the modern grid needs the following:

- Meters to monitor energy quality throughout the system
- Various storage devices to improve the quality and stability of supply
- Many pieces of electronic equipment to instantly correct deformities in electric waves
- New equipment (such as micro-turbines and fuel cells) for distributed generation and the supply of clean energy

Thanks to its advanced control and monitoring methodology, a smart grid will considerably reduce the incidence of drops in electricity quality that originate in the system's transmission and distribution components. As in other aspects analysed, however, applying all this technology to the grid calls for efforts and actions to be coordinated among the government, utility companies and the regulator.

Aims and benefits. The quality of electricity supply is extremely important in today's society, particularly for the normal development of economic activities. Modern digital devices are what drive most industries, and few sectors are immune to reductions in supply quality.

It is precisely for this reason that the general aim of utility companies is to raise the overall level of energy quality and define a range of supply ranging from "standard" to "premium", depending on the demands of users.

The benefits of improving energy quality relate to the lowering of generation costs (as this is another way of optimizing resources), and to the level of productivity of the sectors involved. Indeed, avoiding falls in productivity resulting from low quality electricity supply in commercial and industrial sectors is expected to save the economy large sums of money at the aggregate level, and this could then be reinvested in the development of new markets.

What is more, an across-the-board improvement in electricity quality and in supply reliability should offer growth opportunities for a country's less developed areas, such as rural areas where it would be currently unfeasible to create hi-tech industries.

Obstacles. Voltage drops are currently the main problem in terms of the quality of electricity supply. Given that the causes of voltage drops are unexpected and cannot be controlled (mainly in the form of acts of god), it is normal for their frequency to vary from year to year.

Despite the uncertainty this creates for users, it remains difficult to modernize the grid to prevent these phenomena from occurring, as the entire system was mostly designed to bear very different loads from those transmitted currently.

There are three main types of obstacles that make such modernization difficult:

- **Cost of devices**: The high cost of devices used to improve the quality of electricity supply must be brought down if they are to be more widely accepted and adopted. The mass introduction of these devices would naturally bring down their cost, while the technology involved would also improve once significant market potential had been established.
- Policies and regulation: The lack of a clear policy on whether it is appropriate to differentiate supply quality based on customer needs is a major obstacle to improvement in this context. State regulatory commissions can do much to promote investment and the adoption of different tariffs based on the grade of electricity supplied, which in the medium term would benefit the economy at the aggregate level.
- The lack of subventions to encourage utility companies to constantly improve energy quality is an obstacle that leads to a lack of investment in this area.
- Standards: The organizations that determine the standards of products in the electricity sector usually have considerable influence over the design of devices, fixtures, household appliances and the communication system. However, these organizations have not yet established common standards in terms of quality categories of the electricity supply. Actions in this direction are essential for differentiating the prices for the various levels of service provided, such that customers would choose their level of supply in accordance with certified and guaranteed standards.

BOX 4
SILICON VALLEY, UNITED STATES

Some commercial clusters are particularly sensitive to the quality of electricity supply, and day-to-day economic and commercial activities can be badly affected by a service that cannot keep up with the demands of the twenty-first century.

Silicon Valley is a perfect example, as the computer equipment there is extremely sensitive to fluctuations in electricity flow and any outages could wreak havoc in the industry.

The introduction of smart devices such as sensors and a self-healing mechanism has made it possible for the grid to monitor, manage and ensure a high quality for the energy supplied, thereby reducing losses related to grid malfunctions.

Source: Author's elaboration.

3. Empowering new markets

Modernization of the grid will enable new actors to emerge and existing actors to play a greater role in the electricity market.

How? The transformation of the transmission and distribution systems that will be needed for the higher volumes of energy transported in both directions will require improvements to be made to management, so that there can be an open market and free competition, where alternative sources can be converted into electricity and easily sold to any type of user (irrespective of the distances involved).

In addition, demand-response initiatives and the inclusion of alternative energy resources (such as renewables and storage) will serve to empower new markets and integrate new economic actors. More specifically, smart devices incorporated in the distribution network will turn consumers into "prosumers" – producers and consumers at the same time – which is associated with micro-generation and local energy commercialization. Without the smart element provided by sensors, ICT and the software designed to react instantly to the imbalances typical of intermittent sources (PV, small-scale wind turbines and micro-hydroelectrical generators), distributed generation would be much more of a problem than a benefit.

Aims and benefits. The empowering of new markets is the result of the decision to modernize the grid, and the considerable benefits involve the electricity market at the structural level.

Support systems and infrastructure are crucial factors in the successful transformation of the grid. In order to set up and operate a smart grid, new services and products are required that will open major market opportunities for those enterprises that can generate sufficient profit margins. One clear example is the application of ICTs and their integration into the electricity market.

The gradual insertion of renewable sources and micro-generation in the market is expected to have the positive effect of considerably improving their technological development (reflecting lower generation costs), while also increasing the contribution of renewables to the energy mix. Using the advantages of smart grids, distributed generation can be managed to produce an additional electricity resource that can easily be deployed at the local level. If this dynamic is supported by the appropriate price policies, the development of micro-generation will promote, inter alia, the growth of the renewables market thanks to "prosumers".

Another sector destined for change is the electricity metering and billing market. Ensuring accurate billing that tracks fluctuations in electricity prices as closely as possible will involve the following aspects: technical (replacing existing meters with two-way digital ones) and the installation of smart devices and sensors; managerial (rethinking metering and billing while reducing technical losses); and regulatory (creating flexible tariff policies in keeping with the level of demand).

Empowering the market for electric vehicles is another major change in the economic system, and its success depends mainly on the modernization of the electricity grid and its management.

Obstacles. Although there are many obstacles to the development of new markets, the most common can be summarized as follows:

- Policies and regulations: The lack of clear policies and well-defined regulations that correspond to energy priorities makes decision-making difficult and erodes investor confidence.
- Financial resources: The cost of modernizing the infrastructure may be too high when compared with the advantages derived from the smart management of new resources.
- Resistance to change: Users' cultures, their view of electricity and energy use habits all determine deeply entrenched behaviors. The difficulties in changing these behaviours may make certain markets less attractive in the eyes of investors.

H. Environmental aspects

1. Integrating renewable sources and all types of generation

Smart grid technology will enable the grid to better adapt to the dynamics of renewable energy and distributed generation. This will provide utility companies and consumers with more direct access to the benefits of these resources. The capacities of a smart grid will make it possible to easily and directly control the two-way flow of electricity, as well as enabling monitoring, control and back-up actions at the level of distribution.

How? Besides centralized generation from large power plants (whatever the source), the modern electricity grid must also make room for the growing range of distributed energy resources (DER). Although this type of generation is not yet widespread, factors such as State subsidies inspired by environmental commitments are expected to bring about a major surge in distributed generation in the near future. What is certain is that the new idea of "prosumers" will catch on in the electricity market, mainly thanks to the range and flexibility of new options, in the form of renewable micro-generation, distributed generation and energy storage.

Moreover, the upward trend in the centralized generation of renewable sources (whose main characteristic and problem for grid operators lies in their intermittent and unpredictable input) could end up constituting more of an obstacle than an incentive to their integration in the system.

To achieve an efficient management of this range of new opportunities offered by the electricity market, the grid needs new functions. Modernizing the grid and making it smarter still, will require the following: improved metering and real-time pricing, installation of smart control mechanisms and sensors at all key points throughout the grid, use of new demand response and management software, and the formulation of new standards to encourage metering and interconnections among different parts of the same system.

Aims and benefits. The main aim is to make the system more flexible, so that it can include centralized renewable generation and all the generation and storage options relating to the distribution system.

There are multifaceted benefits to this operation. From the viewpoint of system reliability, combining different types of generation with the opportunities offered by storage will reduce the dependency of the transmission sector, while increasing its operational flexibility. From the security point of view, there will be a sea change, not only in terms of supply but also in the context of external attacks (as decentralized generation will mean fewer sensitive targets such as large power plants). Economically speaking, the considerable advantages range from a decrease in technical losses (as the generation and load sites become closer), to a reduction and reallocation of the investments originally earmarked for the construction of large power plants, substations and new transmission and generation lines.

Lastly, from an environmental perspective, modernization of the system will significantly help to reduce greenhouse gas emissions in the following ways:

- Further developing the implementation of distributed generation, particularly in the form of clean-technology micro-generation
- Promoting the establishment of large renewable energy power plants, particularly for hydroelectrical and solar energy, thereby avoiding the problems of intermittent supply
- Reducing the need to invest in fossil-fuel centralized generation.

Obstacles. Although distributed generation is still at the development stage, there are nonetheless significant obstacles to fulfilling the requirements for its widespread use in the market.

The largest obstacle is that it is difficult to distribute all the above-mentioned devices needed to modernize the entire system. There are also other factors restricting the development of DER:

- <u>Technical</u>: It is not completely clear how the distribution system will interact with the various forms of distributed generation. Further studies are required, especially when system conditions are altered.
- <u>Financial resources and market competition</u>: At present, the cost of distributed generation devices (initial investment, operation, maintenance and fuel in some cases) is too high to compete with conventional generation. Advances in the research and development sector and the commercialization of these devices are vital if they are to be made competitive.
- <u>Limited motivation</u>: Achieving varied yet complementary options for distributed generation is largely dependent on the level of motivation and investment for domestic, commercial and industrial consumers. While motivation remains low, the limited investment in DER will have to come from the electricity industry (which means development will be restricted).
- <u>Conflicts among stakeholders</u>: The independent development of distributed generation among consumers, through which they become “prosumers”, has a negative impact on the profits of utility companies. In fact, the social benefits lauded by governments are not usually considered in the business plans of energy companies and operators. The obvious result of this is that some key modernization projects fail to raise the funding needed for their implementation, thereby obstructing the path to smart grids.

BOX 5
UNITED STATES MIDWEST

The development of large-scale renewable generation is linked to many factors, including geographical ones. Given that the location of a large renewable power plant depends mainly on the site of the source to be exploited (light intensity, wind speed, wave intensity, and so forth), generation centres tend to be fairly far from load centres, which makes the need for an efficient transmission network even more essential.

The intermittent and unpredictable nature of the electricity output causes considerable variability in the supply, which is not tolerable in the current economic and social system. This then creates the need to manage the balance between demand and supply, practically in real time.

The Midwest in the United States is an illustrative example of this need. In order to increase the share of renewable energy and accelerate the creation of a clean-energy economy, work has begun to build a new transmission system linking the East Coast (where solar generation and other sources are rapidly gaining ground) with the West Coast or linking the mountain states (which can use hydroelectric power) with central states.

Source: Author's elaboration.

2. Reduction of deleterious gas emissions

One significant advantage afforded by smart grids is the aggregate reduction in carbon emissions, which refers to the emissions directly and indirectly relating to electricity generation.

How? While electricity is responsible for just 17% of total worldwide fuel consumption, the electricity sector is responsible for 38% of global greenhouse gas emissions, owing to the intensive use of fossil fuels (especially coal).

Grid modernization will make it possible to reduce the sector's strong dependency on fossil fuels, while also bringing down the number of grid inefficiencies that cause large energy losses. According to the International Energy Agency, an estimated investment of around USD 13 trillion will be required to update the world electricity sector over the next 20 years.

The direct reduction of CO2 emissions involves various factors, such as managing load peaks, minimizing technical losses, boosting energy efficiency programmes, user feedback for price policies and the management of the power use of public and business premises.

The indirect reduction of emissions consists mainly of two factors: the increasing integration of renewable sources in the energy mix and the future introduction of electric vehicles (once the infrastructure is in place to definitively open this market).

Aims and benefits. Although the benefits are difficult to calculate accurately at the aggregate level a study has been carried out by the International Energy Agency (IEA) into the reduction of CO2 emissions. According to this study, global deployment of smart grids would help to reduce emissions by between 0.9 and 2.2 gigatons a year by 2050, which is the equivalent of the annual emissions from up to 730 medium-sized power plants.

Other studies have been carried out in the United States and jointly in the member countries of the Major Economy Forum.

The study in the United States estimated annual reductions of up to 211 million tons of CO2 in the United States alone, which is the equivalent of 9% of total emissions recorded in 2006. The reduction can be broken down as follows: [18]

[18] The Green Grid, EPRI, 2008.

- Direct reduction: Improved energy efficiency and greater savings (between 31 million and 114 million tons)
- Indirect reduction: Integration of renewable sources and electric vehicles (between 30 million 97 million tons)

The Accenture study for the Major Economy Forum (MEF)19, showed that introducing smart grids in its member countries would reduce CO_2 emissions by around 20%. It would also significantly decrease the system's technical losses, which in terms of carbon emissions amount to 608 million tons in the most developed countries.

Obstacles. Given the level of investment referred to in the IEA study, the shortage of financial resources clearly remains the main obstacle to the direct reduction of greenhouse gas emissions.

As for indirect reductions, apart from the above-mentioned technical, political and financial obstacles to the updating of the grid, it is vital to overcome obstacles typical of emerging markets (such as renewable energy and electric vehicles), as well as facing up to much more advanced and economically competitive technological developments.

I. Coordinated regional actions to promote and develop smart grids

There are major regional and international initiatives aimed at promoting and developing technology applied to smart grids, from research and development to commercialization.

This section will briefly mention two European initiatives (EERA and EEGI) and an international one (ISGAN).

1. European Energy Research Alliance – EERA

As outlined in the European Strategic Energy Technology Plan (SET-plan), energy technologies will be crucial to successfully combat climate change and securing world and European energy supply. Achieving Europe's 2020 and 2050 targets on greenhouse gas emissions, renewable energy and energy efficiency will require the deployment of more efficient and new technologies.

Europe's potential to develop a new generation of decarbonised energy technologies is enormous. However EU energy research is fragmented, dispersed and often under-funded. If the opportunity facing the EU is to be seized, actions to develop new energy technologies, lower their costs and accelerate the process to bring them to the market must be better organised and carried out more efficiently.

The EERA aims to strengthen, expand and optimise EU energy research capabilities through the sharing of world-class national facilities in Europe and the joint realisation of pan-European research programmes. Development of promising technologies is often hampered at national level as there appears to be sub-critical mass in individual countries. National and European energy R&D programmes have to be streamlined and coordinated, to achieve accelerated energy technology development which can subsequently be shared and implemented via the commercial community. The primary focus of the EERA is on the strategic and targeted development of next generations of energy technologies drawing on results from fundamental research and maturing technologies to the point where it can be embedded in industry driven research.

Preceding the conference on the SET-plan on the 28th of October 2008 in Paris, the founding partners of the EERA have signed a Declaration of Intent on their meeting on the 27th of October. In

[19] "Technology Action Plan on Smart Grids", Report to the Major Economies Forum on Energy and Climate, 2009.

response, EU Commissioners for Research and Energy welcomed the initiative to found the European Energy Research Alliance.

The high-level objectives of the Alliance are to:

- Accelerate the development of new energy technologies by conceiving and implementing Joint Programmes of research in support of the SET-Plan priorities, pooling and integrating activities and resources, combining national and Community sources of funding and maximising complementarities and synergies, including international partners.
- Work towards a long term, durable integration of excellent but dispersed research capacities across the EU, overcoming fragmentation, optimising the use of resources, building additional research capacity and developing a comprehensive range of world class pan-European energy research infrastructures.
- Strengthen Europe's capacity to initiate and execute large precompetitive high-risk high-gain research and development programmes.
- Develop links and sustained partnerships with industry to strengthen the interplay between research outcomes and innovation, facilitate industry access to world-class research and ensure the early take-up of promising results.
- Develop training, education and outreach activities, encouraging researcher mobility, providing a training environment for new researchers and professionals in strategic energy sectors and raising public awareness.

The Alliance is made up of Europe's 10 main renewables energy research institutes20, with a total annual budget of 1.3 billion euros. The overall aim of the more than 10,000 scientists and researchers is to speed up the process to develop new energy technologies, by strengthening, expanding and optimizing research capacity.

- The first EERA Joint Programmes of Research on Wind, Photovoltaic, Smart grids and Geothermal have been officially launched in the occasion of the SET-PLAN conference, which took place in Madrid on the 3rd and 4th June 2010, under the EU Spanish Presidency.
- Three new EERA Joint Programmes on Materials for Nuclear, Bioenergy and Carbon Capture and Storage, have been officially launched on the 15th November 2010 in Brussels, during the SET-Plan Event, organised under the EU Belgian Presidency.

The seven officially launched EERA Joint programmes involve more than 1.000 fulltime equivalent scientists from 74 different research organisations.

- The next EERA Joint Programmes will be launched under the EU Polish Presidency during the SET-Plan conference on 28-29 November 2011. Following the last EERA EXCO meeting on April 2011, two new EERA Joint Programmes are to be officially launched soon, on Concentrated Solar Power and Marine Energy. AMPEA, Energy Storage and Smart Cities are in progress.

More specifically on Smart grids: the EERA Joint Programme on Smart grids provides added value through the involvement of top research institutes aiming at promptly tackling the goals and objectives set by the Strategic Energy Technology Plan.

[20] French Atomic Energy and Alternative Energies Commission (CEA), Spanish Centre for Energy, Environment and Technology Research (CIEMAT), Greek Centre for Renewable Energy Sources (CRES), Energy research Centre of the Netherlands (ECN), Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Portuguese National Institute of Engineering, Technology and Innovation (INETI), Jülich Research Centre in Germany, Danish National Laboratory for Sustainable Energy (DTU), United Kingdom Energy Research Centre (UKERC) and the Technical Research Centre of Finland (VIT).

- Strategic leadership: Aligning the research activities of all R&D participants, having different and complementary expertise and facilities, EERA JPSG promotes strategic leadership both at internal and external (research organizations) level. Internal effectiveness and efficiency are reached by increasing common understanding among participants and through extensive cross-disciplinary collaboration, kept updated through meetings, personal contacts and share of information (also through an "ad hoc" online platform). Strategic leadership, in the field of Smart grids is carried out through mapping activities of strengths and point of weaknesses in this field of research. Mapping and governance activities are supported by the exchange of information in workshops, the coordination of the research efforts towards common aims and the design and development of standard procedures, protocols, technologies and methodologies. Mapping the state of the art, increasing common understanding and strengthening cooperation among involved participants allow to draw up a clear vision on applications of current research and the needs for future research. An appropriate interface and collaboration with industry to exchange needs and visions on the applications of pre-commercial research is foreseen by the programme on Smart grids. Further, the Programme intends to establish a structured dialogue with government bodies (ministries, agencies, other public research organizations) to communicate findings, activities and future research needs.
- Speeding up the realization of SET-plan goals: The programme is built on other SET-plan initiatives and aims at fulfilling the challenges of the European energy policy: competitiveness, sustainability and security of supply. The Strategic Research Agenda forms the starting point for the discussion on priority areas. The programme is addressed in medium to long term research perspective and shares the SET's objective of rearrangement the European energy system in order to foster the reduction of the costs of electricity generation and the increasing of the quality and reliability of supply. In a European perspective, as for all other technologies considered in the Strategic Energy Technology Plan (SET Plan), the focus of Smart grids initiatives is linked with the main commitment to achieve the goals of the Climate and Energy Package 20-20-20, at the light of the three main pillars of the European energy policy: competitiveness, sustainability and security of supply. More specifically, adopting Smart grids will allow the European energy system to integrate renewable energy sources, adopt active demand response measures, reduce grid losses, increase energy efficiency, improve system performance, and the utilization of ageing assets.

Although most of the technologies necessary for the deployment of Smart grids exist, their level of maturity is in many cases emergent (under R&D) or developing (under small scale demonstration) and their penetration is limited or moderate; moreover, technologies integration, standardisation and interoperability is very limited, thus inhibiting a rapid deployment trend.

It is recognised that significant investments will be required to upgrade electricity systems and implement more efficient, smart technologies: as an example, the Organisation for Economic Co-operation and Development (OECD) foresees that the world will need more than 1,200 billion € per year over the next two decades to upgrade the grid infrastructure. To be efficient, this effort must be coordinated; it is essential therefore that actors join forces to set up research and development programs and to implement large demonstration and deployment projects to understand and prove the capabilities of Smart grids. This is one of the messages outlined in the Technology Action Plan on Smart grids developed by the Major Economies Forum and recently approved during the International Conference on Climate Change in Copenhagen.

There are several projects being developed worldwide which can be gathered under the Smart Grids umbrella. Each of these projects is driven by a different set of objectives and benefits, different types of implemented technologies and differs in its complexity of solutions and integration architecture (e.g., demonstration project vs. full-scale deployment). As will be detailed better later in this chapter, in Europe, several electricity operators (TSOs and DSOs) have joined forces in an effort of coordination of

Smart grids demonstration and deployment initiatives and have set up the European Electricity Grid Initiative based on an initial set of large scale demonstrators of existing technologies.

The Joint Program on Smart Grids, by means of an extended cross-disciplinary cooperation involving many Research and Development (R&D) participants with different and complementary expertise and facilities, aims at addressing in a medium to long term research perspective, one of the most critical areas directly relating to the effective acceleration of smart grid development: i.e., smart grids technology, its application and integration.

Several R&D centres are active in the wide field of Smart grids technologies; however, at present, R&D is not entirely coordinated, as there is a natural tendency for institutes and companies to choose to develop technologies most aligned to their capabilities and interests. This may leave some technologies receiving less focus than others. Moreover, given the high cost of R&D, technologies with less potential economic payback in their own right may well get left behind, leaving a maturity gap in the Smart grids technology chain. This JP, through the coordination of the activities of the participants towards common goals, will help to improve this situation and will create the required synergies to achieve the development goals reducing the times and costs and greatly increasing the quality of the research.

Among all aspects related to the development of smart grids technologies and capabilities, general consensus was found on the opportunity to initially focus the attention of the international R&D coordination effort on active distribution networks. In this respect, the integration of variable distributed renewable sources and customer participation were pointed out as main drivers.

The management of distribution networks with variable generation and partly controllable loads (customer participation), maintaining the necessary level of availability and power quality, requires the setting up of advanced network operation capabilities (i.e. maintaining the voltage level and frequency on every node coping for variable sources and loads) and energy management capabilities (i.e. using all technical and economical leverages – e.g. dynamic tariffs - to optimise the energy flows in the network).

These are two important pillars of the JP: Network operation and Energy management.

Main objective of the Network operation sub-programme activity is to contribute to the development of new methods and technical solutions in electrical grid operation in presence of Distributed Energy Resources (DER). Among the main aspects that need to be considered are the managements of DG, load control and the adaptation of primary control comprising frequency and voltage stability issues, islanding, and fault and outage management. Finally, the role of ICT will be examined in relation to the integration of DER in network operation, to the network monitoring system and to implement market mechanisms as incentives for system operation.

The focus of the **Energy management** sub-programme is on the optimization of the management of the distribution network in presence of DER and load control in an energy and market perspective. Technical and economical scenarios will be considered for the active distribution network development, taking into account the most important smart grids features, i.e. resilience to generation and load variability, demand response, energy balance optimization, grid loss reduction and optimal asset management. Specific attention will be given to all ICT implication.

The realization of Smart Grid concept requires an efficient and reliable data information exchange among main Smart Grid actors (i.e., system operators, consumer, etc.) and smart devices on the grid. Interoperability enables the Smart grids networked devices and systems to communicate and work with each other. A specific sub-programme (SP) was therefore devoted to the **standardisation, integration and interoperability issues**: Information and control system interoperability. Main objective of the SP activity is to contribute to the developments and evaluation of interoperability issues in control system applications. Interoperability will be considered at different levels: from physical encoding and transmission of the data to upper level aspects as protocols for business functionality. Cyber Security aspects in control systems need to be considered jointly and designed at architectural level for each different layer. Technical issues relative to communication infrastructures may also be considered. To achieve interoperability and security in real applications also testing and certification of how standards are implemented in smart grid devices, system and processes need to be considered and the related methodologies and procedures have to be developed.

From the technology point of view, the research to be developed along the two subjects identified considers the following main aspects: network automation, protection, control, with the related communication and embedded sensing aspects and the energy storage. Most of the above mentioned technologies are naturally interlinked and well integrated into the main R&D pillars. On the other hand, one technology implies a very wide path by itself, involving specific research infrastructures, capabilities and knowledge and deserving a self-standing R&D sub-programme: Electrical storage technologies. The objective of this research path is to gain a better understanding of the status and development progress of different energy storage technologies and their performance. The concept (measurements, protection, communication and management) for network interface of energy storage is determined. In addition, the potential impact on networks and their opportunities in energy markets and in ancillary services are analyzed.

In conclusion, EERA is a joint European initiative involving the largest research institutes, and its aim is to step up the development of advanced energy technologies that can not only improve resource efficiency but also increase the total budget available to members.

European Electricity Grid Initiative – EEGI

There are two types of factors that inspired the creation of EEGI: external and internal.

- The external factors include the 20-20-20 objectives, the growing rate of electricity consumption, the considerable increase in the generation of intermittent renewable sources and supply security.
- Internal factors include the replacement of obsolete infrastructure, the reduction of the electricity system's total costs, the integration of low carbon emission sources of generation, active user involvement in the electricity market, electrification of the transport sector and improved grid flexibility to cope with situations in the second half of the century.

The initiative involves Transmission System Operators (TSOs) and Distribution System Operators (DSOs). Of the founding members, seven are TSOs and seven DSOs21, and their vision is twofold:

- the integration of all types of innovative generation or patterns of use that increase efficiency,
- the capacity to manage emergency situations in a way that minimizes losses for consumers.

To achieve these aims, TSOs and DSOs have devised a joint research, development and demonstration (RD&D) programme that covers various domains: technology to improve grid infrastructure, redesign of the market to integrate distributed energy resources (DER) and to enable user participation, the management and exchange of data at the European level, and the redefinition of regulatory policies. The European Electricity Grid Initiative (EEGI) Roadmap 2010-18 and Implementation Plan 2010-12, has been prepared by ENTSO-E and EDSO-SG in close collaboration with the European Commission, ERGEG and other relevant stakeholders.

This Implementation Plan has been formally endorsed at the SET-PLAN conference in Madrid on 3rd of June 2010.

The programme focuses on system innovation rather than on technology innovation, and addresses the challenge of integrating new technologies under real life working conditions and validating the results. It aims to coordinate efforts at national and EU level through joint strategic planning and effective implementation mechanisms.

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[21] TSOs: ELIA, AMPRION, RED, RTE, TENNET, TRANSPOWER, VATTENFALL; DSOs: ENEL, RWE, ERDF, IBERDROLA, E-ON, VATTENFALL, CEX GROUP.

European Industrial Initiatives are industry-driven strategic technology alliances to address key low-carbon energy technologies. ENTSO-E is the European Network of Transmission System Operators for Electricity, representing 42 Transmission System Operators (TSOs) from 34 countries. EDSO4SG (European DSO Association for Smart grids) has recently been created by a number of Distribution System Operators. The two associations, jointly with the European Technology Platform SmartGrids play an important role in the planning, monitoring and dissemination of this initiative.

The European Electricity Grid Initiative (EEGI) has proposed a 9-year European research, development and demonstration (RD&D) programme initiated by electricity transmission and distribution network operators to accelerate innovation and the development of the electricity networks of the future: the smart grids. Its deployment will start progressively over the period from 2010 to 2030 and result in benefits such as:

- Increased hosting capacity for renewable and distributed sources of electricity;
- The integration of national networks into a market-based, truly pan-European network;
- A high level of quality of electricity supply to all customers;
- The active participation of users in markets and energy efficiency;
- The anticipation of new developments such as a progressive electrification of transport;
- An economically efficient deployment of future networks, for the benefit of grid users;
- The opening of business opportunities and markets for new players in the smart grids arena.

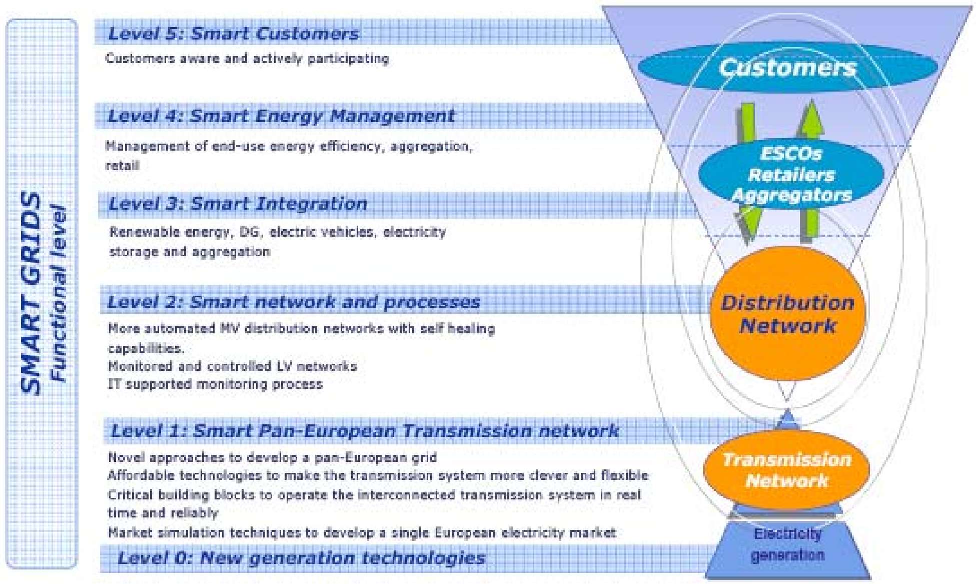
The extra RD&D efforts needed to develop new solutions according to the “Smart grids” approach face several barriers:

- Technology barriers including standards, interoperability, cyber security and data privacy: even though technical solutions often exist at component level, large scale system experiments are needed to validate “system solutions” such as the management of generation intermittency and to promote standardisation and interoperability of the technology solutions which will reduce deployment costs.
- RD&D organisation barriers including the fragmentation of efforts across borders and across the electric system value chain.
- Market failures and distortions: the costs and resulting benefits of the RD&D activities are asymmetric: whereas the investments in Smart grids fall largely on the network operators, the benefits are largely with other stakeholders (society, electricity system, customers, generators etc…). This is not taken into account by current regulation schemes: present incentives are not sufficient for network operators to invest, neither in extra R&D, nor in large scale demonstration or in the deployment of the new technology. Furthermore, current regulatory regimes do not always reflect actual costs of the actions of the grid users and this may not promote the most efficient solutions.
- Public barriers including customer engagement and public acceptance of infrastructure developments.

The actions will be carried out according to the Smart Grid Model adopted by the EEGI, which has following structural levels:

- Level 0: New-generation technologies
- Level 1: Pan–European smart transmission network
- Level 2: Smart distribution network
- Level 3: Smart integration of new markets and operations: renewables, electric vehicles, distributed generation (DG), electricity storage, and so on
- Level 4: Smart energy management
- Level 5: Smart customers

FIGURE 9
SMART GRIDS STRUCTURAL MODEL ADOPTED BY THE EEGI

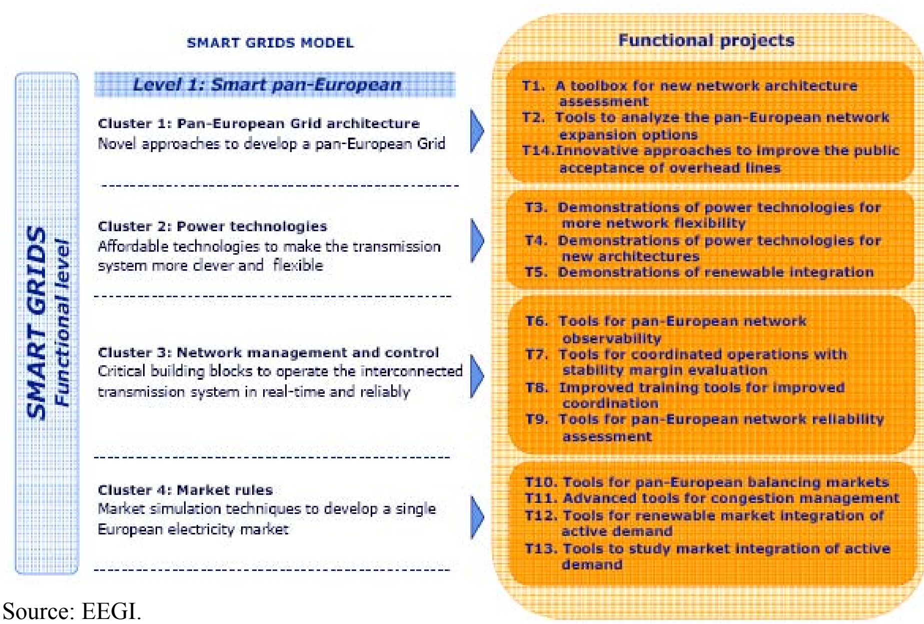


Source: EEGI.

The estimated budget for the total demonstration activities is of 2 billion Euros.

The transmission network activities have been organized according to four clusters corresponding to the four basic activities of a network operator (planning, investments, operations and power markets), as shown at the left side of the figure below:

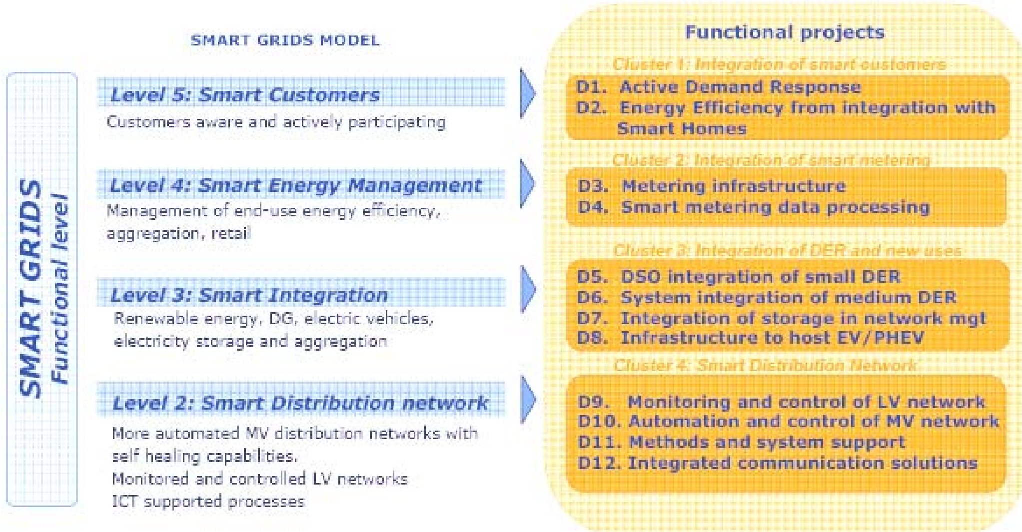
FIGURE 10
CLUSTERING OF THE TRANSMISSION R&D PROJECTS



Source: EEGI.

The RD&D activities needed for the distribution network over the period 2010-2018, have been organized in four clusters according to the corresponding levels in the Smart grids Model with 12 functional projects as follows:

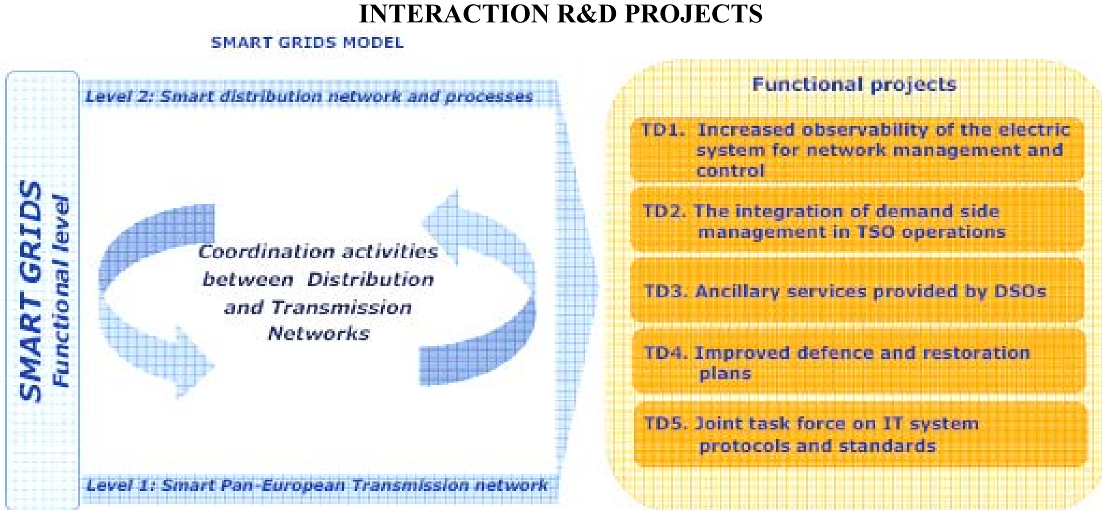
FIGURE 11
CLUSTERING OF THE DISTRIBUTION R&D PROJECTS



Source: EEGI.

Transmission and distribution networks will increasingly need to coordinate their operations and to exchange data in real time for this purpose. They need to prepare for this interaction and propose the following functional RD&D activities to address these issues over the period 2010-2018.

FIGURE 12
CLUSTERING OF THE TRANSMISSION AND DISTRIBUTION INTERACTION R&D PROJECTS



Source: EEGI.

The strength of the programme also lies in its focus on integration with other industrial initiatives, particularly in terms of renewable sources (wind and solar energy).

It is expected that the results will benefit the entire value chain of the European electricity sector, and that they will provide a substantial and active contribution to achieving the major European objectives, such as the integration of renewable energy, unification of the electricity market and the security of supply.

2. International Smart Grid Action Network – ISGAN

As part of the Clean Energy Ministerial meeting, held in Washington DC in July 2010, participants launched the ISGAN in order to step up the development and application of smart grids throughout the world. The initiative lays within the IEA (International Energy Agency) framework and consitutes a new Implementing agreement. The first Executive Committee meeting of the initiative was held in Seoul (Republic of Korea) in June 2011 and the second one was in Scheveningen (The Netherlands) in October 2011.

The initiative, in which participation is voluntary, represents a framework for high-level coordination of activities to speed up the development of smart grids on a global scale. The countries involved in the network work closely with other agencies, particularly the International Energy Agency (IEA), the Global Smart grids Forum (GSGF) and the International Standards Organization (ISO), in order to develop a joint action plan with the following main objectives:

- Growth of renewable energy
- User involvement in improving energy efficiency
- Introduction of electric vehicles
- Reduction of CO2 emissions relating to electricity generation.

ISGAN facilitates the exchange of knowledge, technical assistance, peer evaluation and the coordination of joint projects among participants.

The participating countries, as of November 2011 are the following: AT, AU, BE, CD, CH, DE, EI, FI, FR, IN, IT, KR, MX, NL, NO, SE, UK, US. Participation waiting final signature from BR, CN, DK, ES, EU, JP, RU, ZA.

The initiative sponsors activities to accelerate the widespread adoption of smart grids, and through working groups will direct its efforts towards the following five key areas:

- Policy, regulation and financing of smart grids
- Policies relating to standards
- Research, development and demonstration of technologies
- Training and qualification of labour force
- User involvement at all levels

The workplan is organised into 4 Annexes, covering respectively:

- **Annex 1**: the survey of existing smart grids demonstration and deployment worldwide: leveraging on recent international surveys (e.g. the European smart grids initiatives survey carried out by EC-JRC-IE gathering about 210 projects all over Europe, or the survey from APEC concluded in 2010) the annex will elaborate on the drivers and the motivations at the origin of the initiatives and will draw policy indications on existing gaps and overlaps to be considered in future demonstration efforts;

- **Annex 2**: considers the focus on specific study cases identifying, analysisng and implementing those experiences that can accelerate the smart grids transition. The programme highlights opportunities for identifying and sharing best practices and lessons learned.
- **Annex 3**: considers the cost/benefits aspects of smart grids development and deployment. It aims at setting up tools which can help the smart grids stakeholder to evaluate the costs of the network development and the potential benefits gained through these.
- **Annex 4**: is related to the production of insight materials on smart grids dedicated to policy makers, in such a way as to have at the disposal rational and scientifically sound material, written in a language accessible to the public, depicting smart grids features and their potential in the various possible network or regulatory boundaries.

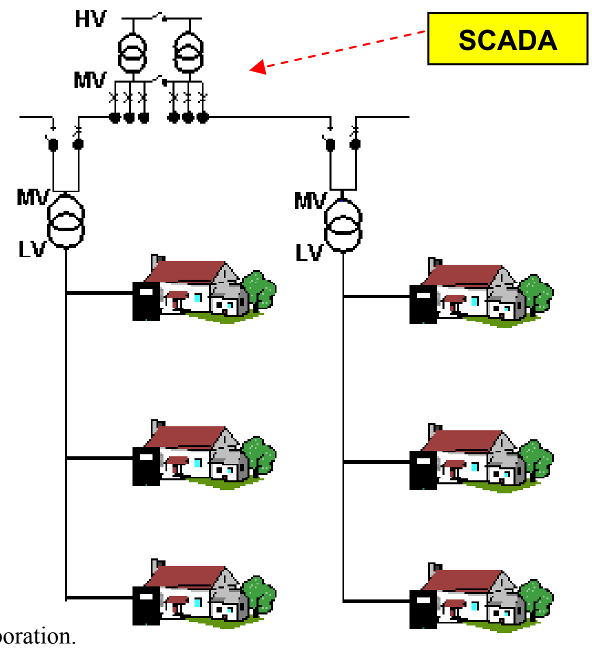
II. Progressive evolution of a distribution network into a smart grid

Among all possible smart grids applications discussed in the first part of the report, we have identified in the evolution of the electricity distribution network a key point for the region, to address the most important local issues of global access to electricity, reduction of losses, energy efficiency and security of supply in the context of a liberalised electricity context. This does not mean that transmission issues are not of interest from the smart grids point of view, as many advanced solutions development could be implemented to increase the security, reliability, efficiency and sustainability of the system in the region.

A. Starting point – the present situation

The present typical section of a distribution network in the region is constituted of primary HV/MV substations from which a certain number of medium voltage feeders depart radially (i.e. from the centre outwards in all directions without interlinks) and progressively widen to feed individual customers, directly connected to the medium voltage network (SMEs, commercial loads etc.) or the low voltage network via the pole-mounted or indoors MV/lv transformers. The interface to the residential user's premises is made through an electromechanical meter or through an electronic meter with little or no communication features, to be read manually by the network operator's personnel. At the residential level, these meters simply record the total energy consumed over a period of time – typically a month. The flow of energy is unidirectional from the utility towards the user, and there is no direct flow of information over the system, to or from the user. Figure 13 shows the typical scheme of this type of distribution system.

FIGURE 13
EXAMPLE OF A PASSIVE RADIAL DISTRIBUTION SYSTEM EQUIPPED WITH ELECTROMECHANICAL METERS



Source: Author's elaboration.

The figure does not show in detail the communication flows of the network supervision system (Supervisory Control and Data Acquisition – SCADA) essential to the operation of the network under the required conditions of reliability and quality of supply. SCADA comprise electronic boards typically installed in substation (see e.g. Figure 14), receiving data from the local sensors and transmitting control commands to the local components, based on supervision commands elaborated at central (or local) control room level (see e.g.Figure 15). Their functions normally consist of data acquisition, data processing, remote control of circuit breakers and motor-operated switches, alarm processing, historical data deposit, emergency control switching, and man-machine interface.

FIGURE 14
EXAMPLE OF THE FIELD PORTION OF A DISTRIBUTION SCADA

Source: Enel distribuzione.

FIGURE 15
EXAMPLE OF THE CONTROL ROOM SIDE OF A DISTRIBUTION SCADA

Source: Enel distribuzione.

The communication technologies normally used for SCADA systems comprise: private cable telephone lines, rented optic fibres and copper circuits, mobile phone technology and radio channels.

Local perspective: in all three Latin America countries visited, SCADA systems are installed and operated on most of the HV and MV distribution networks; very little automation exists in the MV/lv stations and downwards towards the user. Limited automated action is taken based on the acquired data, and most of the system operation (especially on the low voltage side) is manual. The use of meters with no communication feature inhibits any possibility of energy balance at substation level aimed at pointing out excessive distribution losses and energy theft and prevents any dynamic demand-participation measure: the user is informed about its electricity energy consumption through his printed monthly bill. Although the monthly bills of local utilities include graphical information about the trend of monthly consumption during the past year, give suggestions for energy saving and sometimes indicate the equivalent daily cost for the electricity consumption, the lack of interactivity of the meters does not allow the user to have information about its load curve, load peaks, peak hours and the most critical appliances. The user can therefore take no action to add flexibility to the electricity use, as a function of the energy availability on the network.

B. Automatic meter reading (AMR)

The evolution of the distribution network can start with the installation of smarter meter reading, as shown in Figure 16. Smart-meter systems comprise an electronic box and a communication link. In its most basic configuration, a smart meter measures electronically how much energy is used in a certain time-interval, and communicates this information to the utility. In this type of application, most of the information about user's consumption level and related data elaborations flows from the user to the operator. At this level of implementation, the system is defined as Automatic Meter Reading (AMR).

FIGURE 16
TWO METERING GENERATIONS COMPARED

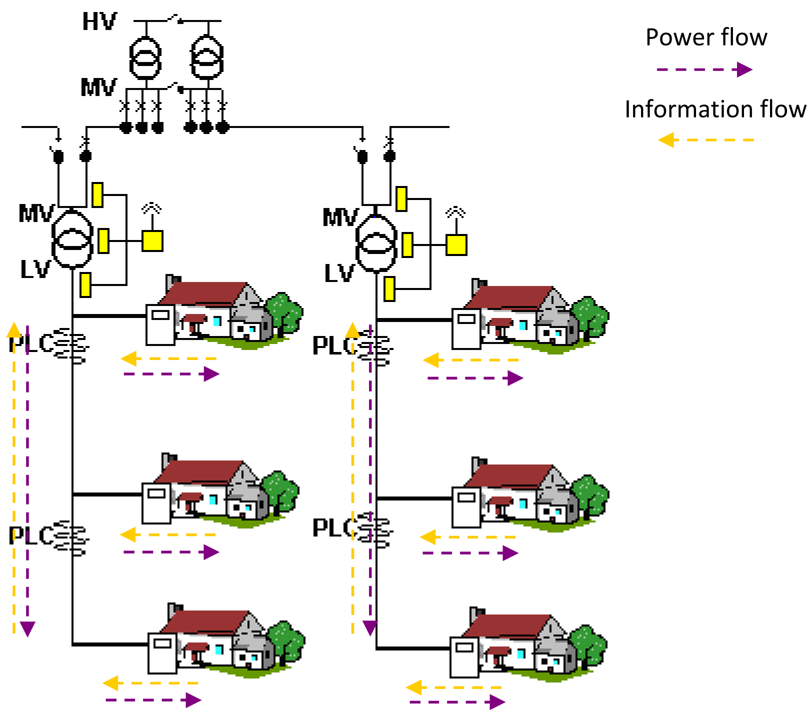
Source: Enel distribuzione.

The initial functionalities implemented with AMR are typically the following:

- Remote reading of the electricity consumption (e.g. every 15 minutes)
- User billing based on real consumption
- Remote tripping and remote consensus to manual reclosing of the switch (management of contractual aspects: disconnection in case of bad payers, reconnection after settlement etc.)
- Remote modification of contractual parameters (e.g. new tariff schemes)
- Recording of unauthorized access to the meter (e.g manipulation attempts)
- Recording of power quality performance at each individual user (e.g number and duration of power interruptions)
- Recording of active and reactive power load curves;
- Energy balance at the distribution power transformer (to point out possible transformers problems or electricity theft);

The typical structure of a distribution system equipped with AMR is shown in Figure 17. The figure also illustrates the direction of the flow of energy and information with purple and yellow arrows respectively. Being the distribution system passive (i.e. with no generator installed on the low or medium voltage portions of the network), the flow of energy is unidirectional: from the High voltage network towards the medium and low voltage network. On the other hand, the flow of information (except for the SCADA) is essentially from the meters upwards to the central or local data management centers. The necessity of a reverse information flow (from the utility to the meter and user) is limited: contractual changes, tripping and consensus to reconnection in case of bill settlement problems etc.).

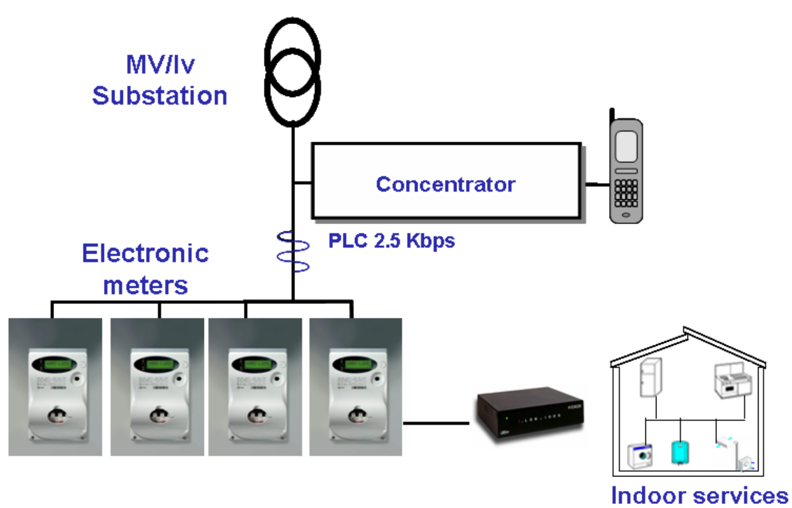
FIGURE 17
EXAMPLE OF PASSIVE DISTRIBUTION SYSTEM EQUIPPED WITH AMR



Source: Author's elaboration.

In terms of communication technologies, the simplest structure of this AMR configuration is represented in the Figure 18 the communication between the electronic meters and the control centre is made in two steps: from the meter to a concentrator the signals are injected on the power cables themselves using a communication technology called Power Line Carrier (PLC) in which a high frequency signal is superimposed on the alternating power frequency voltage and is de-coupled from the power signal at both ends of the line. The second step is from the concentrator to the control centre: in this section several communication technologies can be used, normally using cables of wireless routes as for example the GSM or GPRS protocols widely used in the portable telephones.

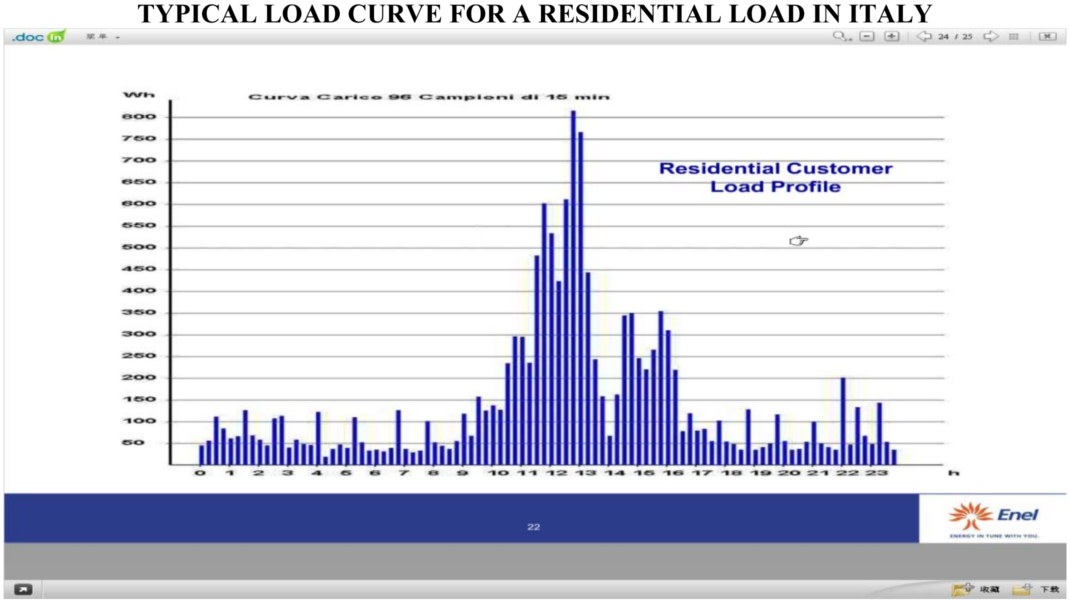
FIGURE 18
EXAMPLE OF COMMUNICATION TECHNOLOGIES MIX USED WITH AMR



Source: Enel distribuzione.

Electronic meters allow a first important step towards the evolution of the distribution system: they allow to enhance the flexibility of the relationship between the electricity supplier (or its commercial branch) and the final user. In addition to the energy consumption during a defined time interval (e.g. one month) obtainable with the conventional meters, the electronic meters allow the measurement of load curves at user level (see example in Figure) and at substation level (see example of Figure). The first type of information may be used by the final user to better understand his consumption behavior, point out peak periods and critical appliances, and take measures for peak shaving or energy conservation, however, with the communication architecture illustrated above, (i.e. where the data communication flows from the meter to the operator and not also vice-versa) this information may not be available to the user dynamically and may not be used directly for demand-participation purposes.

FIGURE 19
TYPICAL LOAD CURVE FOR A RESIDENTIAL LOAD IN ITALY

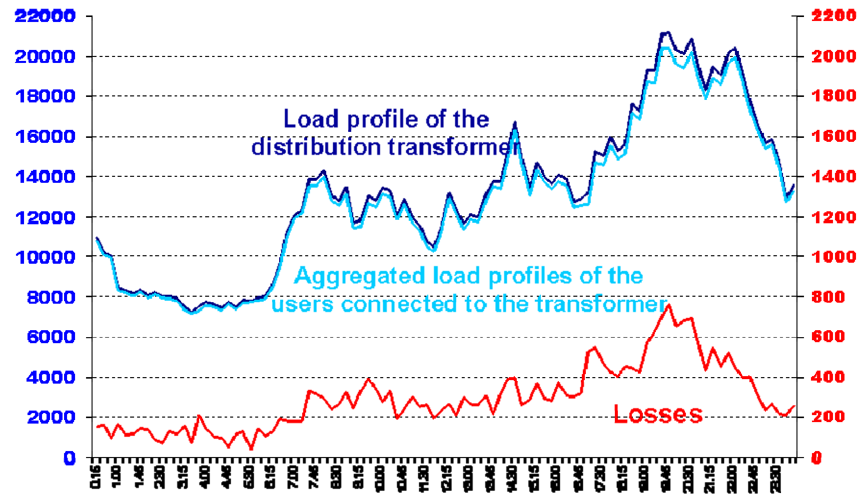


Source: Enel distribuzione.

At substation level, the measurement of the energy consumption of each user connected to a distribution transformer can be combined with the measurement of the total energy at the transformer's terminals, to derive the balance, point out anomalous losses, thefts and many potential problems on the low voltage network. An example of such balance evaluation is shown Figure 20 the dark blue curve shows the trend of the transformer load, while the light blue curve is calculated as the sum of the load profile measured by all electronic meters connected to the transformer. The red curve, computed as the difference between the two mentioned curves, represents the overall losses on the low voltage distribution system connected at the transformer's terminals: i.e. technical losses along the distribution lines and non-technical losses, which can be referred to energy stolen before the meter or to problems along the lines.

Local perspective: These two important features of AMR can be of great interest for the region as non-technical losses reduction remains a very important objective for all the local utilities and because the lack of detailed information on customer load profiles can be of potential interest in the framework of the progressive liberalisation of the energy market, already very advanced in the region. On the other hand, the average monthly consumption of the Latin American residential customer ranges between 150 and 300 kWh/month (i.e. about half the consumption of the average European householder and a quarter of the average American) and the cost of manual reading of the meters is very low. Under these circumstances, it is anticipated that the business case for the development of AMR (and subsequently of AMI) in the region, be mostly related to the potential benefits of losses reduction.

FIGURE 20
TYPICAL DISTRIBUTION TRANSFORMER ENERGY BALANCE



Source: Enel distribuzione.

BOX 6
R&D BEST PRACTICE: THE OPEN METER PROJECT

OPEN meter project, co-financed by the European Commission in the 7th Research Framework Program, aims to specify a comprehensive set of open and public standards for Advanced Metering Reading and Infrastructure (AMR/AMI) supporting multi commodities (Electricity, Gas, Water and Heat), based on the agreement of the most relevant stakeholders in the area. OPEN meter project will carry out the necessary research activities resulting in filling the existing knowledge gaps, and thereby enable the relevant industries to agree, implement and embrace the new set of international standards that are specified. The solution will go far beyond electricity, gas, water and heat meter reading. The high data transfer rates expected to be delivered by the solutions proposed will allow the provision of new services to the customer, given by energy service providers, while at the same time valuable information will be given to network operators that will improve quality, reliability, and responsiveness to network failures. The solution will transform energy metering and control devices from being mere communication enabled devices into intelligent and interoperable nodes integrated in a modern AMI that will eventually reach not only home appliances but will also be connected with a variety of Control Systems and utility applications.

Results:

Provide a selection and a common understanding for the use of available open communication standards suited to support AMI.

Propose recommendations for changes or extensions to existing data communication standards (suited for AMI) adopted by standardisation organisations.

Fill the existing knowledge gaps in order to have definitions and specifications of new communication standards and technologies for those communication channels and/or new technologies where standards don't yet exist, or do not meet AMI needs.

To start and support the official standardization process of the new selected and specified set of standards for AMI.

Source: Author's elaboration.

C. Integration of a limited amount of distributed generation

Distributed generation (DG) is constituted by local power generators connected to the distribution network. Normally these generators are of small size (ratings lower than typically 5 MW to 10MW) and they use locally available non-conventional or renewable energy sources like natural gas, biogas, wind power, solar photovoltaic, combined heat and power (CHP), micro-hydro sources, tri-generating units (combining heat, power and refrigeration features), micro-turbines, fuel cells etc. These generators are not centrally planned by power utility as they are typically owned by local energy producers or directly owned by the users and are not controlled centrally.

Let us recall some of the reasons motivating the development of distributed generation:

- the widespread consciousness of the depletion of non-renewable resources at the base of the fossil fuelled conventional plants, motivates the use of locally available renewable resources or of energy efficiency measures such as those achievable with the combination of heat and power production;
- the expectation that the use of distributed energy resources may contribute substantially to the reduction of greenhouse gases emissions and to mitigate climate changes;
- the availability of modular units of small capacity, geographically widespread and very close to the loads: reducing the necessity to build up larger generating facilities far away from the loads and the related long transmission lines, thus reducing losses and environmental impact; it can also be considered as an important contribution to facilitate the widespread access to electricity, thus reducing the financial burden of such projects;
- the expectation that the presence of generators directly connected to the distribution network can give a substantial contribution to the enhancement of the power quality to the customer and the reliability of the system;
- the opening of the energy market and the progressive deregulation can give distributed generation a great market opportunity.

On the other hand, several challenges and potential drawbacks may be pointed out:

- the high installation costs for distributed energy sources is a great disadvantage in the absence of any form of incentive or subsidies from the regulator of the government;
- the technical difficulties: DG being a recent development there is no wide experience in the control of a large number of small generators connected to the distribution network, especially if this must be coordinated with grid energy management issues where the user actively participates in the form of demand-participation;
- protection and control choices are not yet fully understood and specific telecommunication infrastructures and protocols must be developed;
- the absence of technical standards: since DG is a new area, consolidated technical standards are not yet available for addressing protection and operation issues.

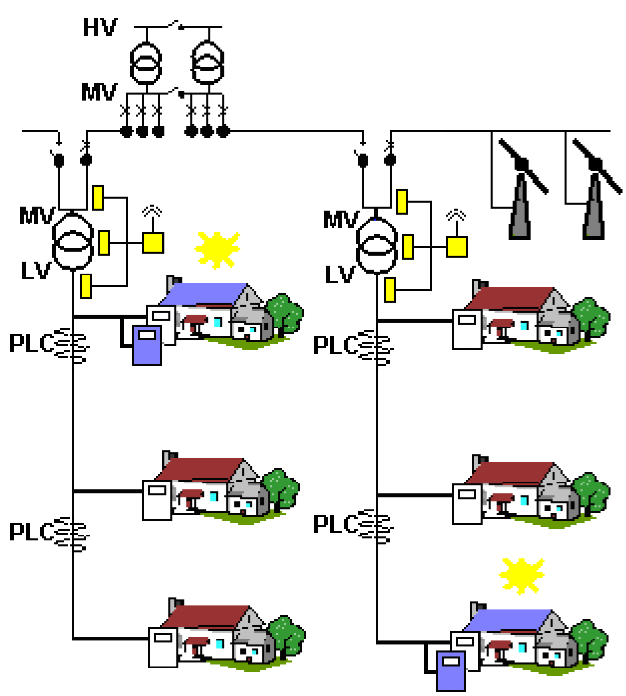
Figure 21 shows an evolution of the distribution network of Figure 17, in which a limited amount of DG is present, in the form of photovoltaic panels on the roof of some of the residential buildings, and of medium size wind generators. In this example, wind generators are connected on the medium voltage network, while PV panels are connected on the low voltage network.

Most passive distribution networks can accept without major modification the integration of a certain amount of DG: this concept is defined as "hosting capacity": i.e. the possible DG installed power which can be connected on a specific node without exceeding the operational values of the distribution network itself. The hosting capacity is always limited by the physical structure and the management of the network. The presence of a generator on a node of the distribution network changes dramatically the flow of power in its neighbourhood and the voltage profile along the line to which its connected; moreover, if this generator has a variable output (e.g. generating much power during windy days and decreasing abruptly its power output after a wind gust) the transients in the network and the consequent flows of power can cause trouble and overloads. The calculation of the present hosting capacity is not an easy task, as multiple network configurations must be considered.

A recent study conducted considering 8% of the Italian medium voltage distribution system[22] has demonstrated that more than 85% of the nodes on the present Italian distribution network can host DG with a rating < 3MW. The histogram in Figure 22 shows, for several levels of DG rating (on the x-axis):

- In gray colour: the percentage of nodes of the MV Italian network that could host the DG without exceeding any regulatory or system limit
- In green colour: the portion exceeding only the steady voltage limits i.e. the value of the voltage at the terminals of the user, whose upper and lower limits are fixed in Italy at 110% and 90% of rated respectively)
- In blue colour: the portion exceeding also the rapid voltage changes in case of abrupt disconnection of a generator (the European standard on power quality EN50160 indicates a maximum limit of 4-6% of the rated voltage)
- In red colour: the portion exceeding the thermal capability of the lines and cables which may be overloaded by the direct and reverse flow of power generated by the generator vs. load oscillations.

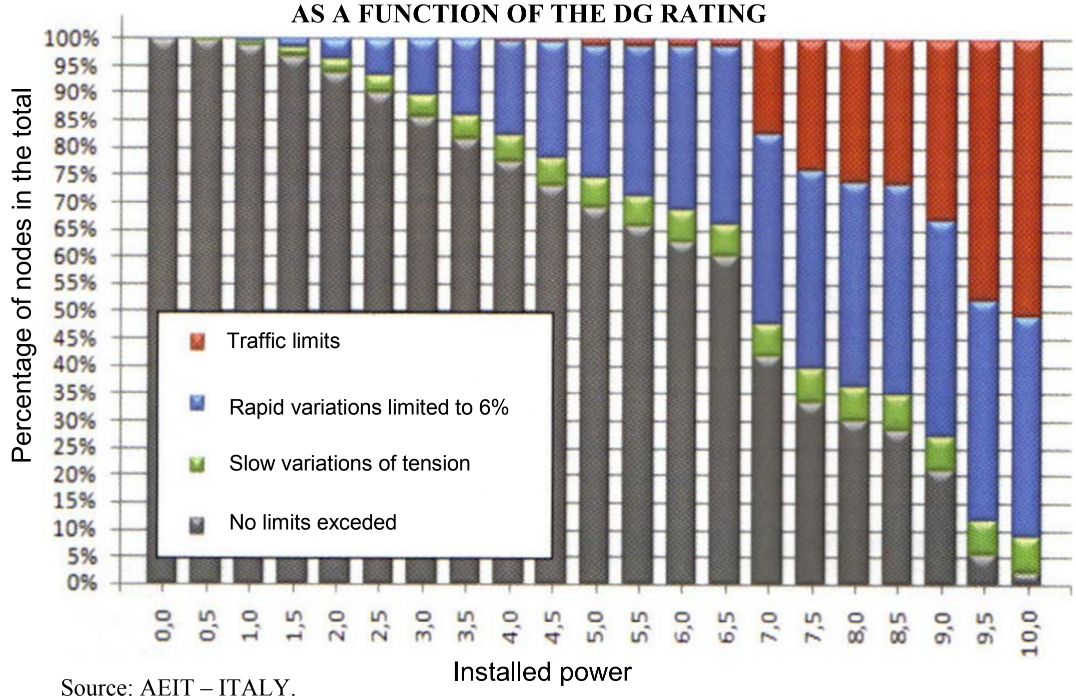
FIGURE 21
EXAMPLE OF A DISTRIBUTION NETWORK HOSTING A LIMITED AMOUNT OF DISTRIBUTED GENERATION (DG)



Source: Author's elaboration.

[22] M. Delfanti, M. Merlo, V. Olivieri, A. Silvestri: “Generazione diffusa: impatto attuale sulle reti e qualche prospettiva” – AEIT n. 5/6 – 2010.

FIGURE 22
EVALUATION OF THE HOSTING CAPACITY OF THE ITALIAN MV NETWORK AS A FUNCTION OF THE DG RATING



Source: AEIT – ITALY.

Finally, the network switching equipment may face serious problems in case of short circuit or fault, as the DG will increase the fault current level up to unbearable levels, thus potentially jeopardising the system and operators security. For sake of completeness it must be mentioned that this last event can be dramatically reduced in all cases where the DG is connected to the system through an electronic converter that will limit the fault currents to only 120-130% of the rated current.

An increased integration of DG can be achieved adapting the structure and management of the distribution system, with particular reference to the protection, supervision and control systems; this evolution is very closely linked with the use of advanced information and communication systems, as will be seen in the following. Particular attention must be paid to the so-called “unwanted islanding” situation, where a portion of the network including DG disconnects from the rest of the system and operates out of control under potentially dangerous conditions for the people and the equipment. Significant changes are needed also in the regulatory and standardisation fields, to set the rules for the connection of DG under safe and reliable conditions and to motivate the operators to access this important field.

Local perspective: It must be noticed that the DG may represent for Latin America a very attractive solution for widening the electricity production mix using locally available sources, for contributing to reduce the carbon footprint of the energy sector, for reducing the necessity to build up new infrastructure in remote areas and for enhancing the access to electricity of the population. In the specific case of the test cases countries, the situation is somewhat different: their energy footprint is already relatively limited because of the importance of the renewable energy sources in the generation mix, and the access to electricity almost generalised. On the other hand, the potential of a change of user behaviour linked with demand participation (see later) is still relatively limited. In this case the main features that can be achieved by the integration of DG is the reduction of distribution losses and the enhancement of the degree of energy security. Therefore, in the test case countries, it is expected that the DG can be better expressed by mostly non residential local generation for which the ratings can be envisaged in the 10MW range per unit of production.

BOX 7
DG REGULATION BEST PRACTICE:
THE ITALIAN REGULATORY DECISION ARG/ELT 39/10

The Italian regulator (Autorità per l'Energia Elettrica ed il Gas) has recently adopted a pioneering decision to motivate the development of smart grids, proposing incentives for the real-scale demonstration of innovative distribution network smart grids projects. In particular operators can propose within September 30, 2010, real scale projects of medium voltage network restructuring using smart grids technologies instead of traditional ones, thus having a more favorable remuneration of the investments. Pilot projects will be financed by means of a tariff-based incentive (+2% of the capital invested for 12 years), instead of the conventional CAPEX and OPEX remuneration rule. To be accepted in this financing framework, pilots projects must satisfy a certain number of criteria:

- The projects must concern portions of a real, working, medium voltage network;
- The network must have distributed generation installed, with backward power flux for at least 1% of the time during the year;
- The projects must include the development and use of advanced network automation and control and events monitoring and recording;
- All communications must be compliant with open and standardized protocols;
- The power quality regulation must be strictly followed in the operation of the pilot networks;
- Bi-directional communication system between the operator and the user to facilitate demand-participation measures can be envisaged;
- The types of DG to be considered is not explicitly specified but it is advised to combine conventional and renewable generators and loads, in such a way as to achieve e regular and predictable power flow;

Key Performance Indicators (KPIs) will be adopted to evaluate the success of the projects, with particular reference to the following aspects:

- Extension of the project (number of delivery points affected by the project)
- Increase of hosting capacity;
- Implementation of measures to allow the participation of the DG to the voltage regulation;
- Use of advanced bi-directional communication systems with the involvement of the user
- Dissemination of the results to enhance the cross-fertilization.

Source: Author's elaboration.

D. Advanced Information and communication technologies (ICT) applied to the distribution system

Information and communication technologies are vital for the development of a distribution system towards a smart grid. This evolution implies the outstanding necessity to collect and elaborate information from electronic meters and distributed sensors and to control and coordinate the automation, protection and control systems. The communication layer fit for this type of network is multi-fold:

- Network operation: in order to allow the smart operation of the network, the communication layer must have a structure allowing to reach each piece of equipment considered, distributed geographically over the entire network, with the adequate performances in terms of volumes of information to be transferred, timing of transfer and reliability of the connection;
- User participation: in order to allow the participation of the user to the market mechanism through the management of his electricity consumption, the communication system must allow the interaction between the user and the distributor or retailer: the gateway for this type of communication is the electronic meter.

In terms of communication system architecture, the conflicting requirements of the widespread and complex topology of the points to be reached and the necessity to moderate the infrastructure and operation costs reduces the appeal of dedicated communication networks and opens the option of the use of communication layers in common with other services (e.g. telephone, radio, TV, internet etc.). In several other fields we have observed in the last decades the clear tendency to converge towards a common Internet Protocol (IP), using different information transmission media (i.e. optic fibre, radio, WiFi, WiMax, PLC etc.) with a single network technology able to integrate several different applications without the need to develop or adopt specific low level communication protocols. The use of the IP infrastructure in conjunction with all other internet applications also in the frame of the electricity system may be considered if specific tools and systems are developed to ensure that the performances and the service quality comply with the requirements of the electric distribution system. It must be observed that the volume of information to be transmitted over the net for the distribution system operation and management is expected to be minimal with respect to the huge flows generated by music downloads or podcasting, but the level of reliability of the connection must be much higher than that required by the standard internet user. In addition, it must be noted that the communication protocol widely used for the substation automation and control named IEC 61850 can be an ideal candidate for the distribution applications, being already perfectly adapted also for the use on IP platforms. Using IP based communication rises the issues of data security and privacy.

The most important dimensioning parameters for a communication network are the information transport capacity (expressed in bits per second), the time delay for the information to be transferred from the source to the target and the connexion reliability. Since the net is a shared structure, the information transport capability may be influenced by the contemporary presence of other sources of traffic on the same communication lines; moreover, the time delay has a fixed component linked with the times of elaboration and transmission of the net nodes and a variable component, again subject of congestions due to other information traffic. The reliability of the connection depends on the elements of the network itself and can be related to the time during which the net can guarantee the correct performance level for each specific application.

As far as smart applications are concerned, three types of messages can be pointed out:

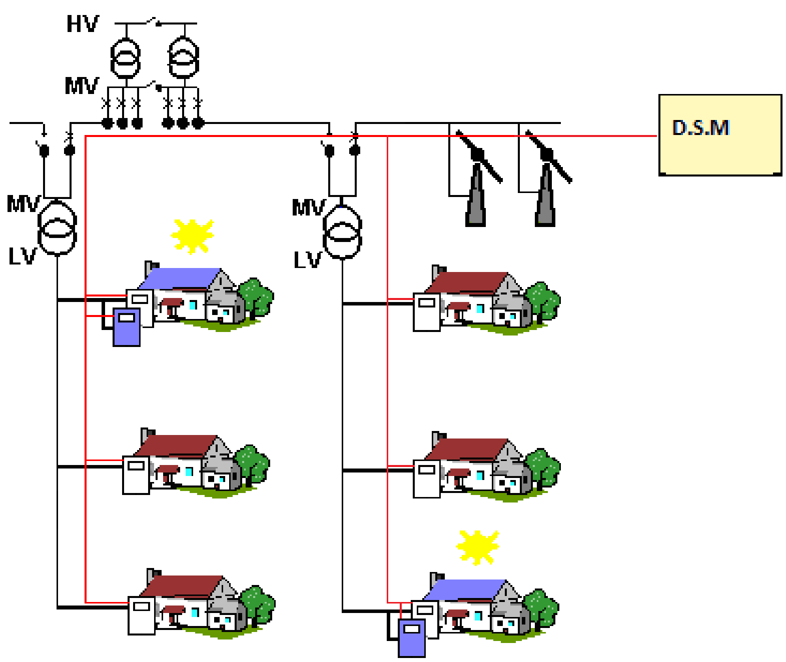
- Monitoring applications: collecting data from sensors on the network (and also electronic meters): these are the less critical applications from the communication point of view in terms of delay and reliability requirements (i.e. there is no immediate consequence if the data is not received at a certain point in time and a further request can be introduced at a later time); however, these applications normally generate huge quantities of data to be transferred and managed, and influence the dimensioning of the size of communication channels;
- Control and management applications: are more critical because of the necessity of a bi-directional communication; on the distribution network, the requirements however are not extreme as the involved timings are in the range of seconds;
- Protection and safety applications: are the most critical in terms of communication requirements, as the maximum delays must be stable and within few tens of milliseconds, with a very high level of reliability. It must be noticed however that several measures can be taken to overcome the possibility that a communication channel be unavailable, even if compromising on the local or temporary system management efficiency.

In terms of communication technologies to be used on the distribution network, their choice is a function of the systems already present locally and of the intrinsic characteristic of the location: high density urban environment vs. sparse high distances rural environments. The IP-based platform allows the integrated use of several communication technologies, organised on the following layers:

- Home Area Networks (HAN): private user network connecting together the different private equipment, appliances sensors etc. and interfaced with the home gateway (electronic meter) supporting also the energy management applications (smart meters); the communication technologies mostly used at this level are WiFi, ZigBee and low voltage PLC (power line carrier)
- Metropolitan Area Network (MAN): local network developed over the geographical range of a city having many access points, where the typical distances for transmission are 5 km; the technologies used for these applications are the Digital Subscriber Lines (DSL) and their evolutions (High Data Rate Digital Subscriber Line (HDSL), Asymmetric Digital Subscriber Line (ADSL), ADSL 2, ADSL 2+, Very-high-bit-rate Digital Subscriber Line (VDSL), VDSL 2, etc.)
- Wide Area Network (WAN): long distances connections to regional and national control centres; telecom lines and long distance radio communication is normally used at this level, less important for distribution systems than for transmission systems.

The Figure 23 shows schematically an example of distribution network adopting advanced information and communication technologies (for the sake of simplicity the advanced information channels are represented with a red continuous line connecting several important elements in the network: i.e. the user, the distributed generators, the power equipment, the distributed sensors). Schematically the ICT converges to a central Distribution System Management (D.S.M)

FIGURE 23
EXAMPLE OF A DISTRIBUTION NETWORK WITH THE APPLICATION OF ADVANCED ICT SYSTEMS



Source: Author's elaboration.

Local perspective: the development of the ICT infrastructure in the region is considered as a key point to ba achieved on the way to the evolution of the electricity system. It is of vital importance to develop and adopt all IP-based configurations sharing the features of this consolidated architecture with other socially important services such as the interne, TV, radio IP-broadcast, telephone (VOIP) etc. Sharing these services represents a good opportunity of cost saving for utilities and opens the door to many socially-essential services that can accompany the social and cultural integration. However, it must be remembered that the use of IP-based platforms must always be seen at the light of the risks for cyber-security and data privacy. Specific actions must be taken in that respect.

E. Advanced metering infrastructure (AMI) and demand-participation

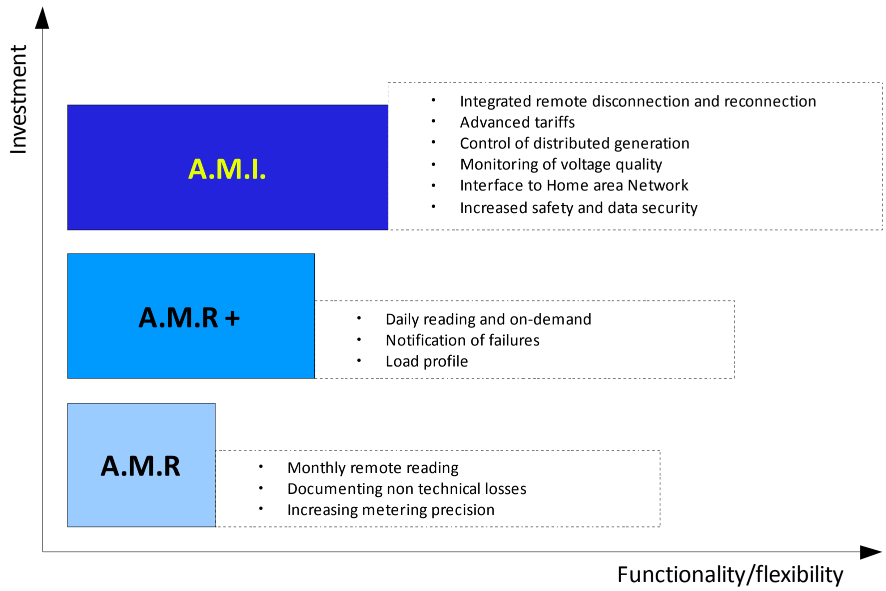
The deployment of more advanced metering management systems is based on a stronger communication link between the meter and the control centre and between the meter and the user: it represents the means of the Demand Participation features, for which the user, having access at his dynamic load profile and to other information on the network and market conditions, can modify his consumption in order to contribute either to the reliability and/or security of the electric system (system led programs), or can be motivated by price signals coming from the electricity market (market led programs). AMI can normally allow:

- Time-based pricing
- Consumption data for consumer and utility
- Net metering
- Loss of power (and restoration) notification
- Remote turn on / turn off operations
- Load limiting for “bad pay” or demand response purposes
- Energy prepayment
- Power quality monitoring
- Tamper and energy theft detection
- Communications with other intelligent devices in the home

Setting up an advanced metering infrastructure requires investments in proportion to the features that the system allows: this concept is expressed in Figure 24 showing the progressive investments increase, when the functionalities and flexibility offered by the electronic meters progress from basic AMR to a fully deployed AMI. Recent studies show that, depending upon the specific network system conditions, the cost per measuring point of AMI (including the communication infrastructure and the automatic meter management system) ranges from 80 € to 150 €, as shown in the following table:

Country	AMI cost per point [€]
Italy	100
The Netherlands	150
Canada	100
US	95-115
UK	107

FIGURE 24
QUALITATIVE RELATIONSHIP BETWEEN SMART METERING FUNCTIONALITY AND INVESTMENTS



Source: Author's elaboration.

In case of progressive roll-out of an advanced metering infrastructure, priorities should be given to system areas (possibly regions, quarters or clusters) where:

- users show consumption levels higher than the system average (statistically, the consumption should be at least one standard deviation higher that the average). These users are characterized by a higher consumption flexibility in comparison to lower consumption users having only basic energy needs;
- users show a monthly variability in their consumption profile higher than the system average (statistically, the consumption variability should be at least one standard deviation higher that the average). Users showing this high variability above their minimum may have a higher consumption flexibility, on which to leverage for demand-participation purposes, as will be seen next.

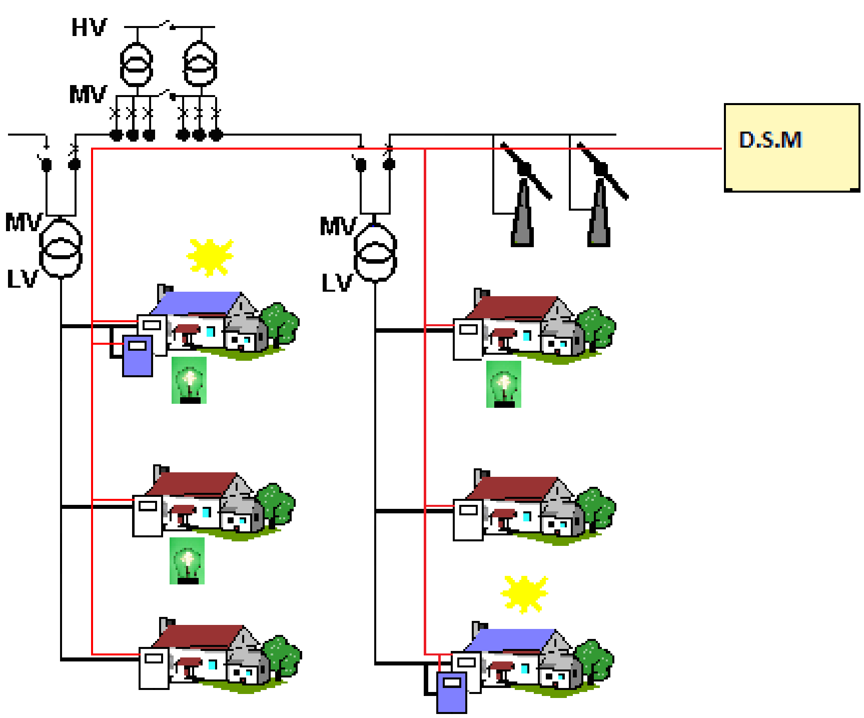
Demand-participation (or demand response: DR): AMI paves the way to demand-participation, i.e. situations where the users may have some flexibility in how and when they use electricity. This means that given both the ability to easily manage their electricity use and information about its value, they can be willing to change that usage. Some part of their consumption can be shifted in time or simply suppressed. Typical flexible loads include space heating, water heating, cooling, ventilation, lighting, electric vehicles charging etc. The users become an integral and active part of the overall electric power system by helping to balance electrical demand with supply. Achieving demand-participation implies the availability by the user of key information (e.g. Real time prices, function of the availability of energy in the system, level of energy consumption, load profiles etc) which be used to implement informed energy efficiency actions. Theoretically, being almost all electricity consumption flexible, the potential for demand response and energy efficiency is huge.
The load flexibility can be achieved through contractual or service agreements based on the voluntary adhesion of the users to specific programs. In practical terms the user accepts to:

- System Led programs request actions that are authoritatively carried on by the system operator (or by the local distributor) in the sphere of his responsibility of the system security. Therefore these actions are mandatory for the participants, after they have subscribed the program, fast and often automated. The very short reaction time required is generally not compatible with market operation, thus the compensation for the service provided by interruptible loads (that can be compared to reserve power plants) is most of the times determined through regulatory provisions and collected from the entire users community by means of a bill component. As an example, in Italy, the Interruptible Service correspond exactly to this scheme. This kind of programs is active also in vertically integrated electric system, because they are functional to the system security.

- In Market Led programs the users respond to price signals (in the form of real time prices, structured tariffs, or contractual agreements) in a time interval compatible with the hourly price broadcasting and consumption planning, i.e. in the order of hours or even days. Here the user's action is always voluntary, only depending on the individual sensitivity to the price level.

The Figure 25 represents a portion of a distribution system in a residential area, equipped with AMI: in this situation, both the power and the information flow are fully bi-directional, relying on technologies that allow information flows over wider bandwidth, characterized by the possibility to transfer higher amounts of data at higher speeds, thus paving the way, not only to the remote measurement of the energy consumption (upwards information flow) but also to the delivery to the user of signals related to system and market conditions (downwards information flow), which is the key for the implementation of demand-participation and empowering of the user, giving him the possibility to shape his power consumption based on dynamic tariffs and to act consciously towards energy conservation behavior.

FIGURE 25
EXAMPLE OF A DISTRIBUTION SYSTEM EQUIPPED WITH AMI



Source: Author's elaboration.

BOX 8
R&D BEST PRACTICE: THE ADDRESS PROJECT

Contrary to DG and large industrial customers, domestic customers are not motivated by purely economic considerations. Moreover, they are not able (e.g. due to the lack of appropriate equipment) or not prone to characterize precisely in advance the services and flexibilities that they can provide. Domestic consumers are not likely to “offer” services. Therefore, the services they can provide will be “requested” through the developed price and/or volume signal mechanisms and will be provided on a voluntary and contractual basis.

To support this approach on the consumer side, both appropriate technologies have to be developed in the houses or at the interface with the aggregator, and relevant accompanying measures have to be studied to deal with societal, cultural and behavioral factors. ADDRESS studies, develops and validates solutions to enable active demand and exploit its benefits. To enable active demand ADDRESS:

- Develops technical solutions both at the consumers premises and the power system level
- Identifies the possible barriers against active demand development and develop recommendations and solutions to remove these barriers considering economic, regulatory, societal and cultural aspects

To exploit the benefits of active demand ADDRESS:

- Identifies the potential benefits for the different power system participants
- Develops appropriate markets and contractual mechanisms to manage the new scenarios
- Studies and proposes accompanying measures to deal with societal, cultural and behavioral aspects

The proposed solutions will be validated in 3 complementary test sites with different geographical and demographic characteristics and different infrastructure mixes. Sites will be selected in Spain, Italy and France to meet these diversity requirements and to provide a representative realization of the ADDRESS architecture.

Source: Author’s elaboration.

BOX 9
MASSIVE ROLL-OUT BEST PRACTICE: ENEL TELEGESTORE

ENEL Distribuzione SpA has introduced through its TELEGESTORE Project (>€2.5 billion investments) a set of innovative smart grid tools in its industrial management procedures. The implementation of the project has led to the replacement of more than 32 million electromechanical power meters with smart meters, the preparation of the system hardware and software architecture, the complete automation of more than 100,000 distribution substations (with automatic fault clearing procedures), the radical change in the management of the operating workforce (through the logistic support to ENEL crews by means of cartographic support available directly on board and interfaced through mobile applications), the optimization of asset management policies based on a GIS census of network assets, a database of network events (power outage notification, fault detection, etc.), and the optimization of network investments based on a risk analysis. The system implemented is in continuous evolution and new features, technologies and flexibility are introduced on a regular basis. As for recent statistics (2007) about the management of the Telegestore system, the following figures are evidenced:

- 182 million regular monthly/bimonthly readings have been conducted with success
- 5 million spot readings have been carried out
- 47 million load profiles have been recorded
- 0.8 million remote contract activation operations
- 0.5 million remote contract termination operations
- 5.2 million remote contractual change operations
- 2.5 million remote bad payers management operations

The system has proven to be reliable and efficient; it allows a yearly cost reduction of 500 million €, in the following areas:

- Customer services: Remote reading, invoicing, customer information, bad payers management
- Company revenue protection: thefts and failures, self consumption management, timely checks on meters
- Purchasing and logistics: purchasing standardization, warehouses, internal transportations
- Field operations: intervention on failures, activation/deactivation of customers, meter readings, installation and recovery, equipment replacement, access to the installation

The AMI system allowing the energy balance on the distribution system transformer; this operation, carried out about 200,000 times in 2007 has allowed to point out potential network or customers problems, increasing the rate of success of these checks from 5% (before AMI installation) to more than 50% (after AMI installation).

Source: Author's elaboration.

F. Integration of extended shares of distributed generation in the distribution network: active distribution networks (ADN)

We have seen that a limited amount of DG can be integrated in the present distribution systems without major modifications: however, the increase of the installed power of DG progressively rises problems in terms of management, protection and safety of the system. Modifications are therefore needed to ensure its reliable and secure operation. Although it is recognised that DG can open the way to a wide diversification of the generation mix, thus reducing the carbon footprint of the generation system and contributing to the security of supply, market, regulatory and technical conditions are still seldom prepared for this progressive transition towards the active distribution network application.

Regulatory barriers to DG: It must be recognised that in the present technical and regulatory situation, the integration of DG is not seen at its full potential; a recent study carried out in UK23 clearly demonstrates the regulatory handicap on the head of DG. The study states that if the value of electricity produced by centralised generation is around 2-3 c€/kWh, by the time electricity reaches the end consumer this value has increased to around 4-10 c€/kWh. This increase in value of electricity is due to the cost of network transportation and distribution services, required to deliver power from centralised generators to customers. DG is located closer to the consumer and has fewer requirements for the transport and distribution services. Therefore the reference to which to compare the value of the energy delivered by DG should be that of the conventional energy at the user's terminals (e.g. 4-10 c€/kWh) and not that of the production costs of centralised plants (i.e. 2-3 c€/kWh) is done conventionally: Ignoring these particular features in the derivation of the value of DG results in non-competitive markets in which DG cannot compete on an equivalent level with conventional generation, and network solutions.

The increasing penetration of DG influences the planning of the power system and, in combination with regulatory issues, may negatively affect the business of Distribution System Operator. Because DG units generally are located closer to demand than central generation, increasing DG penetration may result in decreasing revenues for DSOs, as less transport is needed to deliver the produced electricity to the customer. Next to decreasing revenues, the increasing penetration of DG may lead to increasing costs of management of the distribution networks in terms of stability and power quality, particularly when large amounts of DG are connected or DG is connected to weak grids. Furthermore, the integration of DG with intermittent primary sources, such as wind energy, may create additional challenges to system balancing.

Technical barriers to DG: The introduction of DG implies that electrical distribution networks will lose their passive character and will create new problems for the operation of distribution systems, because distribution systems are designed as passive networks and accordingly also the protection design is based on the passive characteristics. Specific DG related protection schemes must be implemented to avoid users of electricity and workers suffer injuries from voltage and to protect electric appliances and network equipment. In present distribution networks, these schemes usually make use of the fact that power flows are perfectly known, i.e. from higher voltage levels to lower voltage levels and from central generators to spatially distributed loads. With DG feeding the distribution grids at many places, this single direction of power flow is not longer given. Thus, protection equipment might not trip in cases where it should or its selectivity, (i.e. its ability to isolate a network close to the fault), might be lost. The approach envisaged to cope with this unprecedented situation is the setting up of new protection schemes, calibrated in such a way as to disconnect the DG in all cases in which there is a loss of synchronism of a portion of network equipped with DG, with respect to the prevailing distribution network: this event is called an "unwanted islanding conditions"; in case of opening of a main switch in the HV/MV substation, it may in fact happen that the busbar be still supplied by the DG connected on that portion of network: this is a dangerous situation because the DG normally are not equipped to control the supply frequency (and this may cause problems to motors and generators connected) and to regulate the voltage level (and this may cause problems to the equipment and safety concerns). The unwanted islanding must therefore be avoided. Pointing out the occurrence of an unwanted islanding situation is not always an easy task:

- passive protection systems are used to detect frequency fluctuations (protection 81< and 81> detect situations of underfrequency or overfrequency: their respective setting is typically 49.7 Hz and 50.3 Hz) or voltage fluctuations (protections 59 and 27 detect overvoltage or undervoltage situations: their typical setting is 120% and 70% respectively), the rate of change of frequency (with an increased sensitivity with respect to the 81 series), the abrupt variations of the working point of the generators, in response to the loss of part of the network, or shifts in the active and/or reactive power generated by the generators;

23 Goran Strbac, Charlotte Ramsay and Danny Pudjianto: DTI Centre for distributed generation and Sustainable electrical Energy: integration of distributed generation into the UK power system – summary report April 2007.

- active protection systems generate small perturbations at the terminals of the generators and detect the effects, knowing that if the distribution system is correctly meshed, the effects will be negligible, while if the prevailing network is disconnected the effects will be tangible
- adaptative protections, integrated with the advanced communication systems typical of smart grids, allow the effective reaction to the loss of prevailing network, and give the DG the maximum possible flexibility and allow to use the DG in view of a higher system availability. This approach is taken into consideration in the recent Italian technical standard CEI 0-16 (see box)

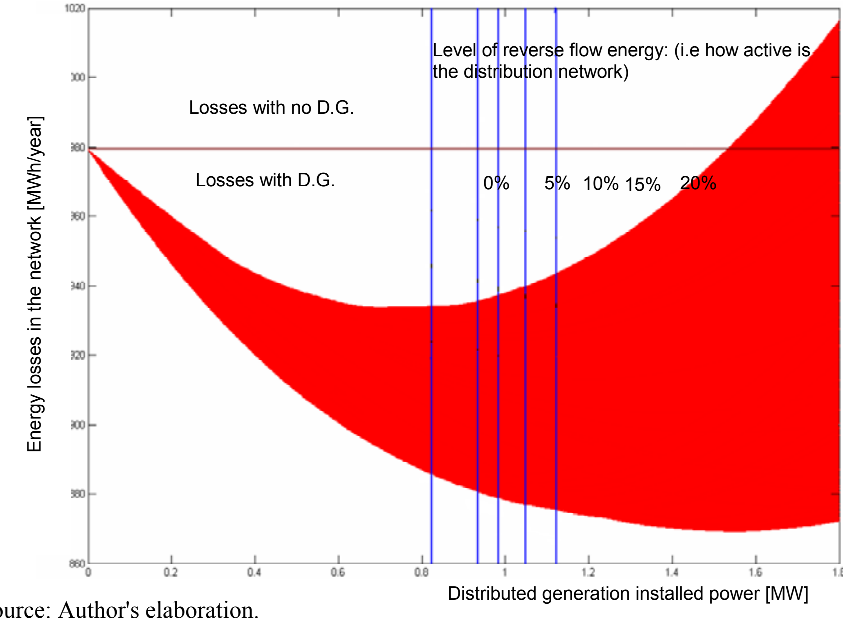
The present management of DG by distribution operators is referred as “fit and forget”: this means that the distributed generators are not managed centrally, they are not dispatched and do not contribute actively to the **system management**: without an active management at the distribution level DG lacks the conditions required to provide system support and security activities, so centralised generation capacity must be retained to perform this function. With growing pressure to increase DG penetration, this passive approach will lead to rising costs for investment and operation of the system and ultimately impact the pace of DG adoption. On the other hand, by fully integrating DG and demand side into network, DG and demand-participation are capable of taking the responsibility for delivery of system support services, progressively helping in this role the central generation. DG can help producing not only energy but also system controllability, reducing the necessary capacity of central generation. To achieve this, the operating practice of distribution networks will need to change from passive to active. This will necessitate a shift from the traditional central control philosophy to a new control paradigm of coordinated centralised and distributed control. This future requires significant Information and Communication Technology (ICT) capabilities to facilitate interaction between thousands (potentially millions) of DG units and the system operators, as well as new decision support tools to interpret and act upon the new information presented by integrated DG. This will bring an increase in complexity of system operation; however, with the correct development and innovation this new paradigm of shared centralised and distributed control should facilitate the development of more reliable, cost effective and sustainable systems that achieve maximum utilisation of all the resources connected within them. The ability of DG to withstand disturbances is also of major importance in order to operate electricity grids with high penetration of these sources reliably.

The effects of DG on distribution network losses (Joule losses): Installing generators on the distribution network, closer to the loads, rises the expectation that technical distribution losses are reduced. This is effectively the case in most practical situations. In fact, knowing that the circulation of the current into the wires causes heating and consequent losses called “Joule effect”, (the losses are proportional to the square of the current value), reducing the distance between the generators and the loads and thus reducing the length of the current path will cause a reduction of the power lost in the conductors. An evaluation of the potential beneficial effect of DG on the reduction of network losses on the medium voltage distribution network has been carried out considering the typical cases of the Italian network configuration[24]. The results of the calculation is reported in Figure 26. Starting from network configurations with no DG, the level of distribution losses is calculated evaluating the annual energy losses (in MWh/year). Different types of generators (in terms of power rating, position in the network, generation characteristics, controllability etc.) and different types of loads (in terms of position, load curve, controllability etc.) have been inserted, progressively increasing the contribution of the DG to the energy balance of the network. Reference points are evidenced, at DG installed power corresponding to different levels of reverse power flow (from the MV network back into the HV network), considering the 0% (balance situation), 5%, 10%, 15%, 20% respectively. Being the network behaviour dependent on many data and parameters (position and characteristics of the generators and loads), several curves are obtained, identifying an area (represented in red in the figure) where all the curves lay. The main findings is that, as expected and in the specific case of the network structures (representing a portion of the typical medium voltage distribution network), generators (hydro, micro-hydro, industrial co-generation and residential co-generation, PV of small and

[24] D. Bertini, R. Cicoria, J. Silva de Assis, A. Silvestri, D. Falabretti, V. Olivieri: “La penetrazione della Generazione Distribuita nelle attuali reti elettriche italiane” – Deliverable D8-2009 Progetto di Ricerca sul Sistema elettrico:Reti Attive, Generazione Distribuita e Sistemi di Accumulo – rapp. 10000473 – downloadable from www.erse-web.it

large scale) and loads (chronological curves etc.) considered, the presence of DG has the effect to reduce the Joule losses in a range 6-12% (in terms of energy) with respect to the passive situations. This fact is valid up to a certain level of DG integration: the losses curve, in fact, after reaching a minimum, starts to rise again, and Joule losses may even increase at high DG integration levels, when the return energy flux vanishes this effect of DG and introduces stray power fluxes in the network.

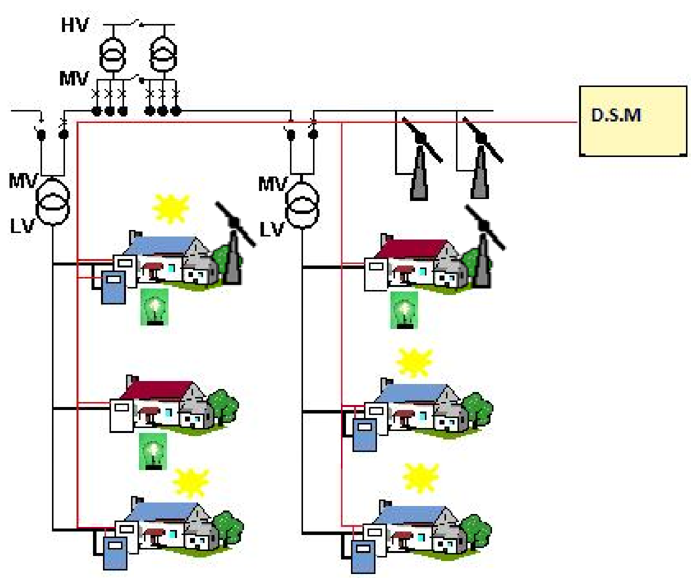
FIGURE 26
THE EFFECT OF DG ON THE DISTRIBUTION LOSSES



Source: Author's elaboration.

Figure 27 shows an example of scheme of a distribution system with integrated DG; the distribution system in this configuration is no more passive, as power can flow also upwards to the MV/lv substation and even to the HV/MV station: in this configuration, the system is defined as an active distribution network..

FIGURE 27
EXAMPLE OF A DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATION



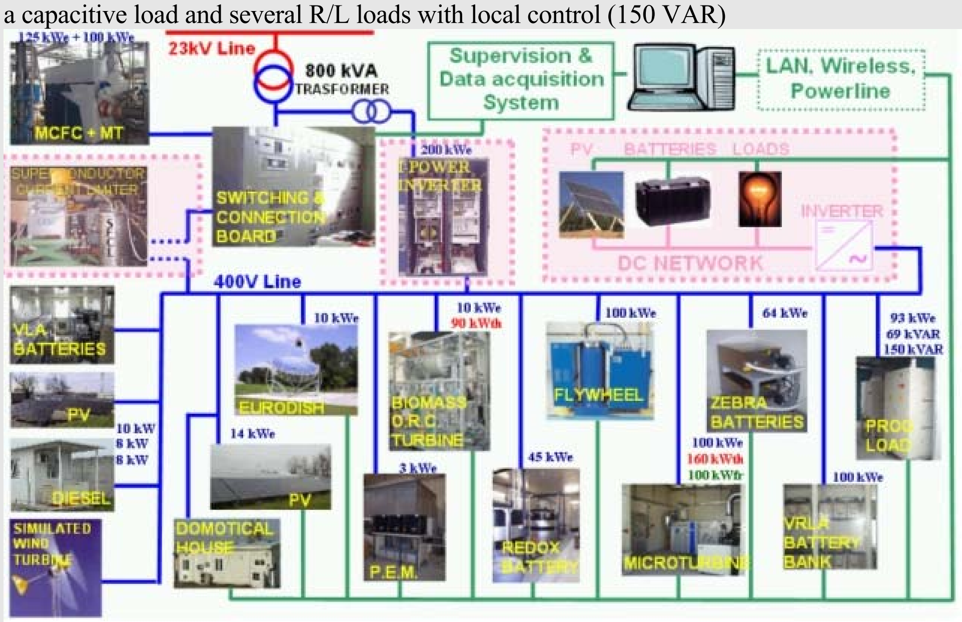
Source: Author's elaboration.

BOX 10
R&D BEST PRACTICE: THE DISTRIBUTED GENERATION TEST FACILITY IN ERSE

The ERSE DER Test Facility is a complete and well-structured system with different generators, storage systems and loads that well reproduces a real microgrid, allowing researchers to develop studies and experimentations on DERs. The test facility is used to perform several different experimentations, beginning with tests on I-Power Inverter operation, continuing with tests on advanced algorithms, developed during multilateral projects. It consists in a LV microgrid, connected to the MV grid by means of a 800 kVA transformer, several generators with different technologies (renewable and conventional), controllable loads and storage systems. DER-TF can provide electricity to the main grid with a maximum power of 350 kW.

The following distributed energy resources are available at the present time:

- a hybrid renewable energy system consisting of a photovoltaic plant (10 kWP), a lead-acid storage system, a diesel engine coupled with an asynchronous generator (7 kVA), a simulated asynchronous wind generator (8 kVA)
- five PV fields of different technologies for a total nominal power of 14 kW;
- a solar thermal plant with a parabolic dish and a Stirling engine (10 kW);
- a ORC CHP system fuelled by biomass (10 kWE, 90 kWTH);
- a CCHP plant with a gas microturbine (105 kWE, 170 kWTH, 100 kWRE);
- a Vanadium Redox Battery (42 kW, 2 hours);
- a Lead Acid battery system (100 kW, 1 hour);
- two high temperature Zebra batteries (64 kW, 30 minutes);
- a high speed flywheel for Power Quality (100 kW, 30 seconds);
- a controllable three-phase resistive-inductive load (100 kW + 70 kVAR);
- a capacitive load and several R/L loads with local control (150 VAR)



All these DERs are connected to the microgrid by mean of a configuration and interconnection board that allows the microgrid operator to change the interconnections of DERs manually or by mean of remote commands from a computer. In this way it's possible obtaining different grid topologies: radial grids and also meshed configurations. There's also the opportunity to extend feeders till one kilometer. The interconnection board and all the DERs are provided with electrical measure equipments, constituting an high-speed Data Acquisition System (DAS), that has been set up to collect and analyze the experimental data derived from the field test. A Communication system has been developed with different technologies: LAN Ethernet, Wireless and Power Line. A supervision and control infrastructure has been also implemented.

Source: Author's elaboration.

BOX 11
DG STANDARDIZATION BEST PRACTICE: THE ITALIAN STANDARD: "CEI 0-16 ED. II, JULY 2008: REFERENCE TECHNICAL RULES FOR THE CONNECTION OF ACTIVE AND PASSIVE USERS TO THE HV AND MV NETWORKS OF ELECTRICITY DISTRIBUTION COMPANIES"

The Italian Electro Technical Committee has issued in 2008 a reference guide for the connection of generators and loads to the transmission and distribution networks. The guide contains also indication about the rules of connection of DG; some of the prescriptions are particularly innovative and deserve being mentioned.

- The standard considers also electrical systems integrating important shares of DG and subject to reverse power flows at primary station level: i.e. active distribution networks. The document requires in these cases that the primary station(s) and line(s) concerned be equipped with specific protection and control devices to ensure the security and operation of the active distribution network.
- Moreover, the document specifies the characteristics of the anti-islanding protection and requires the presence of a remote-trip device to ensure the opening of the interface switch in case of problems with the general protection systems and foresees the presence of an adequate communication channel between the system and the DG protection.
- Finally, Appendix E includes very innovative scenarios for substantially improving the management of the anti-islanding electrical protection. In fact, a double threshold for tripping voltage and frequency is specified , depending on the presence or absence of the communication channel conveying the signals from the network operator: a first set of tight threshold values (e.g.. 49.7 – 50.3 Hz for frequency) is specified for the stand alone system, or in cases where the communication channel between the primary substation and the distributed generator is interrupted. A smoother set of threshold values (e.g. 49 – 51 Hz) is foreseen when the communication channel is present and active; these prescriptions allow the DG to remain connected in case of light perturbations to the distribution system: in these conditions the DG can help the management of the system in overcoming transients. This concept is presently unique in DG-related standards.

Similar concepts are under discussion in the draft standard for the connection of DG on the low voltage distribution network.

Source: Author's elaboration.

G. Storage and recharging of plug-in electric vehicles

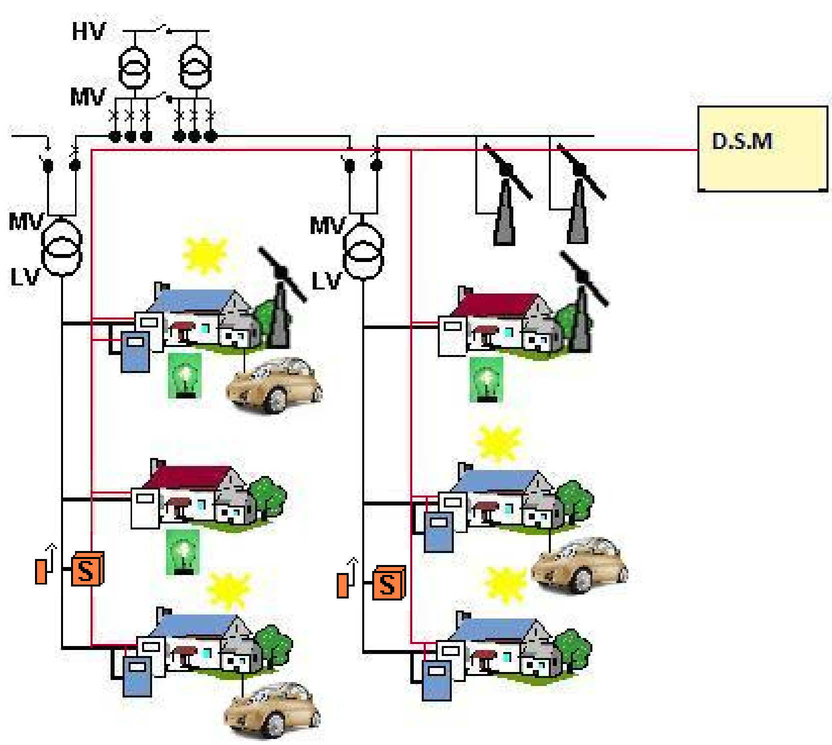
Energy storage is seen as a strategic tool used for managing the variability of renewable energy sources integrated into the modern network thus increasing its hosting and capacity. It is of general consensus that a major share of the evolution of the smart grid will need to rely on cost-effective energy storage, particularly in the early stages while other distribution and demand-side management solutions are being developed, adopted and implemented.

To store electricity, it must first be converted into another form of energy and transformed back when needed. Possible techniques for energy storage include mechanical, chemical, and thermal forms. Smart grid energy storage applications can be divided into two functional classes: generation, and distribution (end-user).

- **Generation**: Electrical energy storage for the integration of renewable must have sound economical pay-back, but with low environmental/ecological impacts in order to gain broad deployment. This will need large efforts in technology R&D. Vehicle-to-grid (V2G) is a concept whereby battery-powered electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) can be used as electricity storage devices to give GWs of capacity. However, their more widespread deployment will only be possible when EVs and PHEVs have batteries with enough durability, economy, and capacity for power control use. Continuous variable energy production with a limited predictability like wind and solar energy production can increase the need of energy storage, especially in weak grid areas. Energy storage implemented with distributed energy generation can increase the share of renewable energy sources.
- **Distribution** (End-use): at the end-user level, new types of customer applications can have remarkable effects on the power grid. Energy-plus houses, end user level solar and wind power production and especially electric and plug-in hybrid vehicles can change the end-use role from consumption towards power production and consumption ("presumption"). This tendency can have a great impact on energy systems. Electrical vehicles (EVs) for example represent at the same time a great challenge and opportunity from a smart grid point of view. EVs loads (charging power) will have an impact on electrical networks, but in large enough volumes they can offer new opportunities on energy markets.

Figure 28 shows an active distribution network integrating also plug-in vehicles and distributed storage.

FIGURE 28
EXAMPLE OF A DISTRIBUTION NETWORK EQUIPPED WITH DISTRIBUTED STORAGE AND CHARGING INFRASTRUCTURES FOR PLUG-IN ELECTRIC VEHICLES



Source: Author's elaboration.

H. Advanced distribution automation and monitoring

Current passive distribution networks have only sparse remote measurements and nearly no power re-routing capability. SCADA systems as seen presently are not sufficient to support the flow of information necessary for the conduction of a smart distribution network equipped with advanced metering, demand-participation and DG. Advanced automation and monitoring systems must be developed and installed, under the supervision of a Distribution control centre, able to maintain an accurate and up-to-date view from network topology (by direct supervision and through coordination with field crews), gather all available real-time measurements, federate the available information highlighting inconsistencies.

Once a realistic real-time image from network's state is available, further analysis and simulations can take place, such as:

- Real-time Network Security Assessment, with alarming for overloads and voltage violations
- Short-Circuit Analysis in real-time, as necessary complement to the planning tools due to the changing configurations (e.g. untimely connection from rotating or power electronic based generators)
- Optimization of distribution system operation for efficiency, losses and reliability
- Voltage and reactive power control to minimize the losses and manage the voltage profiles
- Supply quality monitoring and reporting
- Supporting tools for equipment and system diagnostics.

The Control Centre must be capable of applying correction and optimization measures automatically, in a "closed-loop" mode of operation and without human interaction. The operators shall only be involved in cases of alarming or fault management or coordination with field work or similar activities. An example of excellence in distribution network automation and supervision is the system developed and implemented by ENEL Distribuzione, called STWeb[25], helping the network operators at local and national level to have a full real-time overview of the network and potentially executing commands on central and remote components for maintenance and recovery actions. The system developed supervises on a GIS-based platform the entire distribution system, comprised of 400000 MV/lv secondary substations, 2200 HV/MV primary substations and controlled by 28 control centres. The system is composed of the following main web-based applications:

- **Dashboard of the telecontrol system**: providing data about the individual elements of the distribution network, their installed telecontrol functions and softwares, statistics on outages, warnings critical events, statistics related to the remote network control and to the systema and equipment reliability
- **System and network management**: provides on-line monitoring of the connectivity and working status of each network device, central system component and remote terminal unit. An example of a screenshot from the system and network management is reported in Figure 29.

[25] C. Baldi, C. Noce, P.L. Petroni: "Supervision dashboard to monitor system and network performances at national and local level – CIRED - 20th International Conference on Electricity Distribution – Prague 8-11 June 2009 Paper 0365.

FIGURE 29
SCREENSHOT OF THE SYSTEM AND NETWORK MANAGEMENT DEVELOPED AND OPERATED BY ENEL DISTRIBUZIONE, SHOWING THE CONNECTIVITY OF THE NETWORK COMPONENTS PERTAINING TO A SPECIFIC HV/MV SUBSTATION

Source: Enel distribuzione.

- **Unavailability GIS**-based system: displays the location of MV/lv substations involved in outages or work activities on a map or satellite image (see Figure 30).

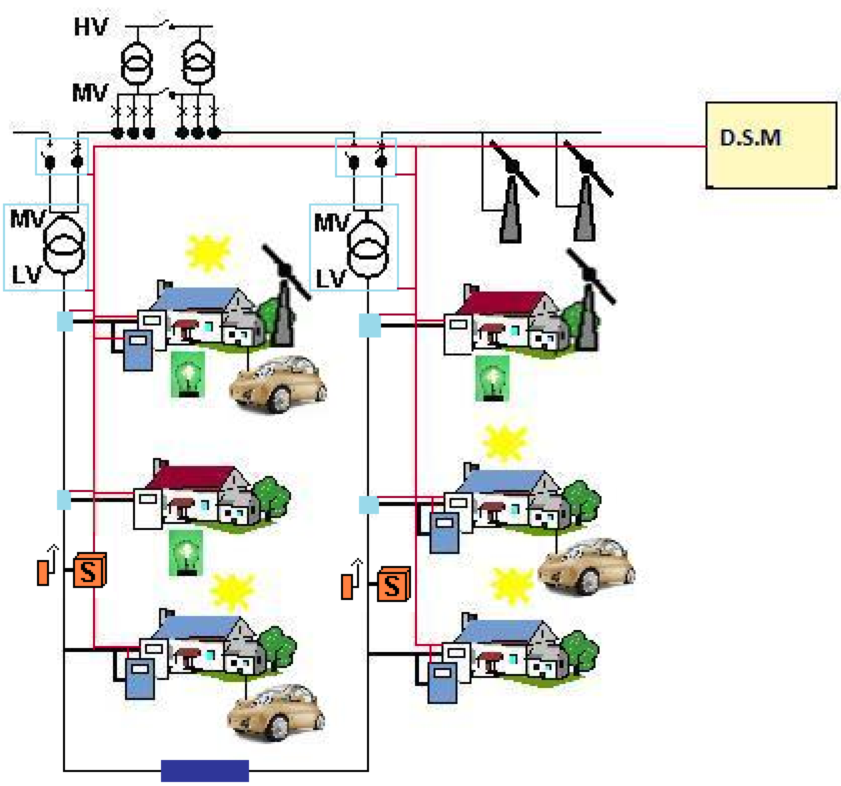
FIGURE 30
SCREENSHOT OF THE DISTRIBUTION UNAVAILABILITY GIS-BASED INTERACTIVE MAP DEVELOPED AND OPERATED BY ENEL DISTRIBUZIONE. THE EXAMPLE REFERS TO THE DISTRIBUTION SYSTEM OF SICILY ISLAND

Source: Enel distribuzione.

- **Remote Terminal Unit** (RTU) data analysis: analyses, compares and aggregates data coming for the field, acquired through the RTUs storing, processing aggregating data coming from the field, calculating trends and typical values, comparing values with thresholds and historical data, preparing reports;
- **Network schematics**: allows the access to the most updated network diagrams, based on the present databases of the telecontrol system;
- **Workplan management**: allows the electronic management of work plans on medium voltage networks, providing plan definition and documentation, network data and diagrams, operation sequences needed, decision support to the on-site operator etc.
- **Daily service reports**: detailing most important interruptions of electrical service at HV and MV levels, maximum and minimum loads, quality of service and indicators, event reports etc.

A schematic picture of an advanced automated distribution network is reported in Figure 31, showing in light blue colour examples of RTUs, local and global supervision systems;

FIGURE 31
EXAMPLE OF DISTRIBUTION SYSTEM EQUIPPED WITH ADVANCED MONITORING AND CONTROL SYSTEMS



Source: Enel distribuzione.

I. Microgrids

DG units integrated in a distribution system with loads and storage devices constitute a microgrid, which could be as small as a city block, and which operates connected to the main grid or in island. The difference between a microgrid and simple LV grids with DG is its capacity to operate in island with coordinated control and the presence of more than one generation source. Microgrids comprise Low Voltage distribution systems with distributed energy sources, such as small-scale combined heat and power (CHP), small scale RES, together with storage devices, i.e. flywheels, energy capacitors and batteries, and controllable loads, operating as a coordinated controlled entity. An example of a microgrid is reported in Figure 32; the figure represents the evolution of the active distribution network of Figure 31 in which an islanding switch is capable of isolating a portion of the network, which can still be supplied by local DG, thus maintaining the required level of reliability and power quality.

From the utility point of view, the application of DG can potentially reduce the need of new distribution and transmission facilities. Obviously, DG located close to loads will reduce flows in transmission and distribution networks with two important effects: loss reduction and ability to potentially substitute for network asset investments. Moreover, the presence of generation close to users could increase service quality received by end customers. Microgrids can provide network support in times of stress by relieving congestions and aiding restoration after faults (black start capability). From the end-user point of view, microgrids provide both thermal and electrical needs, and in addition enhance local reliability, reduce emissions, improve power quality by supporting voltage and reducing voltage dips, and potentially lower costs of energy supply.

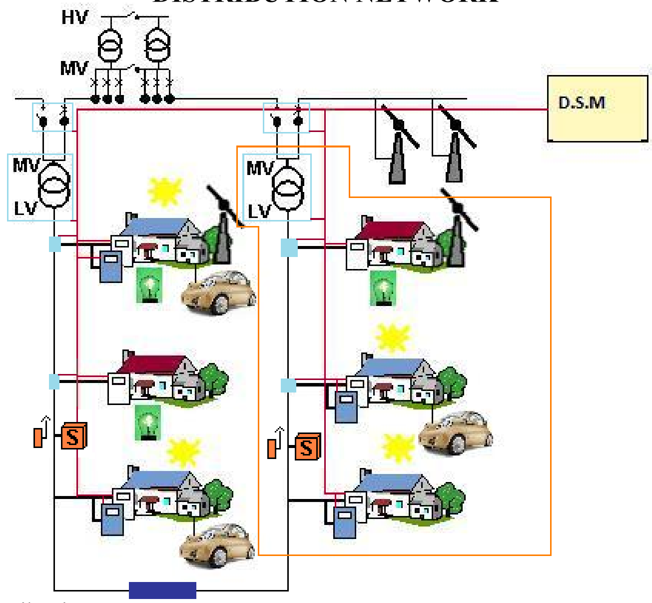
In order to achieve the full benefits from the operation of microgrids, it is important that the integration of the distributed resources into the LV grids, and their relation with the MV network upstream, will contribute to optimise the general operation of the system. The network control system should be adapted to comprise:

- Local Microgenerator Controllers (MC) and Load Controllers (LC): They use local information to control the voltage and the frequency of the microgrid in transient conditions. MCs have to be adapted to each type of micro source (PV, fuel cell, micro turbine, etc.), local Load Controllers (LC) are also installed at the controllable loads to provide load control capabilities;
- Microgrid Central Controller (MGCC): having the function of monitoring the actual active and reactive power flows and optimizating the microgrid management by sending control signal settings to the generators, storage devices and controllable loads;
- Distribution Management System (DMS): It is the controller of the overall distribution network. It manages interface signals between the distribution network and the microgrid. The level related to central control can be in charge to different entities (electricity retailers, "aggregators", able to supply aggregated load management, etc.), following different business models and regulatory limits in different countries.

The development of microgrids opens challenging problems due to the increase in network dimension and operation complexity, since large number of LV generation sources and loads need to be operated together through a MV grid. At the same time it is necessary to integrate these microgrids with existing DG units, directly connected into the MV network, as well as some large MV equivalent loads that may be under a demand participation operation or load curtailment strategy providing ancillary secondary reserve type services. After disconnecting a grid segment from the main network, power sources in these segments potentially could continue to provide electricity and form an unintentional island. The uncontrolled operation under these conditions must be avoided for several reasons, including personnel safety and equipment security. Since the safety of network operation is within the responsibility of the grid operators, they are usually very critical regarding the design of the interconnection protection of DG.

Protection schemes present at the DG need to be coordinated with the installed network protection scheme. Protection systems need to have the ability to discriminate faults in the power system from other events or transients which are not faults to guarantee the continuity of supply and avoid unnecessary disconnection of healthy parts of the network. Microgrids are expected to operate at much wider frequency and voltage variations during islanded mode and transfer to/from the main network. Flexible power electronic interfaces open possibilities of microgrids operating at variable frequencies and even entirely operated on direct current (DC) interfaced to the main grid via DC-to-AC converters with technical and economic advantages in several applications.

FIGURE 32
EXAMPLE OF A MICRO-GRID AS A PORTION OF AN ACTIVE DISTRIBUTION NETWORK



Source: Enel distribuzione.

BOX 12
R&D BEST PRACTICE: THE MICROGRIDS AND MORE MICROGRIDS PROJECT

Microgrids comprise LV distribution systems with distributed energy sources, storage devices and controllable loads, operated connected to the main power network or islanded, in a controlled, coordinated way. Previous research focused on the operation of a single Microgrid, has successfully investigated appropriate control techniques and demonstrated the feasibility of Microgrids operation through laboratory experiments. The project extends this work significantly with the following Scientific and Technical Objectives:

- Investigation of micro generator, energy storage and load controllers to provide effective operation of Microgrids.
- Development of alternative control strategies (centralized versus decentralized control, application of next generation ICT).
- Alternative network designs (modern protection means, modern solid state interfaces, operation at variable frequencies).
- Technical and commercial integration of Multi-Microgirds (interface of several Microgrids with upstream Distribution Management Systems, operation of decentralized energy markets).
- Extensive field trials of alternative control strategies (experimental validation of Microgrid architectures in interconnected and islanded mode and during transition, testing of solid state components and interfaces and or alternative control strategies).
- Standardization of technical and commercial protocols and hardware (to allow easy installation of micro generators with plug and play capabilities).
- Impact on power system operation (quantification of Microgrids benefits regarding reliability, network losses, environmental benefits, etc. at regional, national and EU level).
- Impact on the development of electricity network infrastructures (quantification of the benefits of Microgrids for the overall network reinforcement and replacement strategy of the aging EU electricity infrastructure).

Source: Author’s elaboration.

III. Latin America test cases: Chile, Brazil, Uruguay, Mexico, Panama and Jamaica

Smart grids technologies have the potential to improve the flexibility, competitiveness and sustainability of the electricity system of a country. However there is no smart grid solution fitting all possible situations, because of the peculiarities in system development and history, structure, regulation, management and operation etc. It is therefore essential that a local context be set, to take into consideration local conditions and to set up recommendations in line with the priorities of local governments and adapted for the local Latin American and Caribbean environments. With the intent of stimulating the discussion in the region on the potential features of smart grids technologies, CEPAL decided to investigate the situation initially in three countries of the ConoSur Region, i.e. Brazil, Uruguay and Chile (2010) and subsequently in three more countries of the region of Central America and the Caribbean: i.e. Mexico, Jamaica and Panama (2011).

A. Methodology for the test cases

The methodology followed in view of setting the context of the Latin America and Caribbean countries considered in this report consisted of five phases, and namely:

- The analysis of the most recent literature concerning the energy and electricity systems of the countries considered; a general overview of the energy system in Latin America is reported in Annex I
- The development of a questionnaire (reported in Annex II) distributed by CEPAL to representatives of the different stakeholders of the electricity system, i.e.:
    - Government
    - Electricity (energy) regulator
    - Electricity industry (distribution system operators)
    - R&D community
    - Academia
    - Electromechanical industry;

- The discussions and interviews with major local stakeholders representatives generally based, but not restricted to, the main points of the questionnaire; the list and references of interviewees is reported in Annex IV of this report
- The elaboration of the information gathered in view of the understanding of the present situation of the electricity system and the drawing of the boundaries for the further analysis of the smart grids application potential; the detailed analysis of the local smart grids application and potential is reported in Annex III of this report.
- The setting up of recommendations based on the previous elaboration and taking into account the activities being developed internationally in this field.

In the following we will report the main findings of the local review and the recommendations that can be derived for the countries considered.

B. Fact-sheet of the electrical system of Brazil

Sistema Interligado Nacional: The National Interconnected System (Sistema Interligado Nacional – SIN) of Brazil can be considered, by size and characteristics, unique woldwide. This generation system is huge and mostly hydrotermic, with an important share of hydro power plants. The SIN is composed by generation companies from South, South-East, Center-West, North-East and part of the North regions. Only 3,4% of the electricity production capacity of the country does not belong to the SIN: it is the insulated system located in the amazonic area. A very long transmission system (more than 95.000 km see Map 1) is necesary because of geographical dimensions of the country and its specific hydrological characteristics where hydro power plants are located far away from the main load centres (cities close to the coast).

SISTEMA INTERLIGADO NACIONAL

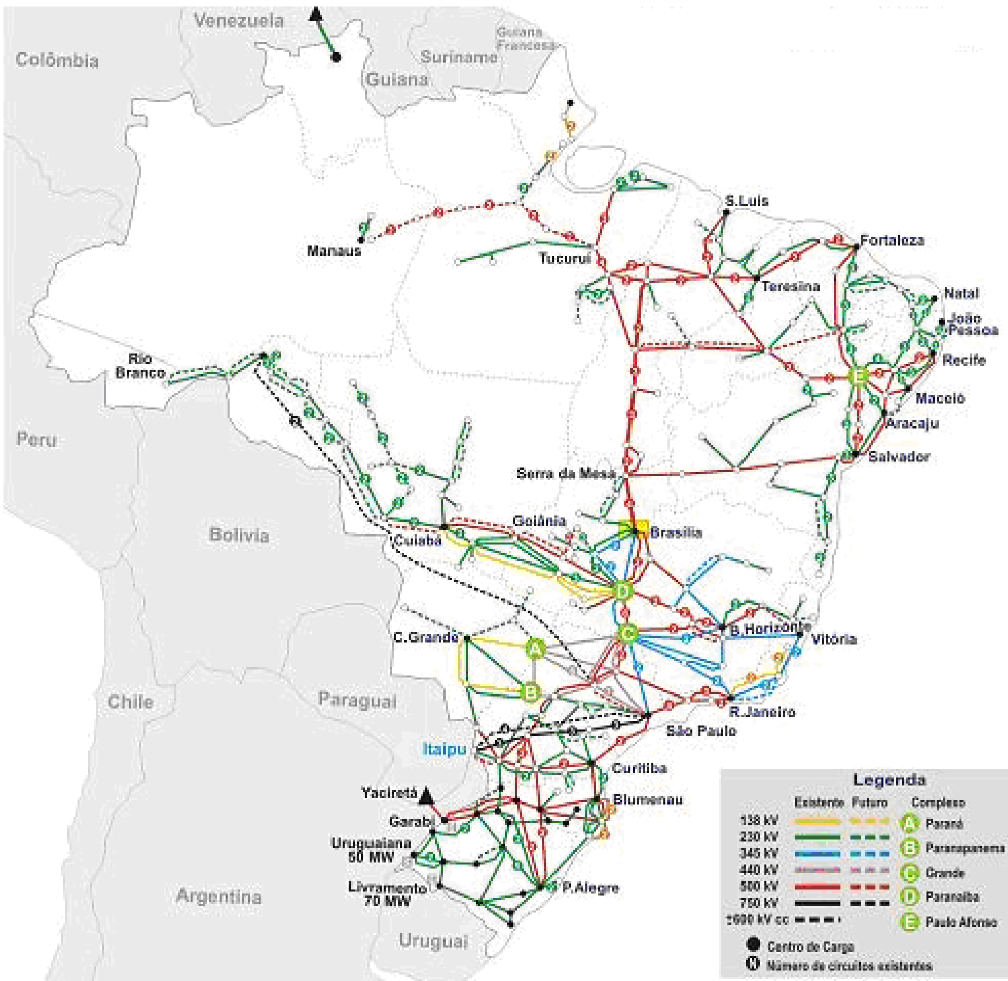
Voltage kV	2005	2006	2007	2008	2009	Var % 09/08	
230	35,736.5	36,342.5	37,155.5	37,709.9	41,503.5	10.06	43.5%
345	9,579.1	9,579.1	9,772.1	9,772.1	9,783.6	0.12	10.2%
440	6,667.5	6,671.2	6,671.2	6,671.2	6,671.2	-	7.0%
500	26,771.1	29,341.2	29,392.2	31,868.3	33,211.8	4.22	34.8%
600 CC	1,612.0	1,612.0	1,612.0	1,612.0	1,612.0	-	1.7%
750	2,683.0	2,683.0	2,683.0	2,683.0	2,683.0	-	2.8%
SIN	83,049.2	86,228.9	87,285.9	90,316.4	95,464.9	5.70	

Source: ONS: www.ons.org.br

The SIN is divided between transmission and sub-transmission grids: the primary transmission grid (voltage rating of 230 kV and above) is designed and operated to transmit large amounts of power, supplying the major load centers and, eventually, the biggest industrial users. The secondary subtransmission grid (up to 138 kV) supplies electricity to small cities and big industrial consumers. Since the mid 70's the whole brazilian electric system is operated in a coordinated manner aiming at optimising the synergies between all operating agents, in view of the reduction of the global electricity production cost, the overcoming of intra and extra-sectorial restrictions and the increase of the systema availability. The system operation coordination is carried out by the Operador Nacional do Sistema Elétrico – ONS. The installed capacity grows at an annual rate between 1,5 and 3% (more than 11% in the period 2004-2009). In order to backup to this increase during seasons with unfavorable hydrological conditions, the thermal power plants contribute to supply the market as a whole. For this reason also the complementary participation of thermal power plants has to be interconnected and integrated to the other agents of the system.

Sistema isolado: The Insulated System ("Sistema Isolados" – SI) composed of 345 power plants spread over almost the 50% of the brazilian national territory and covering 3,4% of the country power demand. Most of the plants are located in the North region (304) and Mato Grosso (36), while Pernambuco, Bahia, Maranhão and Mato Grosso do Sul have only 5 plants. From the consumption point of view the most important Insulated Systems are the ones supplying the North region capitals cities, like Manaus, Porto Velho, Macapá, Rio Branco and Boa Vista, with the exception of Belém that is conected to the SIN. In the majority of the Insulated System the electricity is generated thermally by diesel units or, in some cases, by hydro. The only exception consist of the Roraima state (capital city Boa Vista) which is importing power from Venezuela through a 230 kV interconnection.

MAP 1
SCHEMATIC MAP OF THE HV TRANSMISSION SYSTEM IN BRAZIL



Source: ONS: www.ons.org.br

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

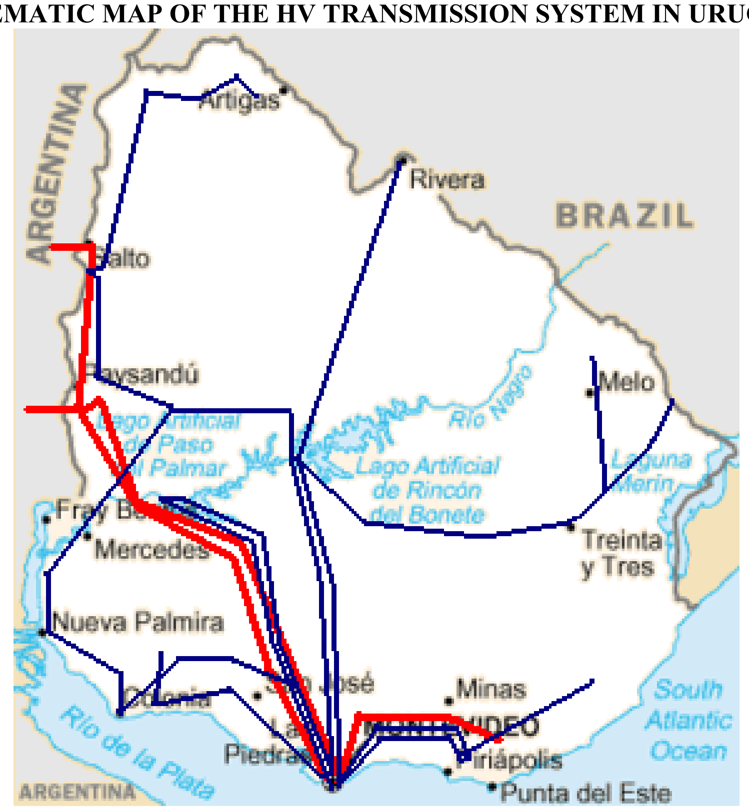
C. Fact-sheet of the electrical system of Uruguay

The state company UTE – Administración Nacional de Usinas y Trasmisiones Eléctricas, vertically integrated, has been created by law in 1912 and has had the monopoly of electricity generation in the country until the launch of Salto Grande power plant in 1979. UTE has the monopoly in transmission and manages most of the electricty distribution, even if in this sector few "sub-distributors" are progressively appearing.

The maximum installed capacity in 2009 was the 1.684 MW and its growth rate depends on the hydrological conditions of a certain year. A large portion of the electric generation in Uruguay is based on renewable sources, with special reference to hydroelectricity. Large hydro power plants are located in the central region of the country not very far away from the important load centers (cities on the south coast or in the north on the brasilian border). An important wind generation project has recently been set up and it is expected that the share of wind generation can score to 10 MW. The rest of the electricity is generated by fossil fueled power plants (approx. 30%), mainly based on oil and natural gas.

The transmission system is much smaller than the brazilian one, also considering the very different conformation and size of the territory. In 2009 the transmisiion grid included: 771 km of 500 kV; 3.567 km of 150 and 230 kV (almost all belong to 150 kV) and 97 km of 60 kV. There has been almost no growth in the transmission system in the last eight/ten years. The scheme of the Uruguayan primary transmission system (500 kV in red and 230 kV in blue) is shown in Map 2.

MAP 2
SCHEMATIC MAP OF THE HV TRANSMISSION SYSTEM IN URUGUAY



Source: Elaboration from UTE.
Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

The interconections of the Uruguayan electrical system with its neighbours Argentina and Brasil are very important: the national system is linked with Argentina with a double conection of about 1000 MW power each that cross the Uruguay river in two different points (Salto Grande and San Javier) and create the so-called “Cuadrilatero del Salto Grande”, a 500 kV transmission system associated to the hydro power plant with the same name. The most recent direct interconection with Brazil is in service since 2000, when a 70 MW HVDC connection was created in the Rivera/Livramento area linking the uruguayan transmission system (150 kV) with the brazilian state of Rio Grande do Sul (220 kV).

D. Fact-sheet of the electrical system of Chile

In Chile the electric system activities (generation, transmission and distribution) are developed entirely by private companies; the State only exerts its competences on system regulation, control and planning of the investments in generation and transmission.

The Chilean electric sector is very dynamic and in the last decades the yearly national consumption growth rate has been around 8%. The companies composing the electric market are divided as follows: 31 in generation, 5 in transmission and 36 in distribution. On aggregate they cover a national demand of about 48.879,8 GWh (2004). The system is divided into 4 non-interconnected, territorially defined electric systems, namely: SING, SIC, Aysén and Magallanes.

The **Sistema Interconectado del Norte Grande** – SING serves the northern regions of Chile (I and II) with the 5.72% of the population providing the 18,8% of the national demand. The installed capacity of this system is 3.650 MW with a peak demand in 2008 of 1770 MW (2008). The generation is almost totally from fossil fuels, even if solar power has a great potential that may be exploited in the future. SING is dominated by independent producers: Endesa-Chile, through its subsidiary Celta SA, accounts for about 20% of the installed generating capacity connected to the grid. Due to the presence of several mining enterprises, this area shows an intensive electricity consumption: 90% of the clients has a no limit contract of supply.

For the same reason in this area the development of micro generation is common, principally by means of diesel generators, aimed at covering the electric needs of the mining enterprises. The auto generation covers the 11,6% of the national consumption.

The **Sistema Interconectado Central** – SIC serves the central regions of the country (from III to X, including RM) and the great majority of the population, i.e 93%. The system installed capacity is around 9.120 MW with a maximum demand of 6.300 MW (2007). It provides energy for the more than 70% of the national consumption. The generation resources are equally divided between thermal and hydro, with a light predominance of the last one. Endesa-Chile, either directly or through its subsidiaries (Pehuenche SA, Pangue SA, and San Isidro SA), is the principal supplier to the SIC grid. This system provides electricity to the principal cities of the country. The majority of the users have regulated contract with limited consumption.

The other two systems, **Aysén** and **Magallanes**, serve the southern regions (XI and XII) and are very small and remote. Both of them cover less than 2% of the population, providing electricity for 1% of national consumption. The total installed capacity of both systems is approximately 100 MW with a maximum demand of roughly 65 MW (2008). The generation resources are split between hydro and thermal, with a little growing presence of wind generation in the Aysén system. On the other hand the Magallanes system, which is operated by only one company (EDELMAG Ltda) is totally thermal.

MAP 3
SCHEMATIC MAP OF THE HV TRANSMISSION SYSTEM IN CHILE – SING

Source: CDEC – SING.
Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

MAP 4
SCHEMATIC MAP OF THE HV TRANSMISSION SYSTEM IN CHILE – SIC

Source: CDEC – SIC.
Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

E. Fact-sheet of the electricity system in Mexico

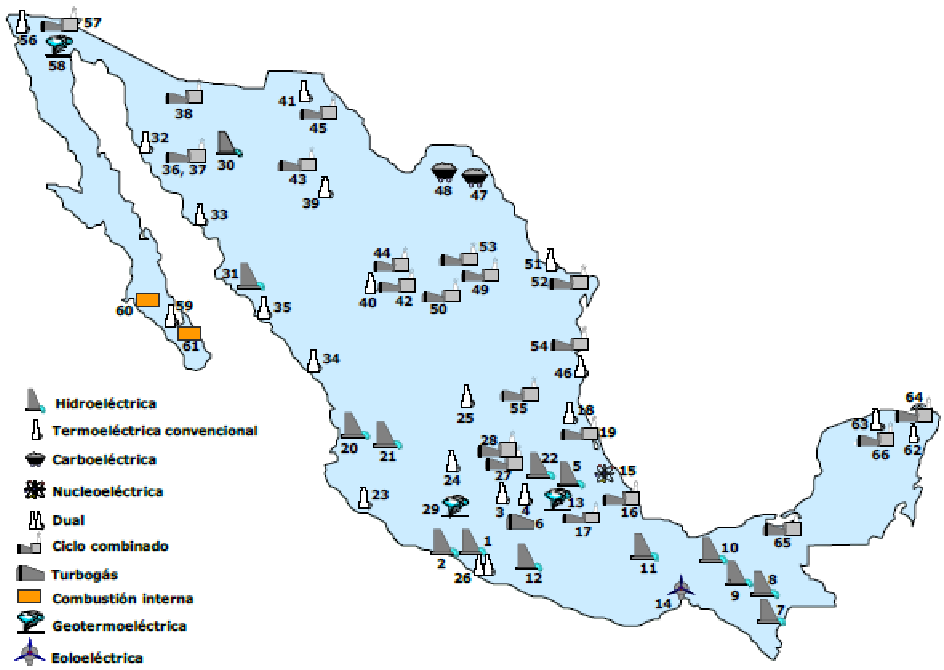
Mexico has a generating capacity of 59000 MW. There is a single national operator, i.e. Comisión Federal de Electricidad (CFE), a public company entrusted to control, generate, transport, distribute and commercialise electricity in the entire Mexican territory.

The total generation in 2010 was 239000 GWh. The electricity matrix is mainly focused on fossil fuels as shown in the following table. Mexico is an oil, natural gas, LNG and coal producer and exporter – because of limited refinery capacity Mexico imports 25% of its oil consumptions. The country exports electricity to US.

Type of fuel	Contribution to generation mix [percentage]
Geothermal	2.77%
Coal	6.90%
Nuclear	2.46%
Wind	0.07%
IPPs	32.85%
Hydro	15.03%
Hydrocarbons	39.91%

The location of the main generation plants is reported in the Map 5.

MAP 5
MAIN GENERATION PLANTS IN MEXICO



Source: CFE.
Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

The energy consumption sectors comprise: Transport: 47%, Industry: 21%, other sectors: 20%, non- energy use: 12%. The total electricity customers amount to 26.400.000, of which:

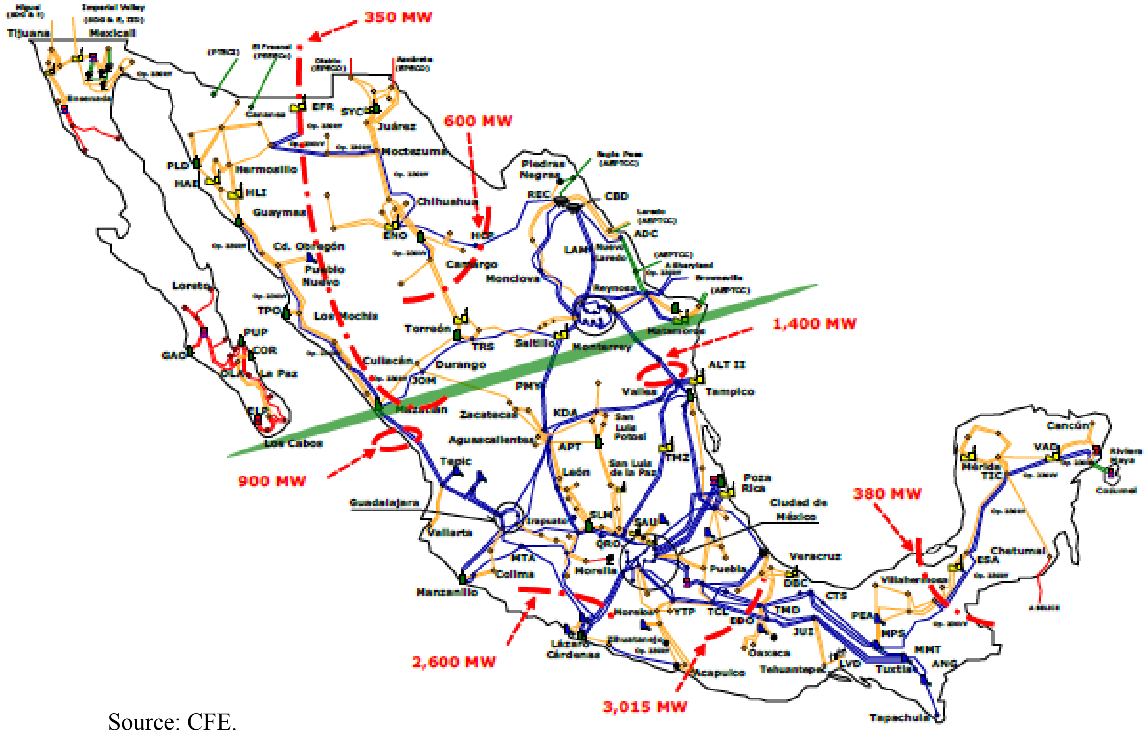
- residential: 88%,
- commercial: 9.88%,
- industrial+services+agriculture: 1.87%.

The **Sistema Eléctrico Nacional** (SEN) is composed of electrical networks at different voltage levels:

- The backbone network has substations and lines at the maximum voltage levels used : (400 kV and 230 kV) having the role to carry the energy between regions; the network is supplied by the main power plants and feeds the sub-transmission system as well as some large industrial users connected on the 400kV or 230 kV systems;
- The HV sub-transmission system, having voltage lines at 161 kV and 69 kV has a regional role and supplies electricity to the distribution network, as well as to some loads directly connected at these voltage levels;
- The distribution networks in medium voltage (between 60 kV and 2.4 kV) distribute electricity within geographically limited areas, supply the low voltage networks as well as to some loads directly connected at these voltage levels;
- The low voltage distribution networks (240V and 220 V) supply low consumption loads;
- The network coming from the former Luz y Fuerza del Centro (LyFC) has a total line length of 74,413 km, out of which 40,606 km are at 6.6 kV, including underground cables, and 33,807 km are low voltage lines (249 V o 220 V).

As for end 2009, the SEN was made of 812,282 km transmission and distribution lines. The main structure of the Mexican electricity system is shown in Map 6.

MAP 6
MAIN STRUCTURE OF THE SIN, WITH THE INDICATION OF THE MAXIMUM TRANSMISSION CAPACITY BETWEEN AREAS



Source: CFE.
Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

A detail of the evolution of the distribution line length for the different voltage levels is reported in the following Table:

Evolution of line lengths for different voltage levels:

Voltage level (Kv)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
400	13695	14504	15998	17790	18144	19265	19855	20364	20900	22271
230	22645	24060	24773	25687	27148	27745	28164	28093	27801	27317
161	508	646	470	475	475	475	547	547	549	549
138	1000	1000	1300	1300	1400	1400	1400	1400	1500	1500
115	36100	38000	38700	40100	40800	42200	43300	42700	42300	42400
85	100	100	100	100	100	100	100	100	100	100
69	3300	3300	3300	3200	3200	3200	3100	3100	3000	3000
34.5	61700	62700	63600	64700	66300	67400	69300	70400	71800	72800
23	24600	25800	26300	27400	27900	28600	29100	29800	30700	31200
13.8	246300	251700	257400	264500	269400	273200	278100	286300	289100	293300
6.6	500	500	500	500	500	500	500	500	200	200
LV	221000	222100	225100	230200	233000	236600	239300	245900	250000	253800

Source: CFE.

F. Fact-sheet of the electricity system in Panama

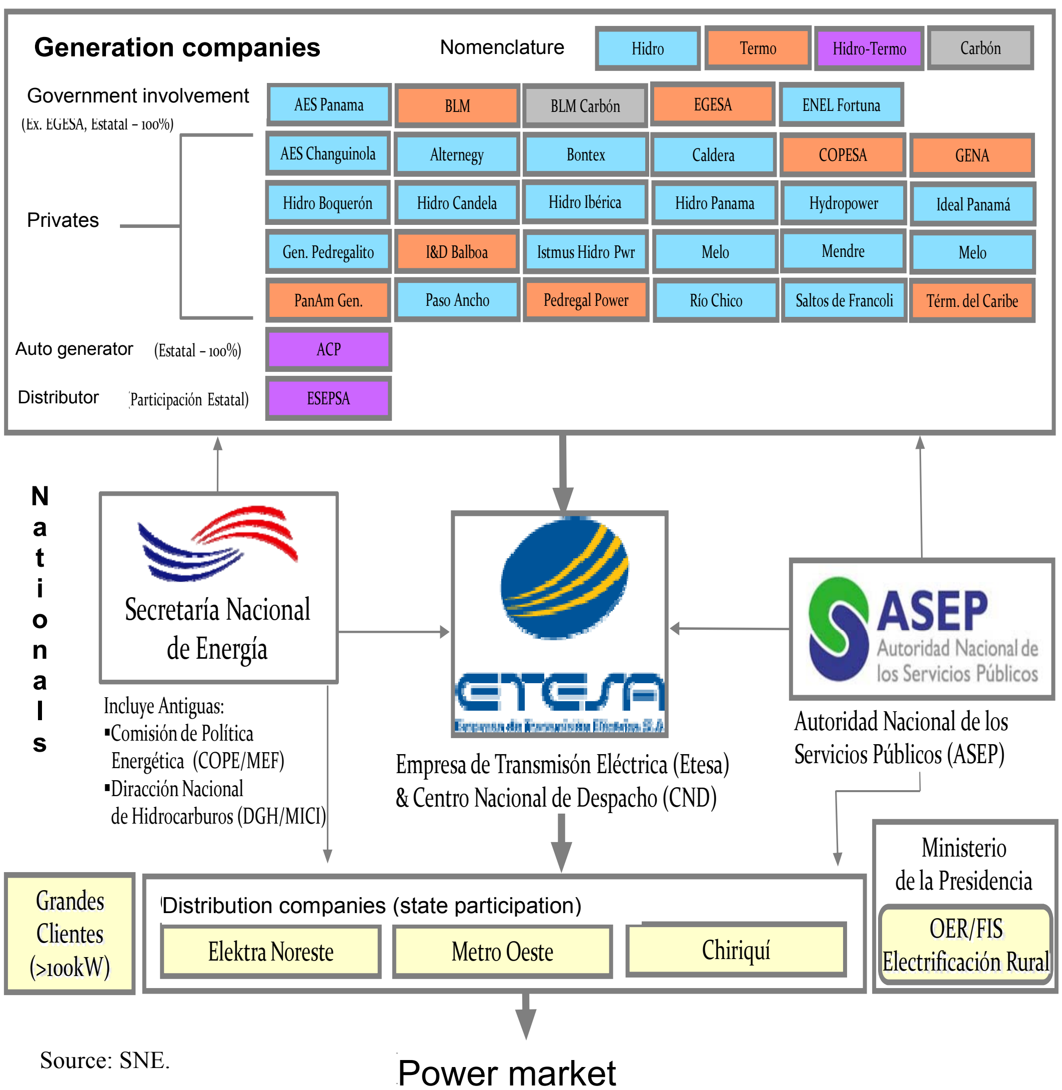
With the Law 6 of 1997, it is promulgated the Regulatory Institutional Framework for the Provision of Public Electricity Service through which the restructuring of IRHE is accomplished and therefore the electric sector in 8 companies:

- four power generation companies
- three electrical distribution companies
- one electricity transmission company (ETESA) where the state owns 100% of the shares

Then in 1998 was conducted the bidding for the sale of 49% to 51% of the shares of these generation and distribution companies implied, where it was reserved as an option for the employees just between 2% to 10% of the shares, and the state would stay with the remaining shares of these companies.

The diagrammatic picture of Figure 33 shows the relationship between different Electricity Sector actors. As of April 24, 2006, the regulator of the Services Utilities (ERSP) became the National Authority of Public Services (ASEP).

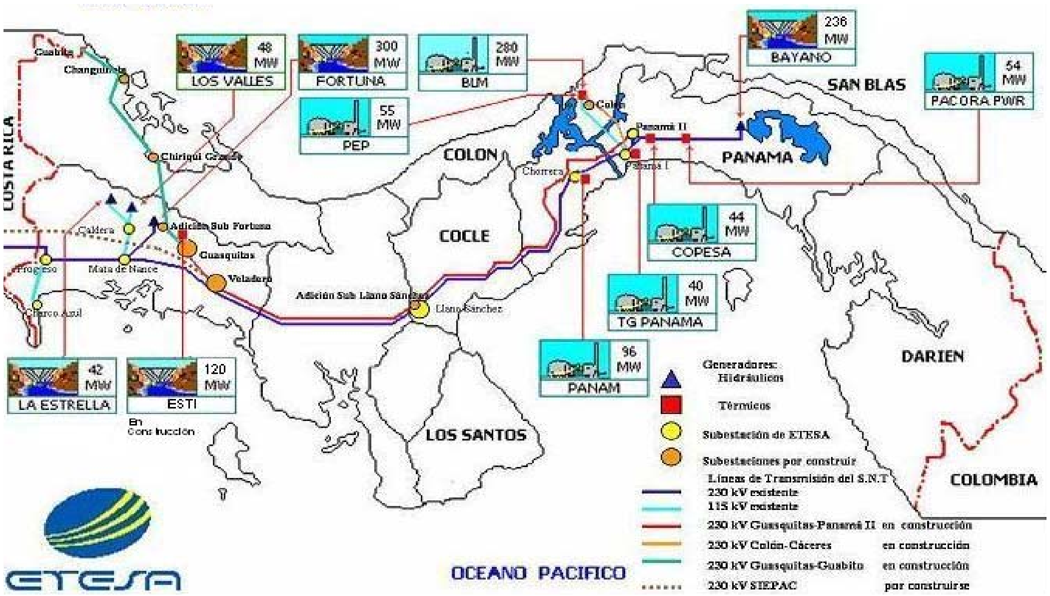
FIGURE 33
SCHEMATIC DIAGRAM OF THE MAIN ACTORS OF THE ELECTRICITY SYSTEM IN PANAMA



Source: SNE.

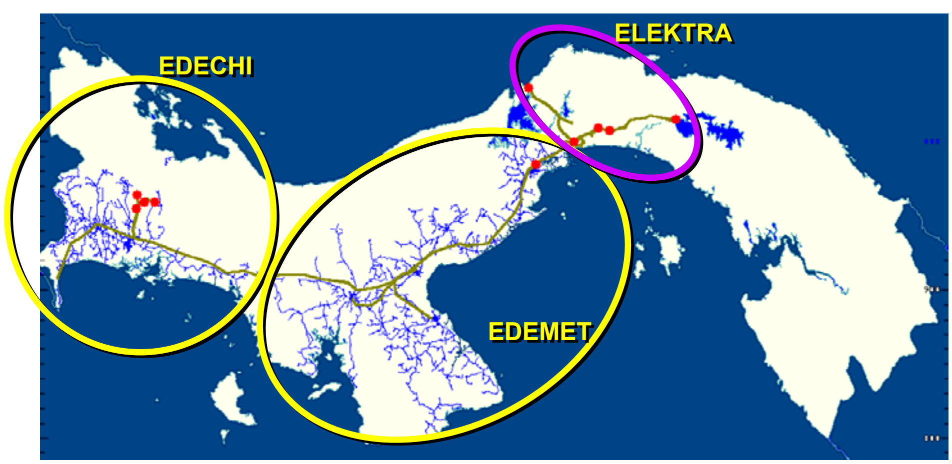
The main structure of the electricity transmission system in Panama is shown in Map 7, where the location and characteristics of the major power plants is also indicated. It must be noted that the figure illustrates the importance of the development plans in the country: in fact, most of the 230 kV system is subject to wide expansion process, with the Guasquitas-Panama II line, the Colon-Caceres, the Guasquitas-Guabito lines and substations in construction and the SIEPAC system planned for the near future. In terms of distribution system, three main actors are presently active: ENSA (Elektro Noreste SA), METRO and CHIRIQUI (Group Gas Fenosa SA).. The main areas of operation of the three distribution companies is shown in Map 8.

MAP 7
MAIN STRUCTURE OF THE TRANSMISSION SYSTEM IN PANAMA



Source: ETESA.
Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

MAP 8
THE 3 MAIN REGIONS OF ACTIVITY OF THE MAIN DISTRIBUTION COMPANIES IN PANAMA



Source: SNE.
Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

As for the distribution system, the following table shows the umero and energy delivered by the three distributors for the different electricity tariff schemes in use in the country.

Number of customers and energy delivered by different distribution companies:

Tarifa	Usuarios				Consumo en MWh			
	Elektra	Edemet	Edechi	Total	Elektra	Edemet	Edechi	Total
BTS	357,589	364,792	110,929	833,310	103,956	114,560	24,330	242,846
BTD	3,990	6,621	773	11,384	54,969	97,370	8,900	161,239
BTH	96	170	20	286	517	1,900	230	2,647
MTD	343	349	244	936	46,338	53,740	8,830	108,908
MTH	4	20	8	32	167	4,140	1,630	5,937
ATD	2			2	11,370			11,370
ATH			2	2			310	310
Totales	362,024	371,952	111,976	845,952	217,317	271,710	44,230	533,257

Source: SNE.

In 2004, the Government of Panama promoted the use of renewable energy sources through the Law 45.

It is a fundamental instrument of energy policy and provides the following benefits:

- Plants of renewable and clean energy up to 500 kW, are to be installed for self-generation and are not to be interconnected to the distribution network, do not pay import tax for equipment and spare parts required for the construction and operation of the plants.
- Plants of renewable and clean energy up to 10 MW:

  - No payment rate for transmission or distribution.

  - No payment of import tax for equipment and spare parts required for the construction and operation of the plants.

  - Are entitled to get a tax incentive up to 25% of direct project costs based on the equivalent of CO2 emissions that are to be displaced during the concession period applicable to the 100% income tax for the first 10 years of commercial process.

  - Are entitled to get an incentive up to 5% of the direct cost of the project works to become of public use.

  - They can contract directly any distribution company regardless of the location of the plant, up to 15% of the maximum demand of the distributors.

  - For direct contracts the regulator allows time and reasonable prices.

  - You can sell power in the market occasionally.

  - They can sell their power to the distributor, generator or another distributor.

  - You can offer your energy in the Central American market.

- Plants 10 to 20 Megawatts have the same benefits than those plants up to 10 MW with the following exceptions:

  - No payment of transmission rate for the first 10 MW during the first 10 years of commercial operation.

  - They can not contract directly with the dealer.

  - The tax incentive up to 25% of direct cost of reducing emissions of CO2 equivalent tons per year, applies to 50% of income tax and not 100%.

- Plants over 20 megawatts and up to any power, have the same benefits as than those plants up to 20 MW but pay normal transmission rate.

Future important developments: Electric Interconnection System for Central America (SIEPAC) and International Connection to Colombia (Interconnection Colombia - Panama (ICP):

SIEPAC project infrastructure consists of power transmission lines of 230 kV circuit with towers planned for a future second circuit. It also includes about 298 MVAR of compensation equipment. SIEPAC Line will be connected to national networks in each country by a total of 28 bays for access. The current line detail is shown in Map 9.

SIEPAC Project has two main objectives:

- Support the formation and gradual consolidation of a Regional Electricity Market (REM) by creating and establishing the necessary legal, institutional and technical resources, to facilitate private sector participation in the development of power generation additions, and
- Establish the electrical interconnection infrastructure (transmission lines and substations compensation equipment) allowing electricity exchange among participants in the REM. Funding for this program comes from an Inter-American Technical Cooperation of the International Development Bank (IDB).

MAP 9
THE FUTURE LINE SIEPAC CONNECTING 6 COUNTRIES IN CENTRAL AMERICA

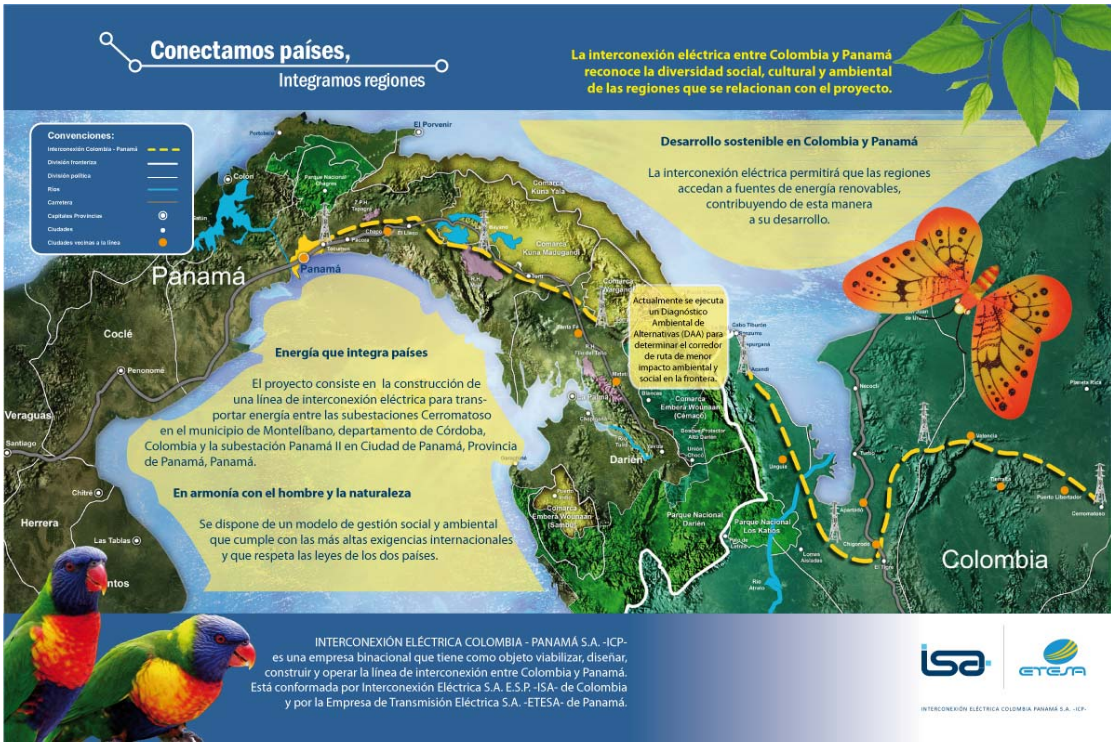
Source: ETESA.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

The power interconnection project Colombia - Panama is a transmission line of 600 km, in direct power (HVDC) between the substations Cerromatoso in Colombia and Panama II in Panama, with a carrying capacity up to 600 MW (300 MW in a first stage, depending on the maximum of exchange authorized by the system operators) and will lead to the integration of the Andean market with the Central American market, with consequent benefits not only for the agents of the two countries but also in terms of optimization of available resources throughout the region.

The process that determines the harmonized scheme Colombia-Panama is in an advanced stage, the regulators of the two countries have issued final regulations, consistent with regional regulation (MER), seeking to optimize the use of the line. The current line detail is shown in Map 10.

MAP 10
GENERAL SCHEME OF THE PANAMA-COLOMBIA TRANSMISSION LINE



Source: ETESA.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

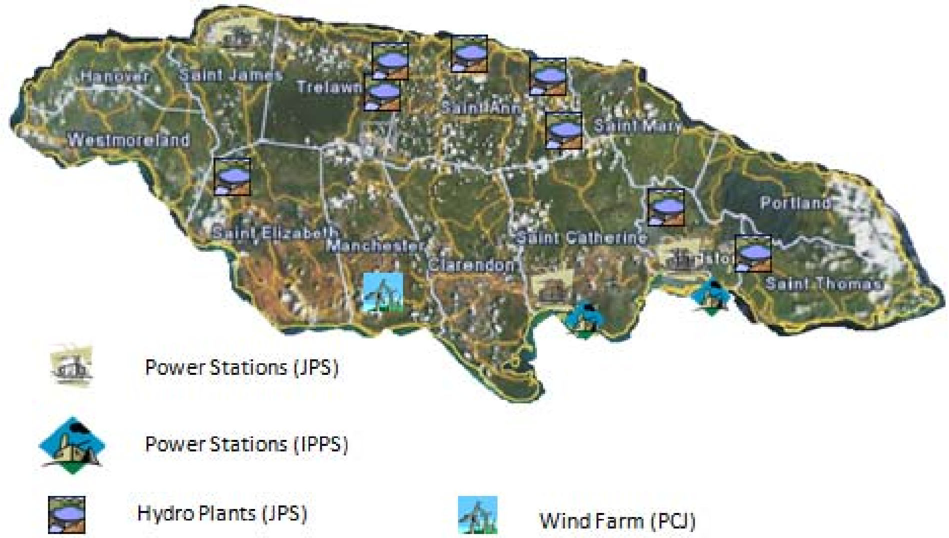
G. Fact-sheet of the electricity system in Jamaica

Jamaica Public Service Limited is a vertically integrated electric utility company licensed by the Government of Jamaica to generate, transmit and distribute electricity in Jamaica. JPS has currently has an installed capacity of approximately 621 MW complemented by almost 200 MW of firm capacity purchased from Independent Power Producers (IPPs) under long-term Power Purchase Agreements (PPAs). This gives a total installed system capacity of 821 MW. The generating systems of Jamaica use a mix of technologies including steam, diesel, hydroelectric and gas turbines to produce electricity.

The All Island Electric Licence, 2001 gives the Company the exclusive right to transmit and distribute electricity and the right to compete with other electricity producers for the opportunity to develop new generation capacity.

Since August 2007, JPS has been a subsidiary of Marubeni Caribbean Power Holdings who acquired an 80% ownership stake and operating control of the Company from Mirant Corporation. The remaining 20% is held between the Government of Jamaica (19.9%) and a number of individual and institutional investors (0.1%). In February 2009, Marubeni announced that it had entered into an agreement with Abu Dhabi National Energy Company (TAQA) of the United Arab Emirates to transfer 50% of its equity stake in its entire Caribbean portfolio, which includes JPS. Generating power plants are reported in the following in Map 11.

MAP 11
JAMAICA GENERATION PORTFOLIO



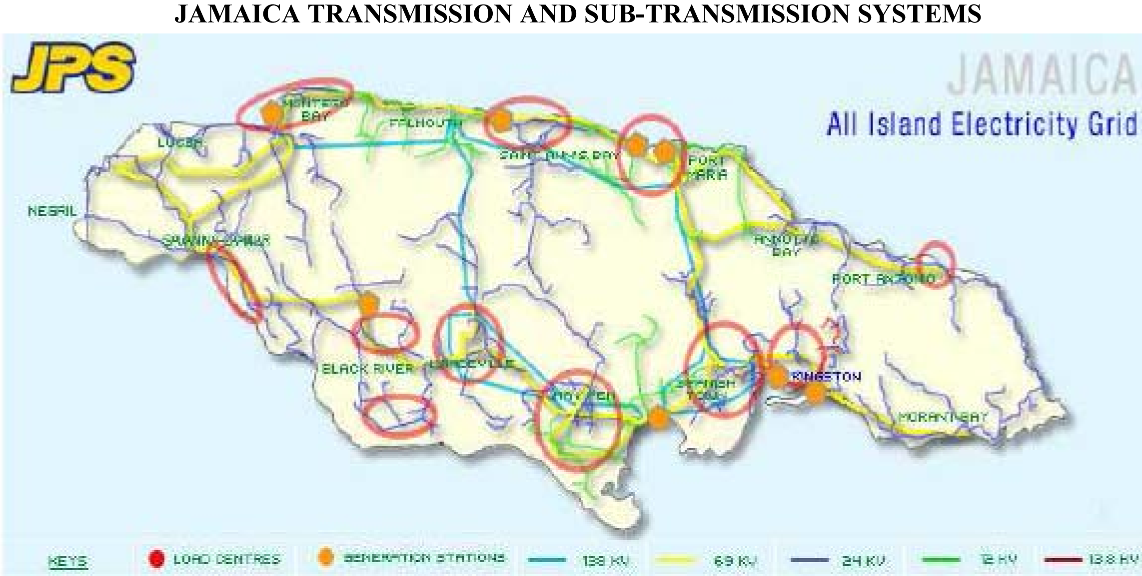
Source: Ministry of Energy of Jamaica.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

The transmission system, which transmits electricity at high voltages to substations across the island, consists of 1,264 kilometers of 138 kV (380 km) and 69 kV (811 km) transmission lines. This transmission network primarily conveys electricity to distribution substations, but some large industrial customers are supplied from the 69 kV system. The medium voltage distribution system operates at 24 kV, 13.8 kV, 12 kV, while the low voltage system is operated at 220 and 110 V. The total length of medium and low voltage distribution lines is nearly 9500 km.

The structure of the transmission and sub-transmission networks are reported in the following in Map 12, together with the geographical indication of the location of main load centers:

MAP 12
JAMAICA TRANSMISSION AND SUB-TRANSMISSION SYSTEMS



Source: JPS.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

JPS serves approximately 590,000 customers; 525,000 (approximately 89%) of which are residential consumers. This customer group is responsible for approximately 35% of the billed energy sales. Small commercial customers make up 10% of the Company's customer base and consume 22% of the billed energy. The remaining customer base is made up of large industrial consumers making up less than 1% of the customer base, but consumes 43% of total billed energy. 95% of the population has access to electricity.

The peak demand growth rate in the last 5 years has been 1.1%; in 2009 the peak demand was 644 MW, showing a substantial increase in the evening peak demand, calling for generation investments. The net generation in 2009 was 4.21 GWh, while the energy sold was 3.2 GWh, showing system loses ranging at more than 27%. Several measures have been recently adopted by JPS to reduce technical and non technical losses. As for the first category we mention: an effective VAR management system, the upgrading of several 24kV feeders, the reconfiguration of long secondary feeders, with the replacements of conductors, a more efficient phase balancing and the replacement of aged high losses distribution transformers.

H. The main actors in the electricity system

GENERATION:

Brazil	Uruguay	Chile
In Brazil, large government-controlled companies dominate the electricity sector. Federally-owned Eletrobrás holds about 40% of capacity (including 50% of the Itaipù dam), with state-companies CESP, Cemig and Copel controlling 8%, 7% and 5% of generation capacity respectively Currently, about 27 percent of the generation assets are in the hands of private investors; this figure is expected to grow up to 31 percent in the medium term and to reach almost 44 percent over 5–6 years.	About 56 % of the generation capacity in Uruguay belongs to and is operated by UTE, the state-owned utility. The remaining capacity corresponds to the Salto Grande hydroelectric power plant (945 MW), cogeneration or small private investments in generation in non-conventional renewables. Currently, there are four private companies that generate electricity for their own consumption and sell their surplus to the grid	Power generation in Chile is organized around four grid systems: Sistema Interconectado del Norte Grande (SING), the northern grid, which accounts for about 19% of national generation; Sistema Interconectado Central (SIC), the central region's grid, which accounts for 68.5% of national generation and serves 93% of Chile's population; Aysén Grid, in southern Chile: In practice, it consists of five medium-size systems located in the southern zone of the country: Palena, Hornopirén, Carrera, Cochamó and Aysén. Its joint capacity represents 0.4% of Chile's installed capacity; Magallanes Grid, also in southern Chile (0.8% of total generation), Consists of four medium-size systems: Punta Arenas, Puerto Natales, Porvenir and Puerto Williams, that supply the cities with the same names. It is located in the southernmost extreme of Chile. Its joint installed capacity represents 0.6% of Chile's installed capacity. There are 31 companies that participate in generation, although three main economic clusters control the sector: Endesa group, AES Generation Tractebel and Codelco (owing the largest generation company: Electroandina, operating in the SING system).
Mexico	**Panama**	**Jamaica**
CFE: vertically integrated public generation, transmission and distribution company; 73% of generation capacity, 100% of T&D network; Generating capacity: 59000 MW Net Generation: 239000 GWh (2010)	Three main groups of generating companies exist in the country: Companies having a state participation (typically 50%): AES Panama (the largest power generating company in Panama, both in terms of installed capacity and average	JPS: vertically integrated public Generation, transmission and distribution company; 76% of generation capacity, 100% of T&D network Generating capacity 770 MW Net Generation: 4.2 GWh (2009);

Customers: 26.400.000 Residential: 88% (of number of cust.) Commercial: 9.88% Industrial+services+agriculture: 1.87%	released energy: four hydroelectric plants, installed capacity of 482 Megawatts), Enel Fortuna (hydro), BLM (thermo), EGESA (fully owned by the State), BLM Carbon (coal fired plants). Private companies: AES, ALTENERGY, BONTEX, CALDERA, HYDRO BOQUERON, HYDRO CANDELA, HYDRO IBERICA, HYDRO PANAMA, HYDROPOWEER, IDEAL PANAMA, PERDEGALITO, MELO, MENDRE, RIO CHICO, SALTOS DE FRANCOLI (all hydro), COPESA, GENA, BALBOA, PANAMA GEN (Thermo), Autoproducers (state owned): ACP. Total installed capacity: 1978 MW, out of which 52% hydro and 48% fossil fueled Net generation (2010): 7630 GWh, 55% hydro, 32% bunker, 9.5% diesel Customers (in percentage of delivered energy): 32% residential; 42 % commercial; 7.5% industrial; 12% public services and government; total losses 14.5 %	Customers: 585.000 Customers Residential: 33 % of delivered energy Commercial: 20% Small industrial: 25 % Large industrial: 19%

TRANSMISSION

Brazil	Uruguay	Chile
In Brazil, transmission has remained almost exclusively under government control through both federal (Electrobras) and state companies (mainly Sao-Paulo-CTEEP, Minas Gerais-Cemig, and Parana-Copel). However, under the new sector regulatory model, there are about 40 transmission concessions in Brazil. Most of them are still controlled by the government, with subsidiaries under federal company Electrobras holding 69% of total transmission lines. The Brazilian transmission system is very advanced and up-to date.	Transmission activities are fully under the control of UTE, the state-owned utility	In the Central Interconnected System (SIC), the incumbent player is Transelec. In the other interconnected systems, the large companies generation or the large clients are the owners of the transmission systems.
Mexico	**Panama**	**Jamaica**
The transmission system is entirely operated by CFE, the state owned utility.	Panama transmission company is ETESA: Empresa de Transmisión Eléctrica (ETESA). The company is fully under the government's control.	The transmission system is entirely operated by JPS, the vertically integrated electricity operator.

DISTRIBUTION

Brazil	Uruguay	Chile
In Brazil, there are 49 distribution companies, 64% of which are controlled by the private sector. Among the most important distributors we can mention: Cemig, Copel, Celesc (public) and Eletropaulo, CPFL, Energias do Brasil, Light, Equatorial, Cemar, Ampla (private) etc.	Distribution activities are fully under the control of UTE, the state-owned utility	There are 36 private distribution companies, in which the more relevant economic groups are: Enersis (Endesa - ENEL), which includes Chilectra PP&L (US); Sempra-PSEG some groups linked to important local families (Del Real, Claro, Hornauer, Pérez etc.)

Mexico	Panama	Jamaica
After the disbanding of LyFC, the distribution operator nowadays is only CFE. The present situation is very complex as it is the result of the merging of 16 different companies with different standards, behaviours and performances.	There are three main distribution companies, having a 50% participation from the government: ENSA (ELEKTRO Norte – SA): has 41% of the consumption and 44% of the customers; METRO and CHIRIQUI (belonging to the Gas-Fenosa Group). Have 480000 clients, out of which 98% residential - number	JPS: vertically integrated public Generation, transmission and distribution company; 76% of generation capacity, 100% of T&D network

REGULATORS AND INSTITUTIONS

Brazil	Uruguay	Chile
MME: Ministry of Energy and Mines has the overall responsibility for policy setting in the electricity sector; ANEEL: Brazilian Electricity Regulatory Agency has the function is to regulate and control the generation, transmission and distribution of power in compliance with the existing legislation and with the directives and policies dictated by the Central Government. CNPE: National Council for Energy Policies, is an advisory body to the MME in charge of approving supply criteria and "structural" projects CMSE: Electricity Industry Monitoring Committee monitors supply continuity and security. ONS: Operator of the National Electricity System (ONS) is a non-profit private entity responsible for the coordination and control of the generation and transmission installations in the National Interconnected System (SIN). CCEE: Power Commercialization Chamber (CCEE) is the operator of the commercial market, is in charge of the auction system. EPE: Power Research Company (EPE) has the mission of developing an integrated long-term planning for the power sector in Brazil.	MIEM: Ministry of Industry, Energy and Mines - Direccion Nacional de Energia y Tecnologia Nuclear: sets the national strategy in the sectors of interest, with particular reference to the diversification of energy sources, the participation of an increased quantity of new renewable power generation, the enhancement of regional energy trade, the availability and acquisition of energy efficient goods and services, including efforts to raise public awareness regarding demand-side management interventions; URSEA (Unitad Reguladora de Servicios de Energia y Agua): the regulator for energy and water services, has the goal to supervise the delivery of services, defining the tariffs to the users and the remuneration for the transmission and distribution services.	ME: Ministry of Energy: has the overall responsibility for policy setting in the electricity sector, CNE: National Energy Commission It is the entity in charge of producing and coordinating the plans, policies and standards for the correct operation and development of the energy sector, and advises the Government on all energy related matters. SEC: Energy Superintendence is responsible It is the entity in charge of producing and coordinating the plans, policies and standards for the correct operation and development of the energy sector, and advises the Government on all energy related matters. SVS: Superintendence of Secure Values is in charge of taxation, as well as directly by the regions and municipalities CONAMA: National Environmental Commission, is the state institution whose mission is to ensure citizens' right to live in a pollution-free environment, to protect the environment, to preserve nature and to conserve the environmental heritage. CDEC: Economic Load Dispatch Centres : private organizations in charge of coordinating the operation of the electricity system. Each interconnected system possesses its own CDEC
Mexico	**Panama**	**Jamaica**
SENER: Secretaria de Energia has the mission to establish the overall energy policy of the Country and to define the LSPEE (Ley del Servicio Público de Energía Eléctrica), stating the basic rules for the delivery of the electricity services at the miminum costs and in compliance with the quality and security of public services. CRE: Comision Reguladora de Energia – office of SENER: permitting generation plants, transmission tariffs, electricity tariffs. .	SEN: Secretaria de Energia Gobierno de Panama: COPE: Comisión de Política Energética : formulates the overall energy sector policy and defines its strategy. ASEP: Autoridad de Servicios Públicos Nacional: aims to provide more effective sector management by separating administrative and regulatory functions related to electricity providers. ANAM: Autoridad Nacional del Medio Ambiente; has a shared responsibility in setting the policy for developing electrical industry activities in the frame f the environmental law establishing that the State will promote and give priority to non-polluting energy projects.	MEM: Ministry of Energy and Mining: has the mission to establish the overall energy strategy and policy of the Country OUR: Office of Utilities Regulation: permitting generation plants, transmission tariffs, electricity tariffs REP: Rural Electrification Program: is an Agency connected to MEM dealing with the aspects of global access to electricity to electricity of the Jamaical population, incentivising the construction of last mile infrastructures for isolated communities.

I. Conclusions on local findings

As for the countries visited during the mission, the following main conclusions can be drawn on the present conditions of the electrical system and in view of the implementation of smart grids technologies. The detailed analysis of each point taken into consideration can be found in the tables reported in Annex III of this report.

- The **generation** of electricity in most of the countries visited heavily relies on fossil fuels: Jamaica; Mexico, Panama and Chile are fully dependent on fossil fuels (coal oil and gas), while Uruguay depends on fossil fuels for about 30% of its production. For some of the countries (e.g. Jamaica) the burden of electricity supply is barely sustainable in situations of high fuel price volatility and motivates the very strong push towards a diversification of the portfolio mix, integrating renewables.
- Conventional renewables (large hydro power plants) play a very important role in Brazil (70%), Uruguay (65%) and Chile (35%), allowing important local developments, but also influencing heavily the system behaviour in all instances of rain shortage, causing (like in Uruguay or Chile) very large energy cost variations.
- **Non conventional renewable energy sources** (essentially wind and biomass) are starting to be installed since nearly 10 years, with particular reference to Brazil (700 MW wind and 8000 MW biomass). Most plants are connected to the sub-transmission or transmission system. All countries visited have programs aimed at the expansion of the non conventional renewables and have inserted this priority in their fundamental energy strategic documents.
- In terms of generation capacity, the situation seems nowadays sufficiently balanced, with eventual integration through reserve fossil generation or electricity imports, but the recent variability of rainfall and consequent hydro plant availability and the forecast for the evolution of the demand shows that power shortage may start to occur in several regions in the next 10 years. The situation is already heavily unbalanced in Jamaica, calling for urgent action in terms of generation system renewal and diversification towards the integration of renewable energy sources.
- The renewable energy potential, especially non conventional, is wide and only partly known: although solar and wind potential charts exist in most countries visited, the evaluation of the real potential still needs to be assessed.
- **Distributed generation** is negligible up to now and the distribution systems can be considered as passive, i.e characterised by a single-direction power flow, from bulk generators, through the transmission and distribution network, down to the loads. All countries have extensive plans to develop the distributed generation, mostly based on wind, solar, biomass and mini-hydro; ratings of generators considered are normally higher with respect to the general concepts of DG, as they are typically in the range of 5-10 MW, thus to be connected to the sub-transmission or medium voltage distribution network. DG may be of interest to avoid the construction of new generation in remote areas, to reduce distribution losses and to complement conventional generation in view of enhancing the system reliability and quality of supply. Grid codes exist for the connection of distributed generators on the medium voltage network: normally the generator must prove, to obtain the connection permit, that it will not disturb the reliability of the network and the quality of power supply. Distributed generators are not dispatched by the distributor but, in case of problem on the network, they are immediately forced to trip to avoid unwanted electrical "islands". No incentive whatsoever is envisaged to favour the insertion of DG (except for the assurance, in some countries, that the produced energy will be dispatched in the network). Under these circumstances, this solution becomes attractive mostly for large electricity consumer with a Time of Use tariff, in order not to be forced to buy electricity during peak hours. The

connection of a DG requires the installation of an energy meter in class 0.2 (versus the class 0.5 of all other meters) and a special anti-islanding protection system. In Uruguay, a very recent law, allows the connection of DG on the Low voltage network.

- The **transmission system** of all countries visited is characterised by adequate voltage ratings and performances, as a function of the local requirements. In Brazil part of the transmission system is operated at 765 kV (AC) and 500 kV (DC); in Uruguay, Chile and Mexico, although the system voltage is not so high, being the distances between generation and load less extreme, the ratings are nonetheless very high (400-500 kV AC). Panama and Jamaica have the lowest transmission system voltages (230 kV and 138 kV respectively), being the load, distances and the system requirements less stringent. Lacking precise information on the system management and operation (automation, monitoring, protection and control there is no specific reason to consider any major inadequacy). In particular Mexico; panama and Jamaica have a national dispatching centre with all up to date features in terms of system supervision and control. Nevertheless the recent blackouts in Brazil (2008) and Chile (2009) indicate that some bottlenecks or structural weaknesses may subsist, needing more accurate evaluation, out of scope of this report. Transmission system operators interviewed during the mission declare that the systems in the region are already managed and operated using smart grids solutions and that the main improvements can be achieved by a stronger interconnection and balancing capability. Several congestion points are reported by the system operators, especially close to large load centres (e.g. Santiago in Chile, Kingston in Jamaica and Panama City in Panama) and voltage stability threats are not infrequent. The structure of the transmission system of some of the countries visited is made of several independent, not interconnected systems: this configuration does not favour the development of large renewable energy plants, as a large balancing capability is required, supported by strong and non congested lines.
- The **distribution system** of all countries shows a very wide range of situations: from the up-to-date underground infrastructure in large towns and new settlements, to the overhead mixed and "messy" situations in smaller towns, rural areas and neighbourhoods of large towns. These systems are typically old, weak and uncontrollable portions of the network requiring modernisation and refurbishment. An example of the latter situations is reported in the following in Map 8 and Map 9, referred to Brazil and Chile respectively, but similar situations were observed in Mexico and Panama and very widely in Jamaica. In all the countries considered the distribution network is designed and operated as a passive system, as the presence of distributed generation is negligible. In general terms, for what concerns the smart grids technologies, we notice a limited distribution system automation, with little observability and flexibility. SCADA systems, often developed in collaboration with local developers and suppliers, monitor and control remotely portions of the medium voltage network only at the substation level, and never at the feeder or derivation level. All low voltage outage management operations are generated by telephone calls from the users; some sort of central network operation decision support systems, comprising a GIS-based view of the entire distribution network, is used in all countries, except Jamaica. No on-line automatic reconfiguration system is in operation, especially on the low voltage distribution system, but advanced on-line and off-line elaboration is made of the data available from the supervision system and from historical manual meter reading data, demonstrating much operation intelligence, even without an AMI.

FIGURE 34
EXAMPLE OF OVERHEAD DISTRIBUTION SYSTEM IN RIO DE JANEIRO – URCA (BRAZIL)

Source: Author's elaboration.

FIGURE 35
EXAMPLE OF OVERHEAD DISTRIBUTION SYSTEM IN VALPARAISO (CHILE)

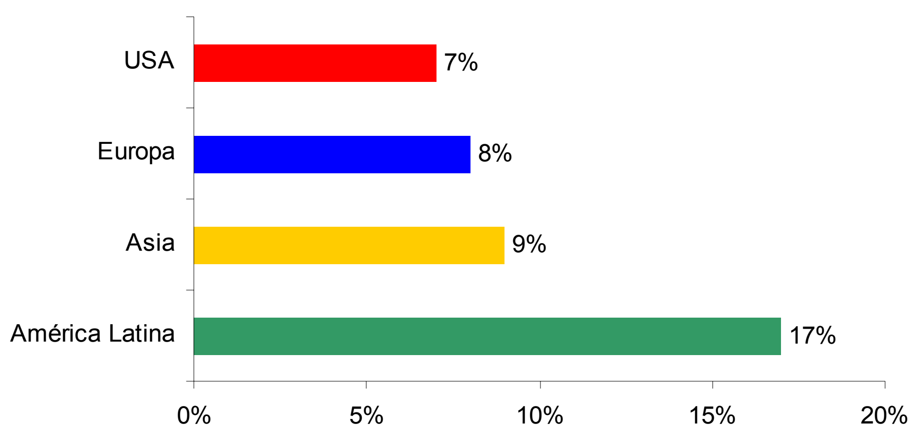
Source: Author's elaboration.

- Modernisation projects, essentially driven by the necessity to maintain and refurbish significant portions of the network, have been developed, and often comprise the network supervision, remote control and self-reconfiguration options. In terms of power quality: the average number of interruptions per subscriber ranges around 10-12 hours, while the duration of interruptions per subscriber ranges from 10 to 18 hours, depending on the country. Higher values must be reported for Jamaica. All power quality indices show an improvement trend, even in absence of any regulatory incentive for power quality improvement.
- The **average monthly consumption** ranges between 150 and 300 kWh/month, i.e. about half the consumption of the European householder and a quarter of the American. The typical loads are constituted of lighting, food refrigeration, TV and partly cooking. Ambient heating is normally by natural gas and air conditioning is very seldom used in household application (a specific situation in this respect must be pointed out in Panama). Brazilians use the electric shower system in which flowing water is heated up instantaneously, causing extremely high load peaks, representing a threat for the distribution system operation; electric water boilers are used in Uruguay, giving a higher load flexibility and controllability. The local consumers, although not much concerned about the carbon footprint of their electricity-related consumption, (based on the perception that electricity is generated based on mostly renewable sources), are progressively more aware of the energy conservation potential in their behaviour.

Wide and effective information campaigns have been imagined and applied fit for all levels of the population and are progressively gaining momentum.

- **Metering equipment** are conventional electromechanical or electronic meters, with little or no communication features (local download of data from the reading operator), except for large users or auto-producers. Electronic meters allow the setting of multi-level Time of Use tariffs. Manual reading is carried out on a monthly base, the billing is monthly and based on real consumption data. The information reported in the electricity bill of the customer reports the monthly consumption trend of the past year, information on the user category, the daily electricity average cost and general advices for energy saving; electromechanical meters inhibit any possibility of indication about the most energy-intensive appliances and therefore offer very little energy saving potential value. A peculiarity of Chile is represented by the fact that the regulation allows the user to hold the property of the meter and to install the meter inside the house, in such a way as to have the possibility to read the consumption directly. This fact rises specific problems in view of the adoption of advanced metering and demand participation opportunities.
- The **present level of distribution** losses ranges from 6 to 24%. It is estimated that non-technical losses are in average 5 to 10%, with peaks as high as 40%. Electronic meters could help substantially in the reduction of non-technical losses, the application of better Time of Use tariffs and demand participation measures. The business cases for the implementation of an advanced metering system needs to be carefully evaluated taking into account the low cost of manual meter reading and considering the relatively low level of pro-capita consumption. More in general we can observe that the biggest challenges that electric sector operators are called to overcome are the long distance between generation and load centers; the presence of large rural areas with low load densities; the supply management for megacities that involves the electricity quality issue; the distribution losses and steal reduction. A comparison of the level of distribution losses in different regions of the world are reported in Map 10:

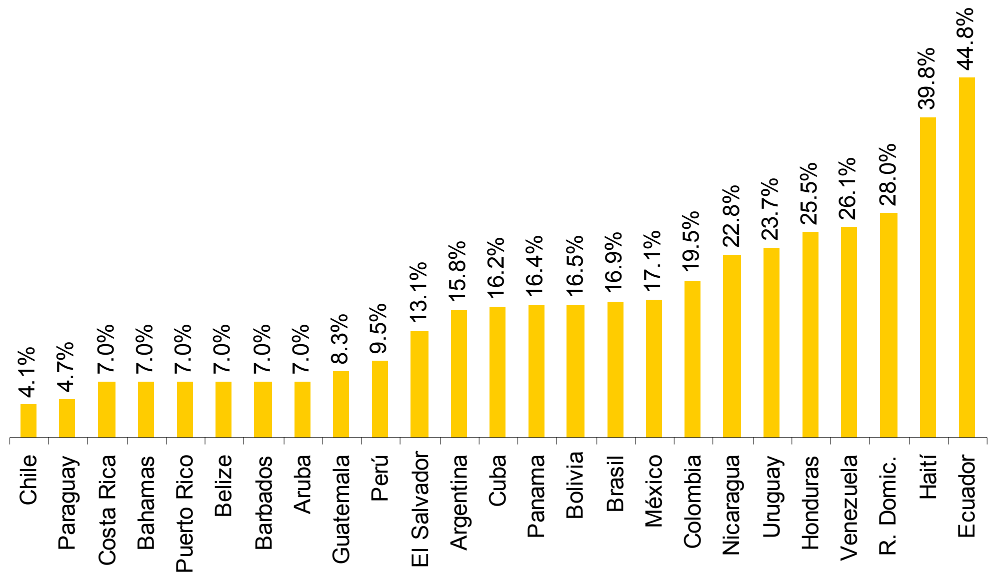
FIGURE 36
LEVEL OF DISTRIBUTION LOSSES IN DIFFERENT REGIONS OF THE WORLD



Source: GridWeek 2008.

With regard to technical and non-technical losses it is clearly visible how these are an important concern for the utilities, even more if we consider their higher level related to other geographical areas. In fact losses reduction and improvement on energy efficiency would partially cover the expected demand rise without the necessity to increase the installed capacity. In detail, it is possible to observe how the electricity losses in some Latin-American countries reach impressing levels, as in Ecuador and Haiti, without mentioning several other countries as shown in Figure 37.

FIGURE 37
DETAIL OF DISTRIBUTION LOSSES IN THE COUNTRIES OF LATIN AMERICA



Source: GridWeek 2008.

- The regulation: transmission and distribution activities in the countries considered are regulated businesses: therefore operators are remunerated essentially based on the following cost categories:

  - prudent investment: i.e the cost of replacement new of the installations considered as having a certain life duration and a reasonable time of return of investment costs, based on the business risks;

  - efficient administration of the company, i.e. the costs for the maintenance of the system at its required minimum reliability level, based on international benchmark, adjusted for local costs and productivity;

  - efficient operation of the system (losses).

  - The operator must ensure that the power quality level lies within a minimum level based on the operational targets and the operational history. Penalties are issued based on the exceeding value of duration of interruptions and the frequency of interruptions. No incentive is allowed in case of power quality performance higher than the expected values, nor on the investments specifically made for innovating the system: this rises the problem for the setting of the business case for the evolution towards smart grids.

  - The regulatory regime in the countries visited has been evidenced as one of the strongest barriers to the development and deployment of smart grids technologies. Except for some specific situations (partly in Brazil) the regulatory framework does not sufficiently encourage investment in grid renewal, with special reference to distribution networks.

- The **human skills**: Latin America and the Caribbean region have top-level universities and academia. The electrical engineering studies do not yet address smart grid application. However the natural skill of local engineers to address problems and projects using a very pragmatic approach and setting up solutions characterised by a very practical approach, cheapness and reliability may be used also for the addressing of smart grids and for the applications in developing countries. Breakthrough solutions are also developed, such as in the demand participation, software and ICT sectors.

IV. Recommendations

In view of the development and deployment of smart grids technologies in the Latin American and Caribbean region context, taking into consideration the worldwide developments and applications in this field, the following ten recommendations are proposed:

A. Develop regional and national road maps for smart grids

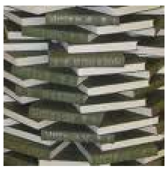
Each country in the region should develop a national road map for the development and deployment of smart grid technologies taking into consideration the country specificities in terms of energy policy, market structure and regulation, electrification priorities, network conditions etc.

The roadmaps should include:

- the vision of the smart grids application in each country of the region, at the light of their potential to reduce technical and non-technical losses, increase the penetration of renewables, enhance access to electricity, adopt demand-side participation, increase energy efficiency and the quality of supply to the final user;
- the prioritization for the development and application of smart grids components and technologies;
- the identification of the local barriers (regulatory, technical, non-technical) for the deployment of smart grids;
- the actions that need to be addressed to overcome the barriers;
- the timetable for necessary smart grids investments by governments, utility and other stakeholders;
- the identification of the standards to be adopted for the rapid deployment of the smart grids technologies.

An overarching Latin America road map for the deployment of smart grids can also be envisaged, with the identification of common characteristics of the region, in terms of energy mix, system structure, transmission and distribution losses, environment, regulation, market rules, etc. The IEA is developing a "How-to" guide for the setting up of regional and local smart grids roadmaps. This could help local governments to better focus and leverage on experience. CEPAL could coordinate the formats and methods for the country and region smart grids roadmaps, in view of identifying the barriers and the opportunities of a common regional approach.

B. Develop a policy framework to promote smart grids



Based on the indications of the smart grids road maps, a suitable legislative and policy framework should be developed at the different responsibilities level: from the municipalities to the national government.

Local governments and municipalities should focus on the potential of smart grids in the context of smarter and sustainable cities, considering the reduction of non-technical losses, energy efficiency enhancement within SMEs, commercial, residential and public buildings using smart electrical technologies, distributed micro-generation and electrical mobility. Moreover, the use of shared ICT infrastructures based on Internet Protocols (smartgrids, TV, internet, TV, telephone etc.) could be synergic in the achievement of societal goals (access to electricity, access to information, education etc.). All these aspects could represent an outstanding opportunity to field-test smart grid technologies, standards, rules and regulation, to demonstrate and deploy business/social development cases and examples on which to build future larger applications.

National governments and public policy makers should elaborate, publish and disseminate a local strategy to address the objectives of security of energy supply, climate change mitigation, market competitiveness, losses reduction and electricity accessibility and costs. This public strategy will help considerably in increasing awareness and commitment from all stakeholders towards the smart grids deployment.

The statements should address the smart grids concept as an enabler to the reduction of technical and non-technical losses, the deployment of renewable energy sources, advanced metering infrastructures and demand-participation features on the one hand, and as a key user of shared ICT infrastructures on the other hand: ICT for the smart grids applications could be one of the levers for the deployment of shared IP-based communication infrastructures that would not be justified for looking at single application (e.g. internet or smart grids) but that would bring societal benefits if seen in a multipurpose framework (e.g. internet and smart grids).

A **Latin America chapter on smart grids** could be created in the framework of the international dedicated partnerships, such as the International Smart Grids Action Networks (ISGAN) or the GridWise Alliance. This would allow to gather the specificity and characteristics of the region and bring it at worldwide level.

CEPAL could have an outstanding role in terms of economic and environmental evaluations, policy companionship and dissemination.

C. Adapt the energy regulation and financing schemes to promote the deployment of smart grids

National governments have an important role in the definition of a legislative and regulatory framework able to foster the deployment of smart grids technologies, also by means of the co-funding of pilot projects demonstrating the applicability of cross-cutting smart grids technologies and thus reducing the level of investment risk.

Regulators are responsible for designing and implementing rules and incentives reflecting the policy indicated by the governments and expressed in the national roadmaps and in the policy statements.

Latin America electricity context is mainly a deregulated environment. Therefore care shall be taken in the development of a regulation focussing on smart grids to efficiently allocate the risks and rewards, also considering the wider societal benefits of the deployment of smart grids technologies. In particular, attention shall be given to the potential benefits to the entire society offered by the smart grids technologies in terms of access to electricity, reduction of system losses (technical and non-technical), integration of renewable distributed generation, increase of power quality and implementation of demand-participation and energy efficiency build-up.

Revenue models and incentive schemes for the network operators should be created to encourage stakeholders' investments in smart grids: in particular, remuneration mechanisms should be set up to promote the adoption of innovative network solutions (e.g. the modernisation of the network to reduce losses and/or increase the renewable hosting capability of distribution networks) and to sustain research and demonstration. This will require major changes in the regulation of many Latin American countries to see it happen. It has been outlined in the discussion about the local findings in Brazil, Uruguay and Chile, that the local electricity regulation is mostly afflictive and that no incentive schemes are presently foreseen to reduce losses, enhance power quality, renewable integration, smart metering and energy efficiency. This situation makes it a difficult task for network operators to build up a positive business case already for what is considered the first step for the smart grids deployment: i.e. smart meters. In fact, with the present levels of pro-capita energy consumption and utility costs for the meter reading, in the absence of any regulatory incentive for example on the enhancement of the situation of non-technical losses, the operator cannot justify the smart meters and network automation investments only based on the reduction of electricity thefts and meter reading costs.

On the other hand, as an example of proactive regulation to promote smart grid technologies, the Italian situation may be considered as a reference: it is well known that the national regulation is very advanced in terms of incentives to the enhancement of the quality of supply; moreover specific market mechanisms exist to promote the energy efficiency (tradable white certificates) and to accelerate the deployment of remote management of smart meters. As already mentioned, a recent deliberation26 of the regulator has launched the process for the selection of demonstration projects aimed at modernizing medium voltage distribution networks, thus giving them more flexibility and efficiency by means of the inclusion of renewable energy sources. The capital investment remuneration rate, recognised in the tariff, for the portions of networks in which smart grids demonstration projects will be realised, is set at 9% for a total duration of 12 years (the normal remuneration is fixed at 7% for normal distribution network investments). Pilot projects considered have distributed generation with reverse power flow (flowing of power from the medium voltage network towards the high voltage network) at least for a certain duration during the year; to qualify for the incentives, the projects must also make use of open communication protocols and ICT technologies to ensure the maximum interoperability. The initial focus for a proactive smart grids regulation in Latin America could leverage on the means and capability of smart grids to reduce technical and non-technical losses.

An important financial leverage for financing smart grids deployment can be represented by the inclusion of smart grids under the international agreement to climate regime (e.g. Clean Development Mechanism). Moreover, worldwide financial packages for access to electricity, public funds created in global carbon markets to support developing countries, or the encouragement of developed countries to co-invest in developing countries could be used to finance the implementation of large-scale smart grids demonstration projects. This would have very favourable impacts also in the development of local business cases, technological solutions, skills and excellences to be exported in other regions of the world.

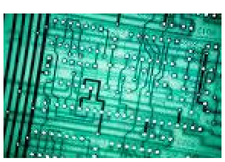
[26] AEEG deliberation n. elt 39/10 see www.autorita.energia.it.

D. Create, collect and disseminate business cases

The deployment of smart grids technologies involves important investments. The different stakeholders need to have a comprehensive view of the costs and benefits in the specific country situation as a function of the local conditions of the power and ICT networks, regulation and potential customer response. There is no business case fitting all situations. In the specific case of Latin America countries, the extensive presence of conventional renewable energy sources (large hydro plants) in the energy mix, the widely liberalised electricity market structure, the absence of any incentive to network innovation, losses reduction, power quality enhancement and non conventional renewable energy integration, the limited costs for conventional meter reading and the low pro-capita consumption may appear as obstacles in the building of positive smart grids business cases. On the other hand other worldwide experiences in regulated and non-regulated environments show very positive perspectives: according to a recent analysis conducted by UTC[27], considering a comprehensive smart grid deployment for a typical utility that installs one million electric meters in a non-regulated environment and a developed country, one can expect smart grid technology to generate at least $110 million per year through a wide range of benefits: from increased rate of return, to lowered carbon emission, to new jobs creation. The study points out that the internal benefits are linked with system reliability increase, carbon emissions reduction, internal rate of return for the smart network program ranging from 14% (base case) to 35% (accounting for the value customers may place on the increased reliability of the electric grid). In a regulated European environment, Enel Distribuzione invested €2 billion (roughly US$2.5 billion) in its 2000-2005 deployment of 32 million electronic meters and can nowadays claim, among the benefits, a 62% reduction in minutes of service interruption per customer, a 61% reduction in distributor meter management costs per customer and savings of $750 million per year as a result of the project.

Specific cost-benefits estimation must be carried out in the various Latin American situations by the different stakeholders and implemented considering the potential of policy and regulation adaptation as stated in previous recommendations. Although it is understood that sharing business cases and experience may sound as an abuse in a market oriented environment, it is recommended that a Latin American permanent forum be set up for the coordination of information resources on financing mechanisms and economic data for smart grid R&D and deployment, in order to facilitate the development of national or regional smart grid financing models, collaborate with cluster countries and venture capital entities on leveraging financing for smart grid programs and facilitate cross-country learning on business case development. In particular the forum should address the collection and dissemination of business case model elements related to the impact of smart grids technologies on costs and benefits, including non-financial and societal aspects and the performance of different financial and commercial models developed to implement smart grids, demonstrating how benefits and risks are allocated and what associated funding sources are used.

E. Develop and demonstrate smart grids technologies



Most of the technologies deemed necessary for the implementation of a smarter grid are nowadays available as the single building blocks of the edifice. In fact, several technological solutions exist off-the-shelf in the workshops of equipment suppliers, others need to be personalised for the specific application, while others still need to be developed; however all need to be tested, in terms of capability to be integrated into the system, compatibility, interoperability, at first in laboratory, then on small scale

[27] UTC Research: The Shpigler Group, Montebello, NY - "Smart Grid Economics: Making the Business Case for Smart Network Technology" - November 2009.

pilots and finally in real situations. One of the keys to the deployment of smart grids technologies is the research, development and demonstration. Demonstration and deployment projects are necessary to validate the integration of the technologies developed as well as the related business models. In view of the longer run, technological developments must continue to ensure that the needs for new functions and technologies are covered in due time. Fundamental research has an important role to play, on the "system" aspects, on the "technology integration" aspects and finally on the cross-cutting technologies. Technological research challenges will certainly arise also during the implementation phases of grid demonstrators: the coordinated use of modern technologies tested on a standalone base requires preliminary verification in extended test bays and small scale demonstrators.

Several research projects are being conducted worldwide and it is of capital importance that the necessary activity to fit the Latin American situation be carried out in close relation to other worldwide developments, in order to limit duplications, cover local peculiarities, fill-in the gaps and optimise overall expenditures. All actors in the research, development and demonstration chain have to play their role: from academia to public and private research centres, to equipment manufacturing innovation groups. Network operators must have a central role, being responsible for the management of the electricity system and the immediate stakeholder in smart grids applications. In order to allow the development to happen, the first step is the necessity to dedicate adequate public resources to research, development and demonstration of advanced smart grid technologies. An interesting example in the region, to be taken as a reference, is Brazil, where a specific and well structured research fund is managed by ANEEL dedicated to electric system research.

In terms of research priorities, based on the test cases considered in this study, the following R&D&D items are proposed:

- Reduction of network losses by means of the deployment of smart grids technologies, with particular reference to the use of smart meters for internal energy balance, advanced network architectures and topologies, innovative technologies (low losses power transformers, power electronics, static reactive compensation etc.), network management tools (monitoring and supervision), potential of DG and demand-participation;
- ICT technologies for smart grids, with special reference to the IP-based shared resources, to pave the way of an innovative model, particularly suitable to large and non-densely populated countries, of communication infrastructure hosting commodities (internet, TV, telephone) on top of technical (supervision, automation and protection) and commercial (electricity, gas, water metering) signals.
- distributed generation integration, and more specifically the integration of medium scale (3-10 MW) generators to the sub-transmission and medium voltage distribution networks;
- active distribution network automation, monitoring, control and protection making use of distributed intelligence,
- electricity storage technologies to balance non conventional renewable variability,
- demand-participation algorithms and tools,

Develop a Latin America smart grids technology strategy to work with current research initiatives to integrate and align current development efforts across the region and align the methods and findings with international research conducted in the framework of global alliances and organisations, such as the IEA (ref. IEA-ENARD – www.iea-enard.org and/or the nascent ISGAN), the Gridwise Global Forum (www.gridwiseglobalforum.org), the European Industrial Initiative on Smart Grids (EEGI) (www.smartgrids.eu), the European Energy Research Alliance and its Joint Program on smart grids (www.eera-set.eu), the CIGRE (International Council on Large Electricity Networks; www.cigre.org), the IEEE (the Institute of Electrical and Electronic Engineers www.ieee.org) etc.

Enable and incentive collaboration on development of key Smart Grid technologies, domestically, regionally and internationally, allowing for shared learning, risk reduction, cost/benefit analysis, dissemination of best practices, leveraging on the learning of the recently set up international research, development, demonstration and deployment initiatives especially for what concerns the collaborative framework, the protection of the intellectual property, the initiative evaluation criteria and its metrics, the up-scaling and replication potential. Develop country-specific or regional assessments on the internal smart grid market, including leading smart grid technologies or methods within the country, and key smart grid products and technologies to be exported.

The expertise of top level Latin America academia, research centres, utilities, local industries and public authorities and regulators should be synergically directed to build up a portfolio of Latin American smart grids research activities comprising fundamental research, pilot projects, small and large demonstrators, possibly integrated with the current efforts deployed worldwide, to contribute to the common research and demonstration effort and to point out and address regional peculiarities in terms of boundary conditions, in view of paving the way of the Latin America smart grids excellence. In this framework CEPAL could have a central coordination and informative role.

F. Demonstrate and deploy distribution network automation and smart meters

Advanced meters, together with network automation, are the pivot of the smart distribution network and a key component in view of the reduction of network losses. Proven technology exist and has been applied in several countries more or less extensively, to demonstrate the robustness of methods and its fitness for the specific country and regulation situation. In the specific case of Latin America where pro-capita consumption and cost of reading would not justify the investments (unless remunerated on the tariff), attention should be given to the potential of smart meters to dramatically reduce system losses and on their capability of being the gateway to the user premises, in view of the delivery of energy, information and social services. Extensive technology roll-out is to be seen in several European countries, the United States, Canada, Japan and Australia, while imminent demonstration projects are planned in several other countries. An example of very extensive existing application of smart meters (more than 32 million installation in Italy only) and distribution automation system (more than 100000 medium voltage substations remotely controlled and equipped with automatic fault detection and clearing) exists in Italy, where it has been developed, tested and applied by ENEL Distribuzione. Advanced meter management is closely linked with network automation, workforce and utility asset management.

Medium to large scale test cases for the demonstration and deployment of smart meters and network automation should be selected, covering an extensive range of situations, in terms of regulation, society, network conditions, environment etc. to prove and contextualise the technologies, their integration and the potential of losses reduction in the specific Latin American country situations.

G. Share best practices and know how

In order to facilitate and encourage collaboration among all interested smart grids stakeholders and to develop a specific Latin American expertise in this field, adapted to the peculiarities of the different countries conditions, collaborative activities shall be encouraged, with a special attention to knowledge sharing and common local know-how build-up. The following steps are envisaged, in line with the recommendations of the MEF Smart Grids Technology Action Plan[28]:

[28] Major Economies Forum on Energy and Climate – Technology Action Plan on Smart Grids – December 2009 – downloadable from www.majoreconomiesforum.org.

- Develop and manage a central repository with past and on-going Smart Grid R&D, pilot and full-scale deployment efforts by different entities (institutions, utilities, municipalities, etc.) to facilitate and encourage collaboration and knowledge sharing among interested smart grid participants;
- Share successful strategies, including policies and business models, for improving smart grid economics (e.g. through on line knowledge tools);
- Create public knowledge base to empower smart grid entrepreneurs with suggestions on how to build a business case, secure funding and partner with companies along the electricity value chain;
- Exchange learning from pilot programs and other smart grid experiences across utilities, also using roundtables with senior executives from utilities;
- Convene industry participants covering the entire smart grid value chain to share best practices and experiences across regions and internationally; a good living example of such initiative is the Latin American Smart Grids Forum (http://www.ecoee.com.br/materias/forum_smart_grid_english.pdf);
- Establish standardized approach to quantifying “intangible” smart grid benefits in business cases and regulatory cases.

H. Promote standardisation

The development and deployment of smart grids technologies relies on technology interoperability. This can only be achieved if an adequate standardisation level is developed and widely accepted. The present standardisation process being very scattered and very long, there is the risk that different standards be developed in the different regions and that the goal of a common communication language and interoperability be vanished. It is therefore considered as a fist priority to promote, in the local development and implementation of smart grids technologies, the use of international standards. Moreover, Latin American countries should increase their participation in the standards development process, contributing to the increase of efficiency of the standard production process itself, in such a way as to produce harmonised standards covering the main interface problems, accepted and issued in time for a wide application, and flexible enough to allow the continuous technological development necessary for smart grids. Latin America should integrate existing or nascent platforms to enable cross-country and cross-regional smart grid standards development and coordination, established with existing international standards associations (e.g. NIST, IEEE, IEC, ISO) and their international or local (country specific) alliances.

Moreover, international access by local technology developers, to global test-beds to verify the coordination, interaction and interoperability of the overall smart grid solution should be promoted.

In terms of communication technologies and systems, attention shall be focussed on two important aspects: security of the communication infrastructure and data privacy, especially in cases where, as stated several times in this document, a shared IP-based infrastructure is developed and used.

I. Engage public awareness

The deployment of the electricity grid of the future will inevitably require, among others, the construction of new power infrastructures (lines and stations). In order to increase the social acceptability of the network, all actions shall be taken to reduce all types of impact of new infrastructures, setting up comprehensive and transparent information to the population concerned. Communication is vital, taking into account that smart grids imply a significant social impact and require a deep involvement of consumers as well as their "smart" cooperation. The fist necessary step is the creation of the public awareness of the impellent necessity to act towards the evolution of the electricity networks: it is proven that the present electricity system structure and management will not permit to maintain the required levels of availability and quality of supply with an increasing injection of variable power from the renewable energy sources. Moreover, the present system structure is not designed for widespread demand-participation actions and the consequent energy saving potential. The progressive introduction of smart appliances and home automation features, available thanks to the diffusion of the two-way communications between the consumer and the electricity supplier, will dramatically change the energy consciousness of the consumers. Information and consumer awareness campaign may be necessary to allow the full understanding of the opportunities offered by smart grids in terms of innovative services, energy saving, sustainability and quality of supply. Educating consumers about the benefits of smart meters, demand-participation opportunities, distributed generation and other smart grids technologies is essential to customer adoption. Actions should be taken to help users (households, electric utilities, industrial facilities, commercial entities, etc.), understand the value and the implications of smart grids working with electricity and equipment suppliers to overcome public misconceptions about smart grids (e.g., that AMI is the only relevant technology). This education process should be carried out by means of scalable, adaptable communications models publicity campaigns that can help increase public awareness and engagement. It may be useful, in this respect, to create and implement at countries level a sort of city-to-city competition that engages policy-makers, energy consumers, local utilities, and other relevant stakeholders to implement key aspects of the smart grid (demand response, electric storage, smart grid-enabled home appliances, electric vehicles, etc..) towards a perspective of future smart cities. Moreover, understanding the consumer needs and expectation from smart grids should also be undertaken, to avoid misalignments.

J. Build up on regional skills and excellence

The network development will be possible only if the necessary professional skills will be made available: human resources having a power engineering education and training are at present not sufficient to guarantee the necessary professional turnover. The question of required skills and knowledge has to be dealt with in the context of a multidisciplinary approach, integrating all relevant technical, social and energy policy aspects implied by new electrical systems based on smart grids. It is therefore recommended to support new education programmes through universities and institutions and to favour skills exchanges between ongoing smart grid programmes.

The discussions held during the mission in Latin America showed a very clear attitude of local engineers towards innovation based on very practical and direct approach. This natural skill to address problems and projects using a very pragmatic approach and setting up solutions characterised by simplicity, cheapness and reliability may be used also for addressing smart grids and their application in developing countries.

V. The way forward

The development and roll-out of smart grids technologies is not a goal per se but a means to achieve the objectives of an accessible, reliable and sustainable electricity supply. We have expressed in several occasions that no smart grids definition and solution fits all situations: priorities are given in one region to the diversification of the energy mix through the integration of large scale or distributed generation, in other situations the primary focus is the enhancement of the performances of the transmission network, in other circumstances to the demand participation issues. Yet, smart grids contribute to all these aspects in an integrated manner: the ICT layer, for example, serves the scope of any smart grids configuration, as well as the electronic meter, at the base of any significant evolution at the distribution level. In the specific case of Latin America, among all possible objectives that can be achieved with smart grids technologies we may focus the attention on two of the characteristics observed in the analysis of the local situation: i.e.:

- the urgent necessity for a reduction of network losses;
- the energy management of mega-cities.

With these premise, it is important to interpret the above recommendations in view of setting up practical actions, involving all the stakeholders of the system. As for the first objective:

Summary of recommendations for the development of smart grids technologies in Latin America and the Caribbean region:

Recommendation	Actions
Develop regional and national road maps for smart grids	As already mentioned in the recommendation, the vision of the smart grids application must take into consideration, among others, the potential to reduce technical and non-technical losses. The roadmaps shall moreover define the priorities of development and application of related grid architectures, components and technologies, identify the barriers and the actions to overcome them, and propose timetables for investments and actions, for each of the stakeholder involved. CEPAL, as the core actor in the support to local governments having implemented a wide continental project on energy efficiency, could play an important role in the coordination of formats and methods for the assessment of the roadmaps.
Develop a policy framework to promote smart grids	The legislative and policy framework mentioned in the recommendation, developed at the different responsibilities level, could be focused on the reduction of losses: smart grids technologies should be considered by municipalities and local governments as key enablers of smarter and more sustainable cities, characterised by a higher quality of life to which smart grids and the related technologies can give a substantial contribution. National governments and public policy makers should elaborate more general strategies considering also the accessibility to electricity and the sustainability of its cost. Here again, CEPAL can have an outstanding role in assisting governments in the definition of the policies.

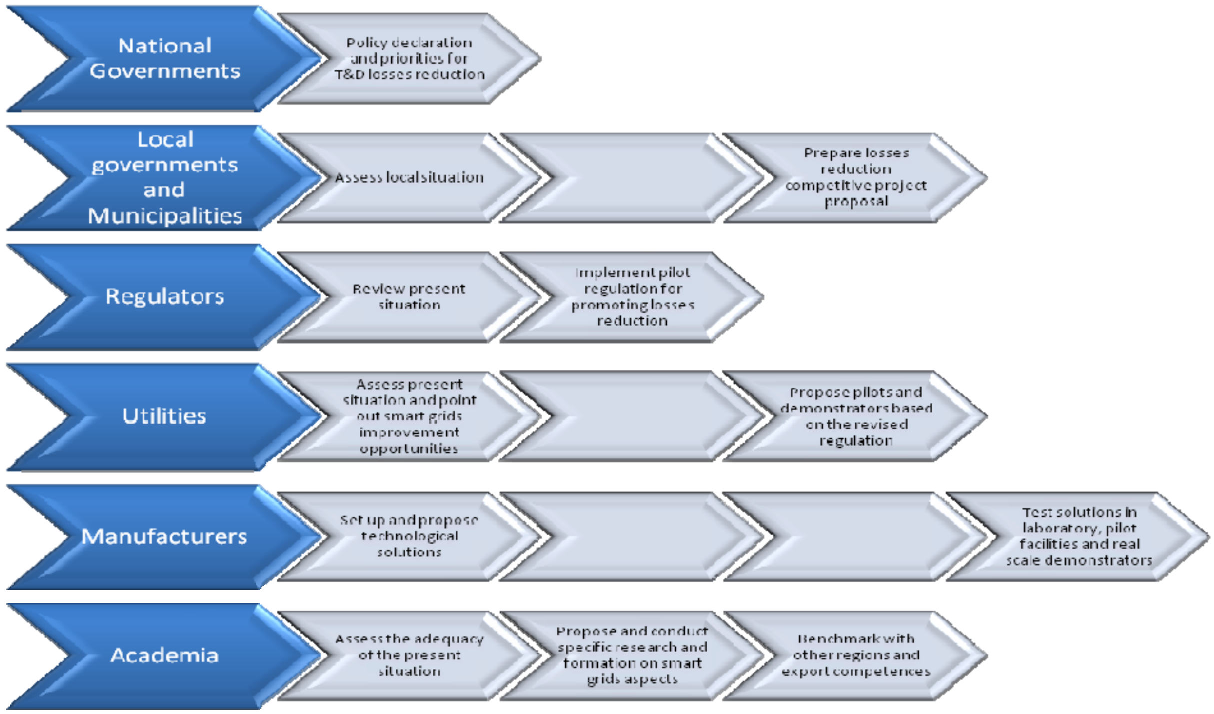
Adapt the energy regulation and financing schemes to promote the deployment of smart grids	Revenue models and incentive schemes for the network operators should be created to encourage stakeholders' investments in smart grids: in particular, remuneration mechanisms should be set up to promote the adoption of innovative network solutions to reduce losses and to sustain research and demonstration.
Create, collect and disseminate business cases	Network losses values differ substantially from one LAC country to another: from less than 5% in Chile to more than 40% in Ecuador. Business cases for losses reduction are therefore very different depending on the specific situation of the country, in terms of pro-capita electricity consumption, network conditions, societal aspects etc. Cost-benefits estimations must be carried out considering also the potential of changes in energy regulation. A LAC permanent forum for the coordination of information resources on financing mechanisms and economic data about the development and deployment of smart grids technologies to achieve a substantial reduction of losses shall be implemented.
Develop and demonstrate smart grids technologies	Smart grids architectures and technologies can play an outstanding role in the reduction of network technical and non-technical losses. Smart meters installed at the user premises and in the primary and secondary substations can be used for assessing energy balances, point out potential problems, and monitor the power flows in each network node, thus revealing the existence of unbalances, harmonics, reverse flows etc that may decrease the losses performances. Innovative network topologies, characterised by shorter and more efficient lines (higher distribution voltage, DC distribution, presence of distributed generation, meshed distribution systems, demand-side participation etc.) can substantially contribute to the reduction of losses and shall be experimented in the laboratories, testing facilities and on the real field. Innovative components such as amorphous-core transformers, electronic transformers, static switches, power electronics can be experimented and used in pilot projects and demonstrators to prove their potential for network losses reduction. Advanced communication schemes can be identified and tested to help follow this implementation. A Latin America technology strategy shall be developed to work in line with the international for a already existing and sharing information, based on the specific local skills and knowledge that will be developed building upon the experience of network losses reduction accumulated in the region.
Demonstrate and deploy distribution network automation and smart meters	We have already mentioned the key role that smart meters may play in the process of reduction of network losses, both in terms of energy balance capability but also for what pertains to the demand-participation aspects. Medium to large scale test cases for the demonstration and deployment of smart meters and network automation should be selected, covering an extensive range of situations, in terms of regulation, society, network conditions, environment etc. to prove and contextualise the technologies, their integration and the potential of losses reduction in the specific LAC country situations
Share best practices and know-how	Collaborative activities shall be encouraged in the different LAC countries to focus on the potential of smart grids for losses reduction. Special attention shall be given to knowledge sharing and common local know-how build-up. A repository with past and on-going R&D, pilot, and full-scale projects shall be implemented covering all Latin America countries.
Promote standardisation	Promote in all phases of the development, application and integration of smart grids technologies the use of international standards, especially in the field of ICT, supervision and control. Attention shall be focussed on the security of communications infrastructure and data privacy.
Engage public awareness	Develop and implement scalable, adaptable communications models and publicity campaigns that can help increase public awareness and engagement on the network losses and the reduction potential that can attained by means of smart grids technologies.
Build up on regional skills and excellence	Create a network of LAC universities and institutes that can develop and test local ways of using smart grids technologies and architectures to reduce losses. This competence will be very valuable at local and international level to build up a local specialised skill that can export knowledge and methods in other parts of the world, with special reference to developing countries.

Source: Author's elaboration.

All these actions run in parallel and inter-relate with one another.

Should we imagine an action plan evidencing the role of each stakeholder we would propose the following interrelations:

FIGURE 38
FRAMEWORK OF ACTIONS FOR THE DIFFERENT STAKEHOLDERS IN VIEW OF THE DEVELOPMENT OF SMART GRIDS IN LATIN AMERICA AND THE CARIBBEAN REGION



Source: Author's elaboration.

It is to be noticed that the way towards the achievement of this goal requires the development and deployment of most of the smart grids technologies: therefore, after full roll-out of the technologies, a network characterised by reduced losses will look like a smart network very much like a network characterised by the integration of DG and/or with demand participation. All smart grids technologies contribute to the achievement of multiple network efficiency, flexibility and sustainability goals.

As for the second aspect (i.e. mega-cities), specific Latin American competitive projects may be developed identifying the main goals to be achieved by means of the deployment of smart grids technologies in the very large Latin American cities, such as, for example, demand response, electric storage, smart grid-enabled home appliances, electric vehicles etc.

A. The first achievements of ECLAC study: smart grids demonstrators in Latin America

1. Smart grids initiatives in Chile

Energy efficiency is at the core of the Chilean government's energy strategy, as clearly stated in the document "Estrategia Nacional de Energía 2012-2030" published by the Ministerio de Energía on February 2012. The same document also indicates the development of distributed generation, smart metering technologies (focusing on Net Metering) and smart grids as a target.

The Enel Group, leveraging on the European experience gained in the field, is already testing under real working conditions these innovative technologies in Chile, in line with the national regulatory plan.

On September 2011, Chilectra started the first project of smart metering in Santiago. At the startup, the equipment was installed in homes and a common point in the "Los Almendros" suburb, in the area of Huechuraba in Santiago. To December 2011, new customers in the areas of "Bosques de La Pirámide" and "La Pincoya El Barrero" have joined the Chilectra smart metering program.

MAP 13
FIRST PROJECT OF SMART METERING IN SANTIAGO

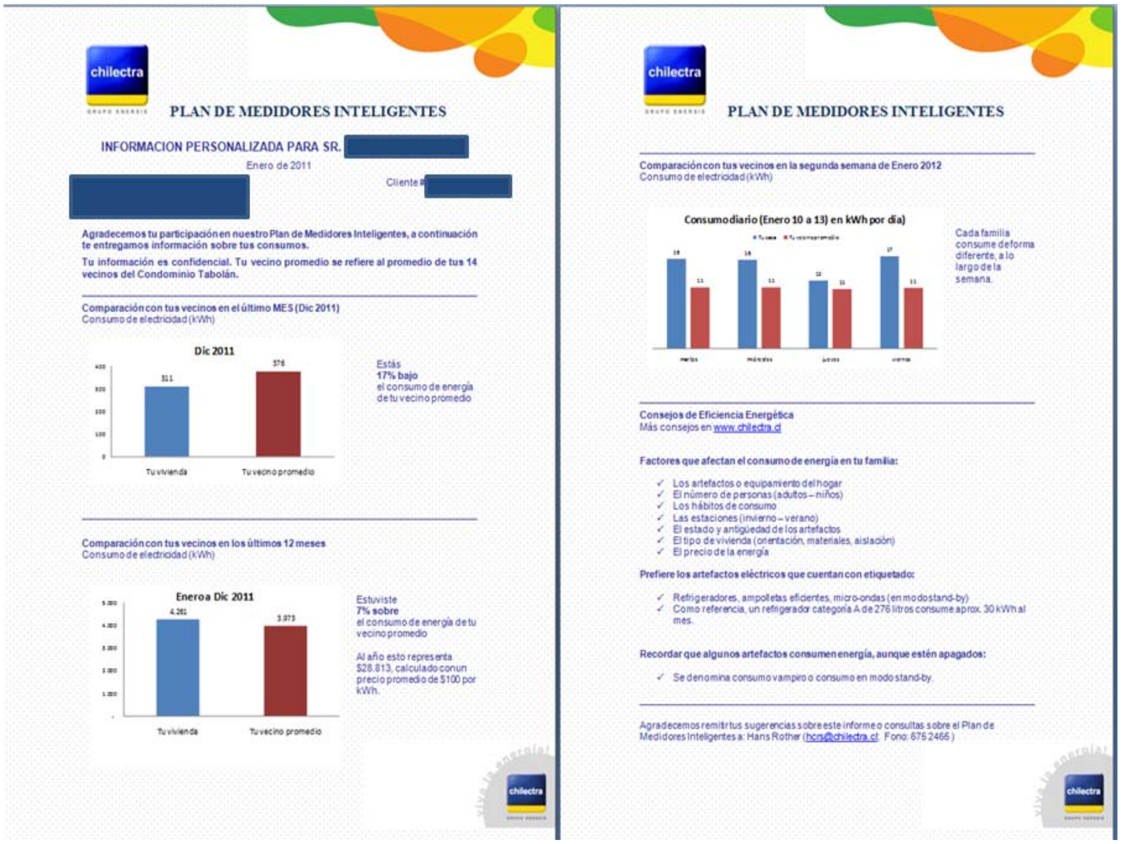
Source: Chilectra.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

Smart Metering constitutes a radical change in the Latin American energy market. In fact, those smart meters allow to manage the bidirectional flow of energy because customers (families and small enterprises) can also install in their houses or for their business the technology needed to produce energy from renewable resources. The consumers can now take decisions on their consumption, because they are more informed about energy efficiency.

Chilectra is supporting the project through a communication campaign aimed at raising awareness in the customers involved, by also sending letters about their energy consumption habits.

FIGURE 39
COMMUNICATION ON THE PLAN OF DEVELOPMENT AND INSTALLATION OF ELECTRONIC METERS BY CHILECTRA



Source: Chilectra.

The smart meters installed in Chile are the same that Endesa is now installing in Spain. Those smart meters leverage on the experience that Enel has proven in Italy since ten year. The Enel Group smart meters have been certified by the Superintendency of Electricity and Fuels-SEC (Res. 1851 July 12, 2011). Chilectra's focus on remote management technology is further reinforced through its recent membership in the Meters and More association, created by Enel and Endesa in 2010.

Smart Metering is the backbone of the smart grid. To demonstrate the benefits of the new network technologies in an urban area, Santiago and Búzios (in Brasil) have been selected by Enel Group, as living labs of Smart grids technologies. Those initiatives integrate in an innovative urban paradigm energy efficiency, by promoting both environmental and economic sustainability: services and technologies together with the public and private sector contribute in saving energy and reducing CO2 emissions.

Smart grids are key to the development of more sustainable energy systems.

The Smart City Santiago project consists in providing state of the art technologies. The area located between Calle Santa Clara and Avenida El Parque has been selected for developing the first phase of the project. The initiative has the objective of attracting the interest of citizens and local authorities on the benefits provided by the introduction of advanced technologies (e.g. smart metering, remote control and automation of Medium Voltage network, efficient public lighting).

The project includes:

- Smart Metering
- Remote Control and Automation of Medium Voltage network

- Technology solutions enabling active demand
- Efficient public lighting
  - Installation of LED lighting
  - Installation of Video Surveillance Cameras
  - Installation of LED traffic lights (pedestrian countdown type)
  - Wireless communication (free WiFi hot spots)
  - Ornamental landscaping lighting
  - Cellular Antennas for broadband signal transmission
- Electric Vehicles
  - Charging System for Santiago Inteligente
  - Electric Taxi and electric buses

Santiago is actually one of the first cities in Latin America supporting the diffusion of electric mobility. Chilectra is offering to its customers a positive experience to refill their cars in a sustainable, green and safe way by accessing charging stations efficiently integrated in the smart grid. The recharging infrastructure developed by Enel is exploiting the experience gained in Italy and Spain during the last years and monitors customers' behaviors, enabling the very first e-mobility market analysis.

MAP 14
ELABORATION ON THE RECHARGING INFRASTRUCTURES FOR ELECTRIC VEHICLES IN CHILE

Source: Enel distribuzione.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

2. Smart grids initiatives in Brazil

In Brazil, Coelce has successfully carried out a smart metering project in Fortaleza, installing 100 Enel Group smart meters and 2 concentrators in the areas of Parquelandia and Aquiraz. It is scheduled a second project on Ampla's network in Niteroi (Rio de Janeiro).

FIGURE 40
DEPLOYMENT OF METERS IN FORTALEZA

Source: COELCE.

Moreover, Enel Group supports Ampla in the design and implementation of Cidade Inteligente Búzios project, a smart grids program aimed to promote sustainability and energy efficiency. Through this project Búzios, a touristic seaside city in the state of Rio de Janeiro, will become a model for energy efficiency management. Structured as a living lab to test new technologies and services among 10,400 customers, the project Cidade Inteligente Búzios also intends to support the Brazilian Government on defining specific laws for smart metering and all its related functionalities. The project, co-funded by the Brazilian Regulatory Agency – ANEEL, should last 3 years. The first step has been the installation of an efficient public lighting system (Archilede by Enel Sole) around the lake, guaranteeing energy savings and improving safety of the citizens.

Additionally, other important technologies are going to be implemented. Smart meters for all costumers, self healing for medium voltage network and distributed generation, as Búzios has a good potential for renewable energy (solar and wind). The project deployment also include electric vehicles and intelligent buildings that will enable customers to manage their consumption in real time and remotely activate their appliances. All technologies will be integrated by a strong telecommunication system.

FIGURE 41
DEPLOYMENT OF METERS AND DISTRIBUTION AUTOMATION IN BUZIOS

Source: Enel distribuzione.

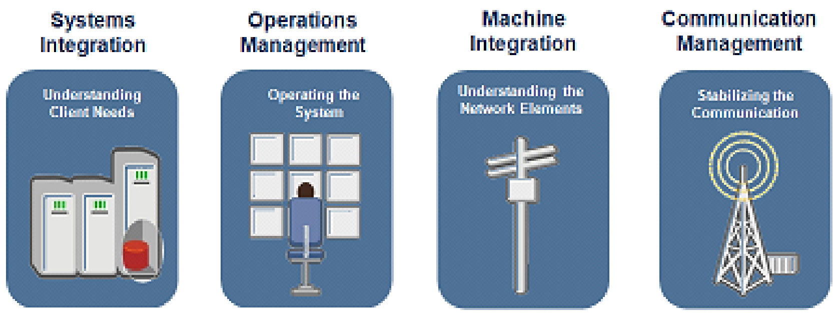
Ampla has developed the Ampla Chip technological solution to reduce the high levels of energy theft that the utility was facing in the state of Rio de Janeiro. The Ampla Chip is an advanced metering system including meters and concentrators that are installed not to be accessible to fraud purposes (installed at the top of the pole).

FIGURE 42
INSTALLATION OF ANTI-DAMPING METERS IN BRAZIL

Source: Ampla.

Up to this date Ampla has invested more than R$768 million (US$432 million) and has installed the technology solutions for more than 540,000 customers, this is the biggest case of smart meters in Latin American with more than 15 million commercial operations monthly.

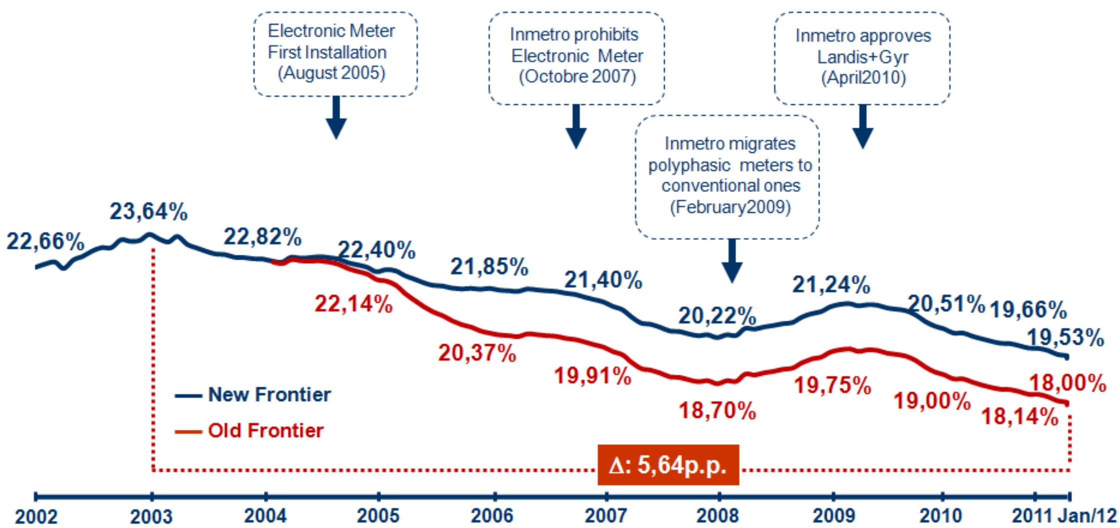
FIGURE 43
FEATURES OF SMART GRIDS APPLICATIONS IN BRAZIL



Source: Ampla.

The energy losses has been reduced from 60% to 10% where Ampla Chip technology is applied. Losses have reached the lowest levels in the company's history (reduction of 5.64 point perceptual since 2003).

FIGURE 44
TREND OF LOSSES DURING THE APPLICATION OF AMPLA-CHIP



Source: Ampla.

Ampla Chip has been awarded by the Metering International's Excellence Awards for Latin America in 2011 and elected as the most important innovation in the last ten years in Brazil by *Exame Business Magazine* in 2008.

3. Introducing a smart grids regulatory framework in Panama

The Secretaria Nacional de Energia de Panama (SNE) has acknowledged the importance of the potential of smart grids as an enabler for the National Energy Strategy in terms of integration of renewable energy sources, enhancement of the energy efficiency policies, integration of distributed generation, rational use of energy, development of smart buildings, integration of electric mobility, etc.

It is the intention of SNE to conduct a study on the legislative, regulatory and operational actions that need to be undertaken to progressively adopt smart grids concepts and technologies in the electricity distribution system of Panama. The study will leverage on the survey carried out by CEPAL and focus on the specific situation of Panama which is characterized by the open market situation, covering the following aspects:

- Identification of the main national policy drivers that can constitute the base for the electricity system evolution towards smart grids;
- identification of the smart grids concepts and technologies that would best respond to those drivers;
- identification of the barriers for smart grids development in the region and assessment of the possible solutions to overcome the barriers;
- highlight of the legislative tools oriented to the mentioned drivers, already present in the local legislative framework regulating the electricity sector and the energy efficiency;
- identification of the amendments to the present regulatory regime that would be necessary to implement the smart grids concepts and technologies and the related projected costs and benefits;
- indication of aspects to be taken into account in the formulation of the new calls for proposals for the electricity distribution licences.