Implementation Schemes of Smart Distribution Grids at the 2025 Horizon

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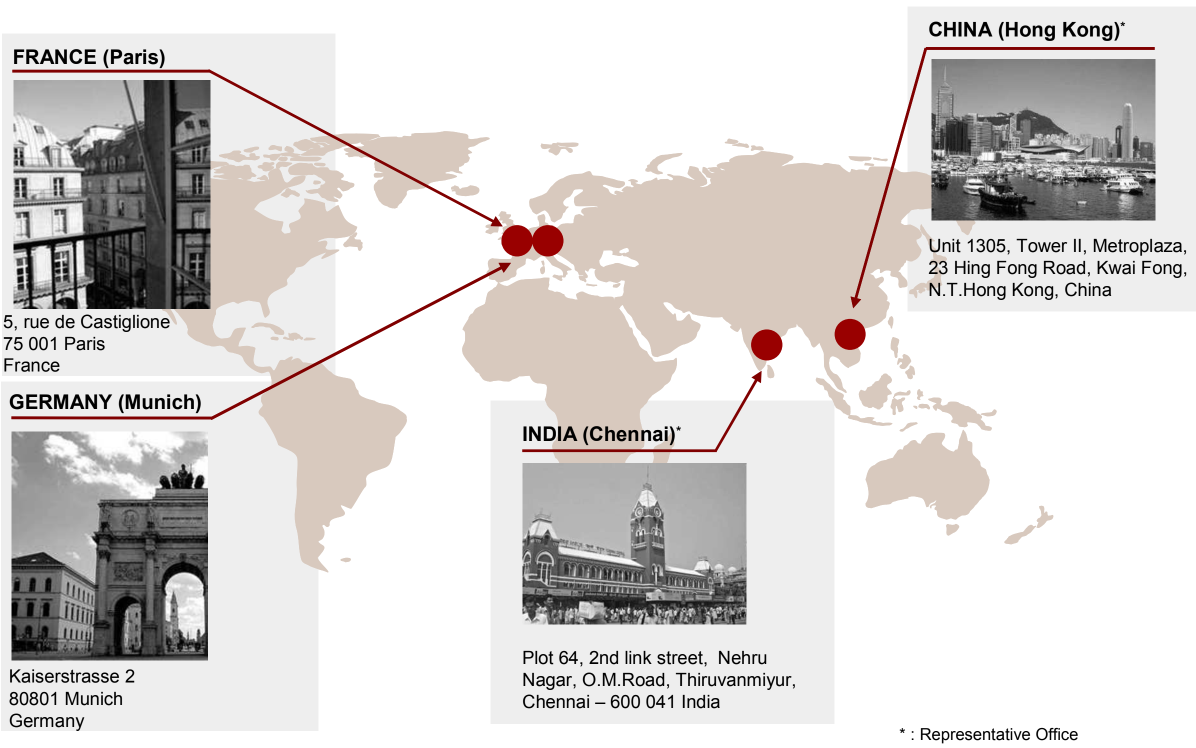

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Abstract

Electric grids are currently facing new challenges: increasing demand, large scale insertion of renewable resources, emergence of electric vehicles, etc. Achieving new ambitious goals using traditional grid conceptual approach requires considerable investment[1)]. The Smart Distribution Grid concept emerged as an alternative to bulk replacement of assets thanks to more automation, IT and telecommunication in the grid, therefore optimizing required investments.

Many global studies have been realized on smart grids potential, with different perimeters and objectives. All of them agree on two conclusions: the market is huge (hundreds or thousands of billions € worldwide) and Smart Metering will be the trigger application.

Smart Distribution

Making the distribution smarter will require shifting from a traditional "fit and forget" approach, where consequences of interventions on the grid were barely observable, or observable only after a long duration, to real-time monitoring. In a Smart Distribution Grid, thanks to telecommunication, information from sensors on the network is analyzed in an advanced DMS/SCADA[2)] system, which then remotely controls several assets on the grid (transformers, feeders, switch, etc.) to optimize the power flow and therefore enhance efficiency, stability and reliability.

If Smart Metering is the first of all smart grid components to be deployed, Smart Distribution (as a central node connected to final customers, distributed generation and storage) is the next sweet spot and our study's focus : our research establishes that the world investments in smart grids at the distribution level should reach over 150b€ by 2025.

Our objectives also were to break-down these potential investments into technical solutions (sensors, switches devices…) and enablers (IT, telco…). Our approach has been to rationalize these investments either as a "business case" or as a "rate case". Three configurations were analysed in our model: 1– investments relying on a pure economic rationale (*e.g.* smart grids investments reducing maintenance expenditures); 2– investments that found economic rationale through valorisation of externalities (*e.g.* CO2); 3– investments required by regulators or public policies (*e.g.* insertion of renewable generation or Electrical Vehicles).

Multiple interviews have been conducted with different stakeholders (DSOs, T&D, IT and telecom OEMs, etc.) around the world in order to calibrate our underlying quantitative model. A regional approach has proven to be essential to understand smart grid investments due to strong local specificities on grid quality and regulation objectives. Disparity in electricity regional contexts will lead to different implementation schemes. Three distinctive patterns have been identified:

- **Quality Catching-up**: a common pattern in North America where smart distribution grids are a response to aging networks, by differing or avoiding expensive replacement thanks to a better understanding of asset condition,
- **Environmental Challenge**: the main drivers are minimizing the carbon footprint, integrating more new green energy resources at the distribution level and dealing with bidirectional power flows as opposed to traditional networks were radial structures developed around large power plants with unidirectional power flows,
- **Technological Leap**: in developing countries the smart distribution grid is a disruptive opportunity to: keep pace with the economic growth, massively improve quality of service and reduce non-technical losses for a limited cost and shorten deployment time compared to standard investments.

1) In Europe, T&D upgrades needed by 2030 will be worth 500 b€ of investments according to European Smart Grids Technology Platform (ESGTP) [2006]

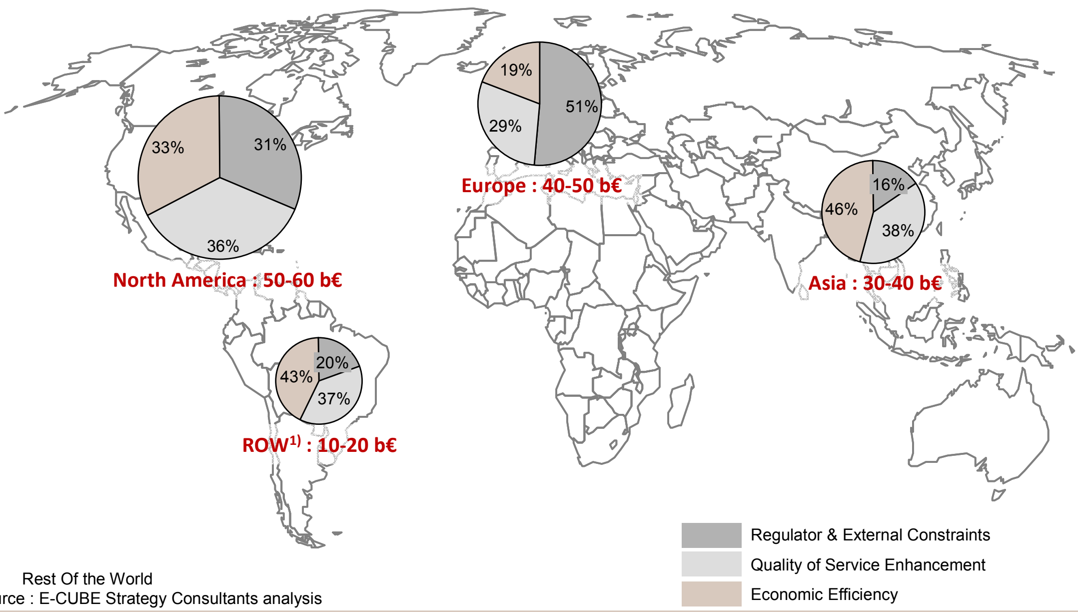
2) Distribution Management System / Supervisory Control And Data Acquisition

Global Overview: Investments to implement Smart Distribution Grids[1)] should reach up to 150 billions € worldwide by 2025

Distribution used to be a passive connecting segment between transmission and customers in the former one-way electricity value chain. Now, distribution is becoming a central node of the grid that is bound to integrate new functions and actors (distributed generation, distributed storage, energy balancing, electrical vehicle charging infrastructures, etc.). However, compared with transmission, which is usually considered "smart" thanks to advance monitoring and automated control, one could qualify distribution networks as "blind" if not "dumb". For example, most DSO only know when an outage occurs when disconnected customers call to report it. Smart metering emerged as the first step to build a smart grid; massive implementation is underway (EU target is 80% of equipped households by 2020). If smart meters can provide useful information to pilot the network, it is mainly a new interface between DSOs and customers that reduces metering costs and informs the client on his consumption. Therefore, E-CUBE decided to focus its investigation on smart grids at the distribution level, from HV/MV substations to the smart meter (the meter itself being excluded). The following study aims to give a better understanding of applications supported, enabling technologies, expectable implementation and possible investments in the next 15 years.

Compared to the 5,000 billion $ investment in T&D sector by 2030 forecasted by the IEA, the incremental costs for smart distribution grids are moderate. Actually, smart grids at the distribution level will be a revolution of the approach, but only an evolution of the assets. The prevalence of one driver is noticeable in each area and will therefore lead to different implementation schemes. A large part of the worldwide investment will focus on North America, where the need for smart grids is more urgent to avoid an unacceptable drop in the quality of service, while investments needed to renew the grid should be optimized. Europe will attract more than 40 billion €, mainly to facilitate the achievement of the ambitious 20/20/20 commitment. The current passive network should evolve to actively integrate intermittent renewable energy sources.

Illustration 1: Incremental Investments to make the distribution smarter by area and by drivers (2010-2025 cumulative estimation)

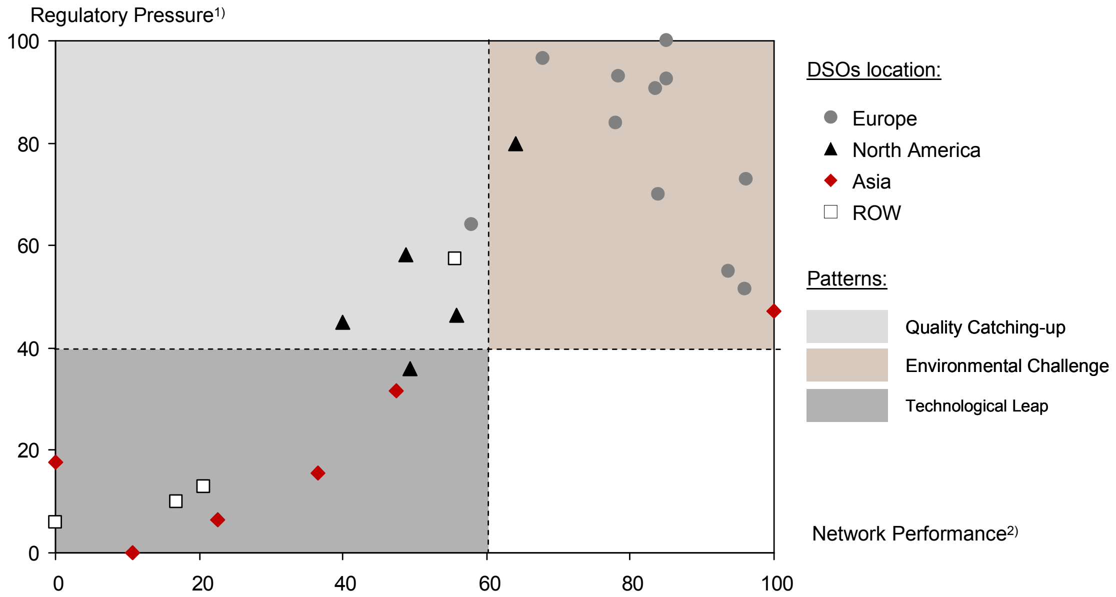


1) Rest Of the World
Source : E-CUBE Strategy Consultants analysis

1) These investments are incremental to capital expenditures required by "business-as-usual" networks growth. Smart meter investments are not included in these forecasts; however, whenever smart meters are deployed, we integrate investments related to piggy-backing applications.

Meanwhile, in Asia and in the rest of the world, smart grids by 2025 will mainly emerge in cities and urban areas where benefits are directly observable[1].
Technologies and applications implemented will obviously depend on DSO's specific operational and regulatory context (incl. public policies). To better understand the breakdown of these investments, we focused our research on three contrasted patterns.

Illustration 2: Smart Distribution patterns



1) Rating from lowest (0) to highest (100) regulatory pressure based on investments required by "Regulator & External Constraints" as of E-CUBE Strategy Consultants model's output ("Regulator & External Constraints" based on officially communicated performance commitments and direct interviews)
2) Rating from worst (0) to best (100) based on service interruption duration and distribution losses 2005-2010
Source : World Bank, CEER, DSO Corporate Communication, E-CUBE Strategy Consultants analysis

Developing an understanding of distribution grids specificities on a local base is essential when it comes to smart grids

Analysing smart grids at a regional level is key as technical specificities, public policies and regulatory frameworks dramatically vary around the globe and will result in different implementation schemes.
For instance, customer density and grid architecture choices related to low and medium voltage network split – three to four customers on a single MV/LV transformers in California as compared with several dozens in most European Countries – affects smart meters communication choices between radio and PLC.
Energy policies focus (renewable energy insertion, Electrical Vehicle Development, competition facilitation, rural access to energy…) or local authorities requirement (energy efficiency, microgrids…) will shift investment priorities.
Regulation frameworks, whether "cost+" or "asset-based", will drive DSOs behaviour and technical choices, smart grid solutions allowing arbitrage between CAPEX and OPEX.

E-CUBE Strategy Consultants' quantitative model evaluates investments as a function of these local specificities. The model is based on an investment cost optimization for each DSO considered, taking into account descriptive features (current QoS, km of lines…) and scheduled development (smart meters implementation roadmap enabling low voltage monitoring…). Investment costs are optimized under external constraints resulting from public energy policies and regulatory framework (ex: objective of a minimum SAIDI reduction). Externalities are valued based on conventional costs whenever applicable (ex: cost of undelivered energy due to outages).
To assess local specificities, desk research was

1) Cities like Shanghai, Delhi or Masdar City are technological showcases and catalysts for smart grids technologies

completed with extensive interviews with DSOs and OEMs representatives and with academics. DSOs selected for analysis, were considered representative on a regional scale: regional investments were therefore derived by triangulation of investments as estimated by our model on these DSOs.

Smart grid solutions are multifunctional making it difficult to develop a separate analysis for each solution: the optimization was therefore run globally for every smart grid solutions.

We also assume that at a 2025-horizon, no smart grid solution will change the distribution network from a radial to a matrix architecture.

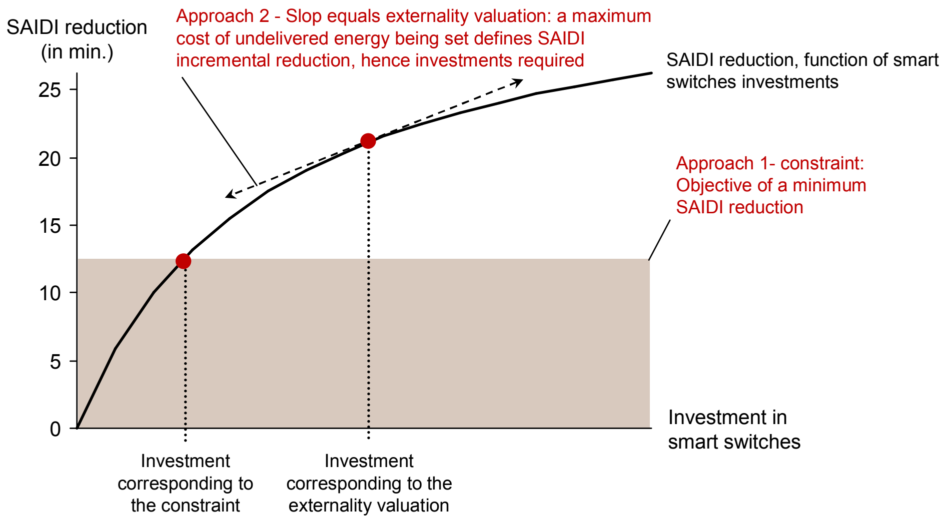
We identified four groups of smart grid solutions:

- **Switching devices**: Connected and remotely actionable grid switches,
- **Substation automation & voltage control**: Dynamic Line Rating, FACTS,[1)]
- **Sensors**: Voltage, Phase, current, outage sensors,
- **Distributed storage**: Feeder centralised storage (ex : NaS, Redox), consumer distributed storage (Electric Vehicles),

and two groups of enablers, used and shared by the different smart distribution grid solutions:

- **IT**: Data centres and software, GIS[2)], SCADA[3)], DMS[4)], Smart operational team dispatch, Optimized preventive maintenance,
- **Telco network**: PLC[5)] infrastructure, GPRS.[6)]

Illustration 3: Illustration for SAIDI of constraints and externalities integration in investment modelling



Source : E-CUBE Strategy Consultants analysis

Quality Catching-up: North-American aging networks

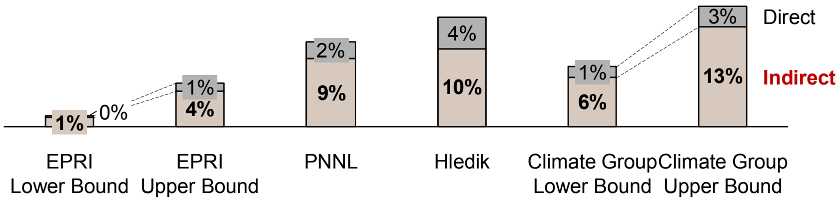
Improve or stabilize the degree of quality of service at minimal cost

Underinvestment in the power grid during recent decades brought the quality of service down with high rate of failure and outages significantly impacting the economy. The Department of Energy estimated power outages and interruptions impact on American business to at least $150b yearly. Revamping the grid thanks to smart distribution is the cheapest way to prolong life of ageing assets (the average US transformer age is around 40 years old) while keeping an acceptable level of quality[7)] and provide new services like electric vehicle charging.

1) Flexible Alternating Current Transmission Systems
2) Geographic Intervention System
3) Supervisory Control and Data Acquisition
4) Distribution Management System
5) Power Line Communication
6) General Packet Radio Service : a standard mobile phone radio protocol
7) With present maintenance system, instantaneous failure rate jump from 25 % for 40-year-old transformers to 50 % for 50-year-old ones (William Bartley, The Hartford Steam Boiler Inspection & Insurance Co.)

CO_2 emissions reduction: a collateral benefit of Smart Distribution

Smart Distribution will help to reduce carbon emission either directly, at the grid level, and indirectly, by facilitating green applications integration. For example, technical loss reduction, thanks to power factor optimization, advanced transformers or *in situ* consumption, will directly make the grid greener. On the other hand, distributed Renewable Energy Sources integration and Electric Vehicles implementation relies extensively on Smarter Distribution, while DSOs do not draw any direct remuneration from their services. Future regulations should take into account these collateral impacts of distribution and give fair incentives to DSOs.



CO2 emissions reduction estimations in the U.S. thanks to Smarter Distribution (DOE/EIA 2030 Reference Cases)

Source : PNNL

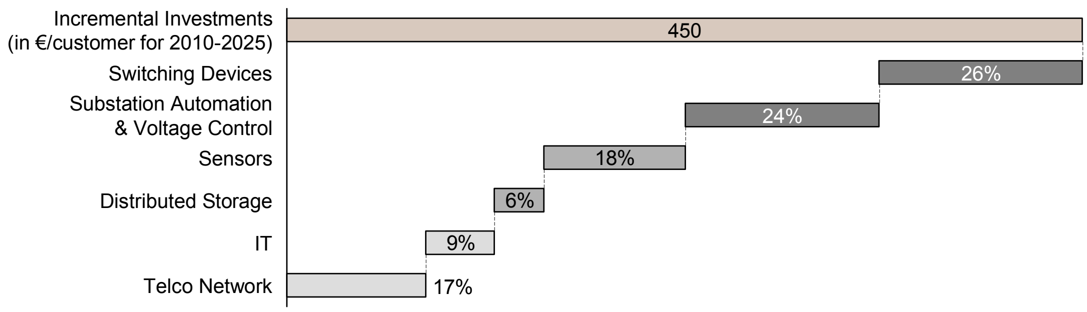
Sensors installation and condition-based maintenance to optimize expenditures

Advanced monitoring (nearly 20% of forecasted investments) of the network will help DSOs to identify the weakest spots in the network and conduct optimized replacement. A better understanding of the energy flow, paired with an adaptive topology, will relieve stress on fragile assets. Also, thanks to a condition-based maintenance, the assets' life span can be extended while the quality of service is increasing[1)]. Recent experiments showed quick enhancement of the reliability after such implementation and consequently a reduction in operation expenditures. As a side-benefit, the growing numbers of successful projects will reduce the regulators' demands for demonstrative pilots before massive implementation of such solutions in the future. As smart grid solutions are multi-functional, collateral benefits will also come from advanced monitoring, like quicker outage detection, better customer information and higher renewable energy sources penetration. Because customer density is low in some areas, the implementation of a telecommunication networks will catch a significant part of the investment.

Massive investments focused on high density areas

United States will be the biggest market for smart distribution solutions during the next 15 years, mainly driven by the urge to keep an acceptable degree of quality. In 2009, the Obama administration tackled the issue head-on by announcing $3.4 billion in investment to support smart grids development. A majority of granted pilot projects are focusing on smart metering. However, states like New York, with ambitious renewable portfolio standards (29% by 2015), are testing distribution automation technologies. Because each state has its own public utilities commission and renewable standards, disparity in the smart distribution implementation will appear between states.

Illustration 4: Estimation of Smart Distribution investments breakdown for the "Quality Catching-up" pattern – Example of a North American Integrated Electric Utility



Source : E-CUBE Strategy Consultants analysis

1) Risk of unexpected station transformer failure can be reduced by 2.5 fold (based on a CIGRE study)

More over, smart grids initiatives will first take place in cities where high urban density guarantees superior benefits, while rural areas will bridge the quality of service gap more slowly.

Environmental Challenge: renewable energies and CO_2 reduction commitments in Europe

Distribution network ability to integrate intermittent energy sources while maintaining stability

For many countries in Europe, the main driver for smart grids investments is the need to integrate 20 % of Renewable Energy Resources (RES), one of the 20/20/20 commitments. For example, to reach this goal at the national level, Portuguese electricity industry must integrate 45% of RES by 2020 (30% was reached in 2007). Other European countries like Spain proved that financial incentives can rapidly increase the penetration of distributed renewable generation[1)]. In this context, European distribution networks, originally designed for one-way power flow, have to evolve quickly to integrate massive intermittent distributed generation on the low voltage (LV) grid in order to avoid potential quality and reliability issue.

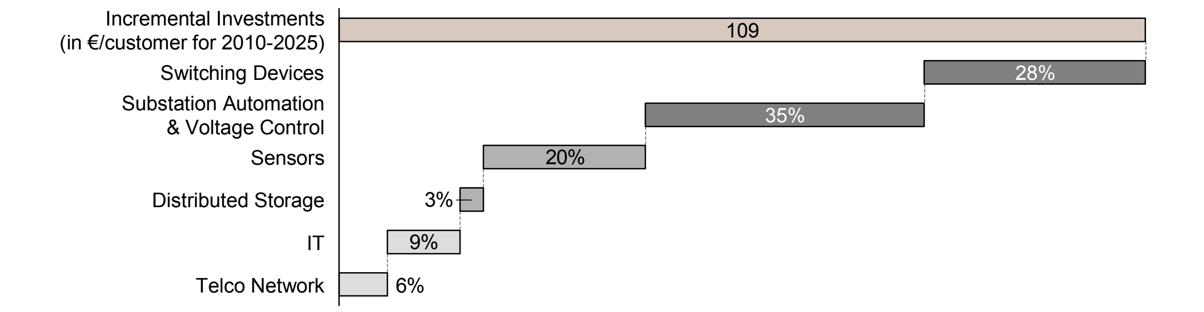
Automated voltage control and sensors installation will ease massive RES penetration

Collecting information from smart meters, installing sensors on parts of the grid currently blind, will increase visibility at the LV level. This, combined with automated Volt/VAR control on feeders and distributed generation sites, will help to reach renewable energy goals in the next decade. Distributed storage will also be effective to contribute to RES insertion. Current costs are nevertheless too high to expect significant implementation in the near future. Obviously, European smart distribution development will rely more on a policy and social-welfare case than on an economic case – policy constraint and quality of service requirements will generate 80% of the total smart grid investments in Europe. Eventually some additional benefits will come from deferring, avoiding and optimizing investments. Full benefits of smart replacement of ageing assets will be observed only in some decades because aging processes are not fully understood today. Substantial savings are expected in a longer term by optimizing network design thanks to smart grids instead of bulk business-as-usual replacement[2)].

Regulation will also drive smart distribution roll-out

As relevant technologies emerge, the other trigger to smart distribution large scale implementation will be regulatory framework adaptation. For instance, in most regulated

Illustration 5: Estimation of Smart Distribution investments breakdown for the “Environmental Challenge” pattern – Example of European Electric Utility



Source : E-CUBE Strategy Consultants analysis

1) + 352% in PV capacity installed between 2007 and 2008 in Spain (Photovoltaic Barometer “EurObserv’ER” Project)
2) According to the Danish DSO, DONG Energy, estimated capital savings on planned grid reinforcements of up to 90%, when smart grids functionalities will be fully implemented

tariffs, network revenues are directly based on volumes of distributed energy; therefore, DSOs receive no incentive to facilitate energy efficiency via smart grid solutions. One could also considere unfair that, in a European unbundled electricity sector, investments in the distribution network, bringing benefits to different stakeholders on the value chain (from generators to energy service companies), should be carried by DSOs only. Moreover, shifting from mature technologies (electro-technical equipment) to innovative solutions (including IT and telecommunication) is perceived as a risky strategy by DSOs; acknowledging this risk in regulated rates of return would be a lever to promote disruptive technologies.

Electric Vehicle batteries grid insertion: a dramatic threat and huge opportunity

"Electric vehicles, deployed in mass volume, and unmanaged represent a tremendous threat to the stability of the grid. Electric vehicles, deployed in mass volumes and intelligently managed by a utility or network operator represent a huge opportunity to add grid stability and versatility, and exploit the storage capacity to stimulate private investment in intermittent renewable electricity."
Jon Wellinghoff, FERC Chairman

	Unmanaged Charging	Off-Peak Incentives	Managed Charging
Additional Distribution Cable (% of the current grid)	4.9 %	3.6 %	**0.6%**
Corresponding Distribution Investments (€/car)	1450	1060	**190**

Israel case study:

- 2 millions EV for 2.4 millions DSO customers
- All things being equal, 5% cable's growth is equivalent to 3-years investments

Source : Israel Electric Corporation, E-CUBE Strategy Consultants analysis

Technological Leap: a disruptive opportunity to quickly improve service quality and keep pace with

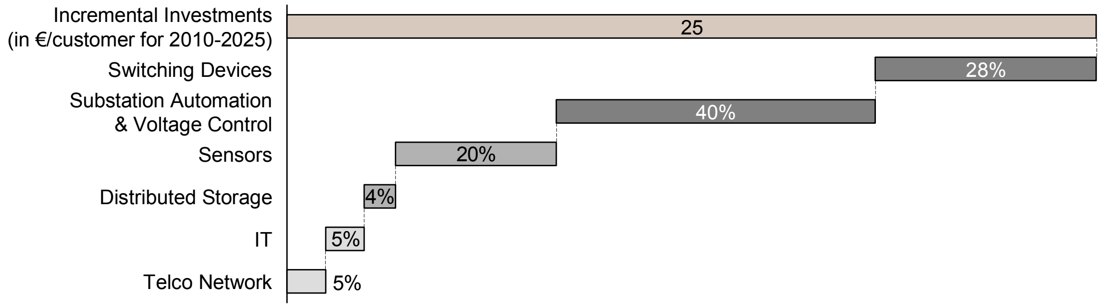
The challenge to both keep pace with, and support economic growth

Developing countries, becoming more and more power-intensive, struggle to build enough generation capacity[1]. On top of generation issue, existing networks are often obsolete and require massive improvement to support the growth of emerging economies. These low-quality networks are penalizing both the electricity sector and the national economy: it is difficult to justify investments in generation plants when more than a fourth of the generated energy is lost on the grid[2], or to attract foreign industries when the average interruption duration per subscriber exceeds dozens of hours per year[3]. Replacing medium voltage lines by high voltage ones, harder to wire-tap, and coating low voltage cables are the first steps to reduce pilferage. Smart Distribution brings flexibility to this traditional approach with theft detection and ways to help people who cannot pay their electricity bill: SMS prepaid meters is an example of smart solution. Smart grid solutions also provide a drastic improvement of the quality of service that is needed to support the economic rise.

In developed urban areas, in China mega-cities for instance, smart grid investments will not be mainly driven by non-technical losses reduction or quality of service improvement, but by the economic rational to directly integrate latest technologies on a fast expanding network and by environmental concerns that may resemble European ones.

1) In India, the 2030 power need estimation is more than 6 times the 2008 generation capacity
2) India, Libya, Pakistan, Uruguay and Venezuela are examples of countries with T&D losses equalling or exceeding 25%
3) While Japan has less than 20 minutes of outage duration per customer and per year, it can reach more than 60 hours in Colombia

Illustration 6: Estimation of Smart Distribution investments breakdown for the "Technological Leap" pattern – Example of a Mega-City utility in a fast developing economy



Source : E-CUBE Strategy Consultants analysis

Remote-control operation and network protection provide proof of an effective solution

During last decade, North Delhi Power Limited (NDPL), an Indian DSO, managed to reduce T&D losses from 53% to 23%. Remote-metering twice a month gave NDPL enough insight to detect theft and improve failure detection. A supervisory control and data acquisition (SCADA) including a geographical information system (GIS) has also been implemented and now allow faster outage management and smart asset management. Remotely controlled switches are being rolled out to reduce outage duration and frequency: system average interruption duration is expected to drop 63 % below 2007 levels before the end of 2011.
The forecast for 2010-2030 is that, in Asia and in the rest of the world, Smart Distribution investments will focus on substation automation and power factor control, representing 40% of total investments.
In more advanced cities like Shanghai, where theft is not a major issue, the development of smart distribution grid may be close to European ones, with advanced DMS controlling an automated network (smart switches and voltage control).

Smart grids offer multiple synergies with different applications

Smart grids can be used to directly reduce non-technical losses. In Brazil, having a better knowledge of the network helped Ampla to identify areas where the losses were important and allowed it to remotely disconnect pilferers where sending an agent could be dangerous. Ampla also implemented educational programs in slums based on management of pre-paid communities meters: these programs facilitate the transition from former energy thieves into future customers. The implemented solutions for energy theft also lead to great improvements in outage reduction which is often a problem in these areas.
Senegal and Ghana are other examples of smart grids roll-out offering side-benefits. Pilot projects show promising results on leveraging Broadband over Power Line to offer internet access, giving power distribution a positive image. As most of these countries are in the process of urbanization, smart grid implementation will focus on cities where positive impacts are assessed easily.
In China, major cities are potential technological showcases for Chinese or foreign equipment and technology providers potentially featuring microgrids.

Smart Distributed Storage

Many smart grids goals can be achieved thanks to distributed energy storage: peak shaving, RES integration, outage duration reduction, ancillary services, etc. Its current high capital cost (more than 250 €/kWh for most high power battery technologies) penalizes massive implementation in the short term. However, in specific cases, like islands, battery storage is already a cost-effective option; NEDO, Japan's largest public R&D organization, is conducting a 2.5 MW microgrid project, with a PV insertion rate target of 50% or greater, notably thanks to NaS batteries. Feedback from ongoing pilot projects will be necessary to identify the best technology features for each application: number of charge/discharge cycles, round trip efficiency, energy density...
If large pumped storage plants (>600MW) are critical to facilitate RES insertion (in Spain, Iberdrola manages more than 2300 MW of pumped storage to back the variability of its 4500 MW wind capacity), they could prove of limited use for generation schemes highly distributed on the Low Voltage grid.

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