MSc Program
Renewable Energy in Central and Eastern Europe

Smart Grids

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Graz, March 2012

Affidavit

I, **Verena Lenhardt**, hereby declare

1. that I am the sole author of the present Master Thesis, "Smart Grids", 78 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Date Signature

Abstract

Smart Grid is one of the major trends and markets which involve the whole energy conversion chain from generation to consumption. The electricity system will change from a unidirectional power flow with centralized generation to a bidirectional power flow with numerous decentralized power stations. The way a power system is operated will change from a hierarchical top-down approach to a fully automated power network with two-way electricity power flows and real-time information between generation plants, various appliances and all points in between. The three key components of Smart Grids are distributed intelligence, communication technologies, and automated control systems.

The need for adapting the electricity system derives from different aspects such as environmental concerns, scarcity of non-renewable resources, new technologies, and aging infrastructure. This development goes hand in hand with a continuous reduction in non-renewable energy resource.

We have to deal with an area of challenges between reliability of supply, environmental sustainability as well as economic efficiency. Thus, it has become urgent to adapt the electricity system and make it a Smart Grid.

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1 Introduction

Remember life before Email? Fewer and fewer people do. There will also come a time when we won't remember life before the Smart Grid!

Climate change and resource scarcity heralds a new age for our energy supply system. We are living in times when significant transformation needs to be made in order to cope with the changing energy landscape. Increasing use is made of renewable resources, the number of regional peripheral energy suppliers grows – this is a major challenge for the utility grids.

This change has also found its way into legislation and regulation at the EU level by setting the 20/20/20 targets: a 20% cut in emissions of greenhouse gases, a 20% increase in the share of renewable sources in the energy mix; and a 20% cut in energy consumption by 2020.

Renewable energy sources, such as solar or wind power have been utilized for many years now. But what has been missing is an infrastructure that integrates these energy sources into conventional distribution grids. It is clear that these challenges will even grow in the future as the current trends towards more renewable energy is further enforced by social preferences, political will and economic evidence.

Intelligent or smart electricity grids are capable of merging renewable sources of energy with established facilities. The introduction of Smart Grids will not only increase the efficiency of RES, but also promises to provide additional energy storage possibilities.

In the next coming years, the industry will not only experience advanced metering infrastructure deployment, but also new improved grid technologies. These new technologies will greatly expand the scale of benefits to both customers and utility. Consumer demand and supply in real time will be connected, to maintain reliable power despite the fact the wind does not always blow and the sun does not always shine.

Intelligent electricity networks – Smart Grids - are a key component in the energy strategy for implementing the delivery of renewable energy supplies and to create a sustainable, reliable, and efficient energy infrastructure.

1.1 Motivation

The energy infrastructure is facing massive changes in the medium and long term. Smart or intelligent grids are at the beginning – thinking systems make the record, analysis, control, storage, and transport possible. A new movement is going on. More and smaller energy suppliers are joining the market, cities and communities are striving for independence energy supply. The trend is getting away from big energy suppliers towards decentralized units and using more renewable energy resources. This movement also goes along with the goal of the European Unions by cutting the emissions of green house gases by 20% until 2020.

The current energy system is being confronted with a number of uncertainties and changed conditions:

- Unpredictable and volatile fossil fuel prices
- Geopolitical risks related to import dependency
- Fossil fuel scarcity
- Green house gas emissions are increasing causing the climate change
- Electric energy demand is expected to increase
- Renewable power is growing

In order to deal with all those challenges we need a sustainable transformation of the energy system, in economic, ecologic and social terms - a fundamental structural change. The decisions that are taken today will have an impact on the energy system of tomorrow as investments in this sector are usually long-term oriented. There is a clear need for the implementation of the Smart Grid which interacts with all the interrelated challenges.

1.2 Core objective

The core objective of the thesis is to give the reader a comprehensive overview of all the components that come along with Smart Grids.

The paper is intended to provide an understanding of the historic development of electric grids, the change over time and the new conditions we are confronted with. Further, the thesis explores the range of technologies and applications and their benefits enabled by a Smart Grid infrastructure. The thesis addresses barriers and opportunities to deploying Smart Grid technologies to enhance the electric power delivery system to meet the challenges of the 21st century.

The thesis focuses on the following specific questions to implement Smart Grid technologies:

What makes the grid a “smart” grid?
What are the driving factors of Smart Grids and why do we need Smart Grids?
What are technologies and applications of Smart Grids?
What are the challenges we are facing for implementing Smart Grids?

1.3 Citation of main literature

The main source of literature derives from international associations, European and US American governmental commissions and diverse platforms working on the Smart Grid topic. Listed below is an overview of the main sources used for this thesis:

International Energy Agency
International Electrotechnical Commission
European Commission
European Smart Grids technology platform
Eurelectric
U.S Department of Energy
National Energy Technology Laboratory
Federal Energy Regulatory Commission
Electricity Advisory Committee
Roadmap Smart Grids Austria

Further literature is taken from diverse companies or organizations like Greenpeace, ABB, SAP, or Microsoft.

1.4 Structure of work

The scope of this thesis is to recognize the challenges that Smart Grids are facing, while extinguishing the main driving factors for their introduction.

First, the thesis starts with giving a general overview by examine the definition of Smart Grids, discussing the historical background, illustrating the vision of a Smart Grid, identifying the shareholders, and examine the European legislative principles.

Further, the challenge and the need for changing the existing energy infrastructure are being addressed. The key drivers for the need of implementing the Smart Grids are being discussed in detail. The key driving factors define where value will be created by the Smart Grid.

For enabling the Smart Grid the paper lays out the technologies architecture and applications. The deployment of the Smart Grid key technologies and applications is summarized in four milestone areas: Consumer Enablement, Advanced Distribution Operations, Advanced Transmission Operations, and Advanced Asset Management.

Figure 1 below illustrates the linkages between the Smart Grid vision, key technologies and applications, and how system assets and utility processes can be optimized. These key success factor value areas include expected improvements in reliability, economics, efficiency, security, environmental friendliness, and safety.[1]

[1] NETL (2011)

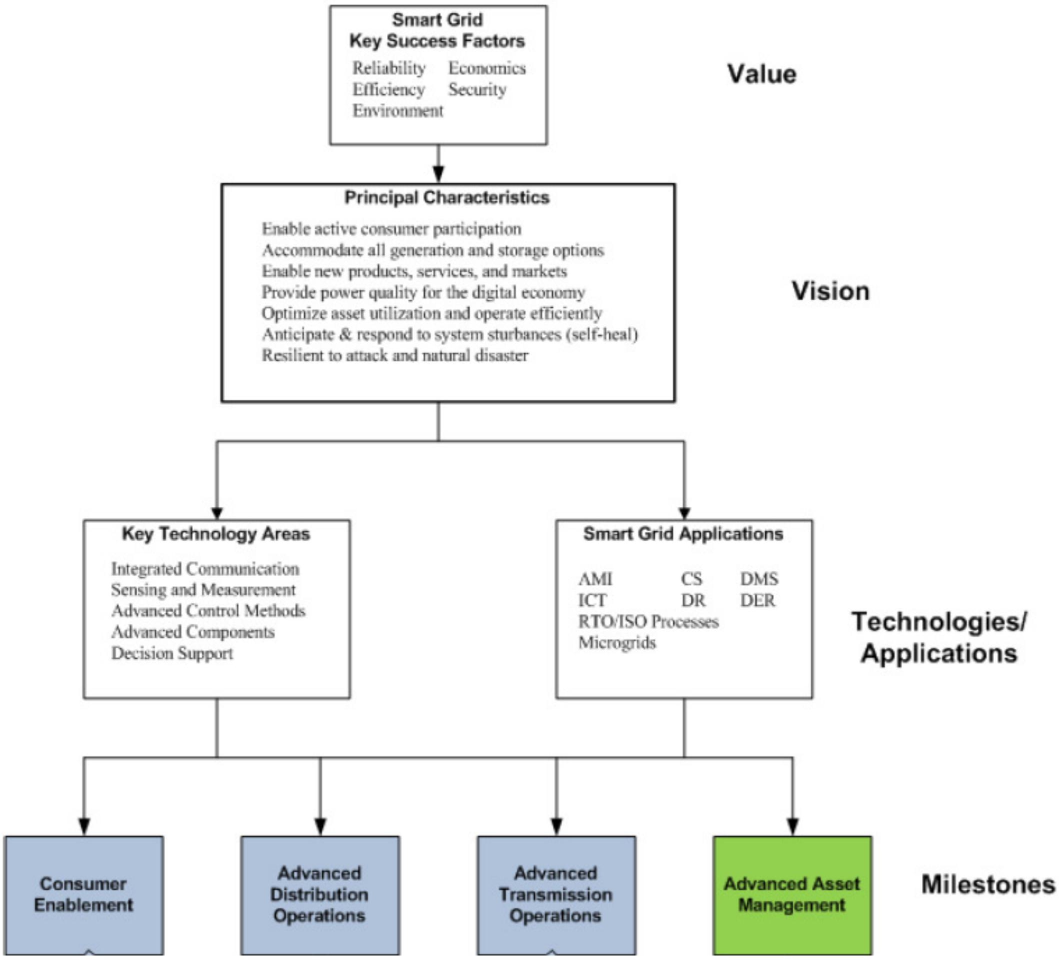

Figure 1 Linkage between the Smart Grid [2]

[2] Horizon Energy Group (2010)

2 Overview

2.1 Definition

There are several definitions of the term Smart Grids due to the large number of stakeholders and their various perspectives. But until now, there is no standard global definition. A common element to most definitions is the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. A variety of definitions from different institutions is listed below:

The European Technology Platform (ETP), the European Regulators' Group for Electricity and Gas (ERGEG) as well as the European Smart Grid Task Force use the same definition. Both organizations define Smart Grids as electricity networks that can intelligently integrate the behavior and actions of all users connected to it - generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high level so quality and security of supply and safety.

The International Energy Agency (IEA) defines the Smart Grids as 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.

In the United States the Department of Energy has defined the Smart Grid concept as the modernization of the nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve each of the following seven characteristics:[3]

- Enables and motivates active participation by consumers
- Accommodates all generation and energy storage options
- Enables new products, services and markets
- Provides the quality of power required for the digital, computer and communication based economy
- Operates efficiently and optimizes the utilization of existing and new assets
- Anticipates and responds to system disturbances in a self-healing manner

[3] DOE (2008)

- Operates resiliently against attack and natural disaster

The focus of the European Electricity Grid Initiative (EEGI) has been on defining the major Smart Grids functionalities necessary to reach the vision rather than focusing on the definition. To meet this goal, a Smart Grids model has been developed to guide in the process of defining the functionalities and the needed projects. Below Figure 3 summarizes the model.

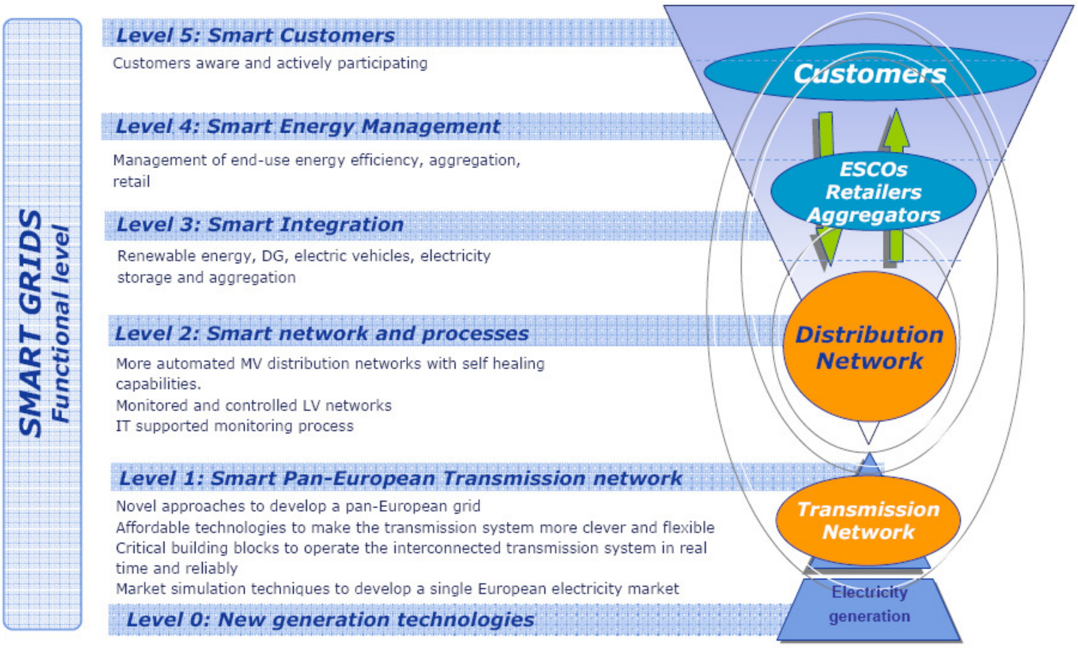

Figure 2 Smart Grid model[4]

“Smart Grid” is today used as marketing term, rather than a technical definition. For this reason there is no well defined and commonly accepted scope of what a Smart Grid is and what it is not. However, for the purposes of this thesis, a Smart Grid is defined as a broad range of solutions that optimize the energy value chain.

2.2 The traditional grid

Our present grid was designed at least 50 years ago. Since then, all electrical products have been upgraded or reinvented, except the power grid. If Thomas Alva Edison, one of the grid’s key early architects, were somehow transported to the 21st century, he would be totally familiar with the grid. It remained almost like it was 50 years ago.

[4] EEGI (2010)

The conventional grid is based on the production of energy in centralized power stations and supplying the consumer via the grid. The power flow goes in one direction from the power stations, via the transmission and distribution systems, to the final customer.

The transmission and distribution systems are commonly run by monopolies (national or regional bodies) under energy authorities' control. Storage possibilities are almost not possible, thus demand and supply always needs to be in equilibrium. The grid represents the ultimate in just-in-time product delivery because electricity has to be used the moment it is generated. There is little or no consumer participation and no end-to-end communication.

The grid design has evolved through economics of scale in large centralized generation and the geographic distribution of generation resources. The grid was optimized for regional or national conditions. Interconnections were originally developed for mutual support between countries and regions in emergency situations, but they are increasingly being used for trading between states.[5]

Historically, it had a single mission, namely "to keep the lights on". Any other modern concerns like energy efficiency or environmental impacts were simply not a primary concern when the existing grid was designed.[6]

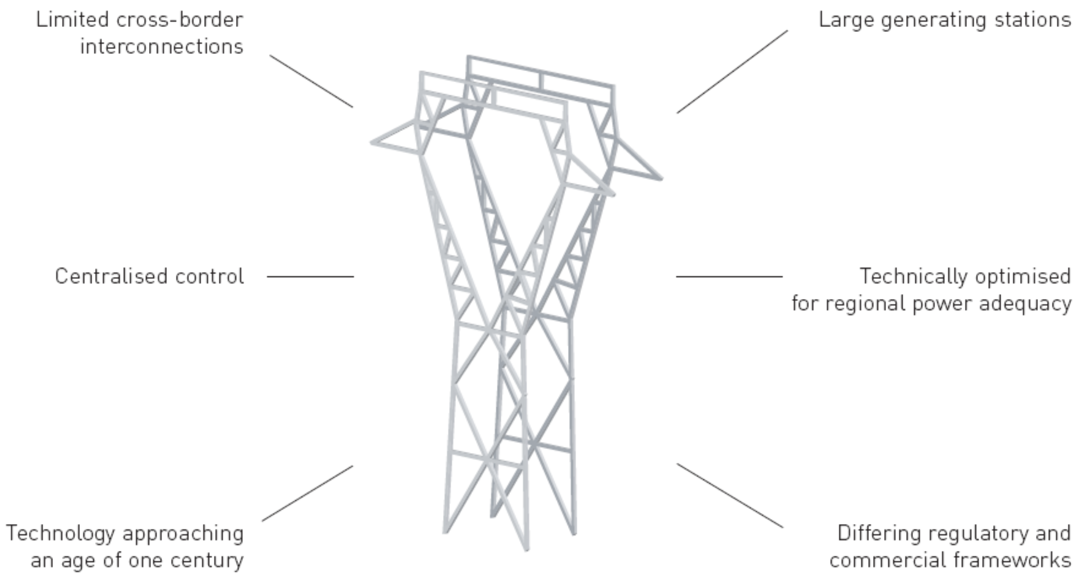

Figure 3 The traditional grid [7]

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[5] EC (2006)

[6] DOE (2008)

Today's grid was designed to move power from centralized supply sources to fixed, predictable loads. This makes it challenging for the grid to accept input from many distributed energy resources across the grid. More and more small, decentralized unites are becoming part of the energy supply system. The growing number of photovoltaic- , biomass- , and small hydro power plants are additionally feeding in electricity to the grid. The equilibrium between producer and user and the security and quality of supply is becoming a big challenge.

2.3 The Smart Grid vision

The vision of the Smart Grid is to connect the growing number of market players as well as from producer and also consumer side with each other. Electricity is flowing in both directions depending on supply and demand. New storage possibilities like E-cars and active control of demand side with smart metering are helping to optimize the use of renewable energy.

The change from a monopoly-based regulation of electricity supply to liberalization can bring the benefits of competition, choice and incentives for an efficient development. The trend goes towards an open market with a free choice of power supplier by the electricity consumers.

The Smart Grid solution to be developed should serve the following goals:[8]

- Further development of the electricity infrastructure as a basis for achieving political goals in the direction of sustainability.
- Optimal integration of renewable energy sources and of decentralized generation.
- Increased efficiency within the energy system and optimization of infrastructure.
- Making demand more flexible.
- Furthering new technologies, e.g. smart services, electro-mobility.
- Support for developing energy regions of tomorrow which aim at a high degree of self-sufficiency.

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[7] EC (2006)

[8] Energiesysteme der Zukunft (2011)

Smart Grid capabilities will make it easier to control bi-directional power flows and monitor, control, and support the distributed renewable energy resources. Future models for electricity grids have to adapt to the changing requirements in a liberalized market environment. Reliability, sustainability and cost effectiveness are the new keywords in the new system.

The European Union vision of a Smart Grid is to make a new concept for electricity networks bringing benefits to all users, stakeholders and companies. Europeans vision of an electricity networks in 2020 and beyond are defined as follows:[9]

- Flexible: fulfilling customers' needs whilst responding to the changes and challenges ahead
- Accessible: granting connection access to all network users, particularly for renewable power sources and high efficiency local generation with zero or low carbon emissions
- Reliable: assuring and improving security and quality of supply, consistent with the demands of the digital age with resilience to hazards and uncertainties
- Economic: providing best value through innovation, efficient energy management and 'level playing field' competition and regulation

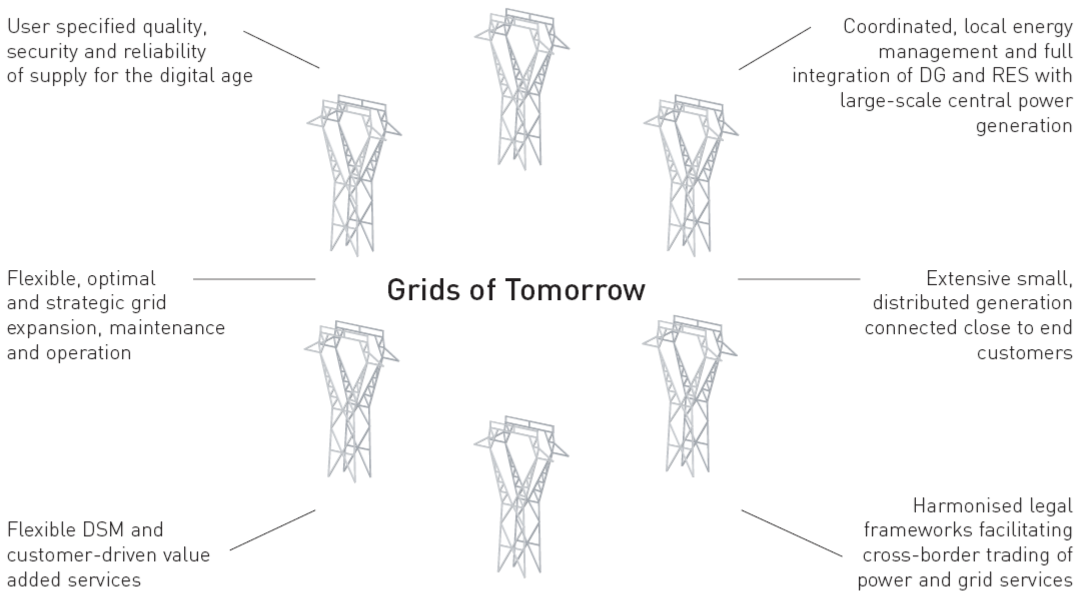

Figure 4 Grids of tomorrow [10]

[9] EC (2006)

The DOE defines the Smart Grid vision by its seven principal characteristics which are listed as follows: [11]

- Enable active participation by consumers;
- Accommodate all generation and storage options;
- Enable new products, services, and markets;
- Provide power quality for the digital economy;
- Optimize asset utilization and operate efficiently;
- Anticipate & respond to system disturbances (self-heal); and
- Operate resiliently against attack and natural disaster.

The strategy to achieve this vision hinges upon activities that directly address the technical, business, and institutional challenges to realizing a Smarter Grid. Below, Figure 5 shows the relationship between the specific activities is undertaking and the overall vision.

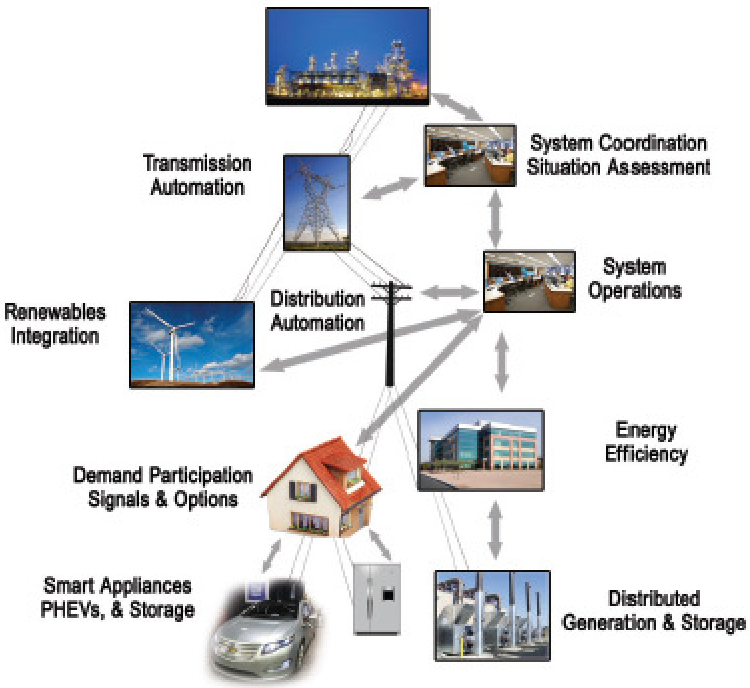

Figure 5 Scope of Smart Grid as defined by the DOE [12]

[10] EC (2006)

[11] DOE (2009)

[12] DOE (2009)

2.4 Participants/stakeholders

There is a wide and growing set of active participants within the smart energy system. Each participant – being organizations, people or intelligent devices - has its own roles, interests and associated responsibilities.[13]

Utilities and related companies, including:

- Distribution companies
- Independent System Operators (ISOs)
- Regional Transmission Operators (RTOs)
- Transmission market operators
- Transmission companies
- Generation companies
- Distribution balancing authorities

Service providers, including:

- Energy aggregators
- Maintenance service providers
- Metering service providers
- Weather forecasting
- Retail energy providers
- Equipment providers (PHEVs, solar panels, storage, etc.)

Customers, including:

- Residential
- Commercial
- Industrial
- Governmental

Further Smart Grid stakeholders are:

- Government Regulators
- Environmental Groups

[13] Microsoft (2009)

2.5 Policy and regulatory framework

Europe's Smart Grid policy is primarily represented by the European Union (EU). The EU does not have yet in force any legislation that would directly oblige the Member States to invest and deploy Smart Grid technologies. Initial steps towards related legislation at European level are listed as follows:

The 2006/32/EC directive on energy efficiency encourages the Member States to take into account efficiency gains obtained through the widespread use of cost effective technological innovations, for instance electronic metering.

The 2009/28/EC directive on the promotion of the use of energy from the renewable supports the development of Smart Grids indirectly. The directive recognizes need for "intelligent networks" in order to allow secure operation of electricity system with further development of renewable sources but focuses on access to and operation of grids. It is just saying that "Member States shall take the appropriate steps" to develop Smart Grids.

The 3rd Energy Package's provisions encourage the long term modernization of the European grids across Europe, subject to individual Member State's transposition. In addition, the Annex 1 of the new Electricity Directive (2009/72/EC) explicitly encourages the Member States to assess the conditions for roll-out of the smart meters as a first step towards the implementation of Smart Grid

As according to the directive of the European Union the aim of the Smart Grid technology roll-out is to provide the necessary framework and initial incentives for rapid investments in a new "intelligent" network infrastructure to support

- a competitive retail market,
- a well-functioning energy services market which gives real choices for energy savings and efficiency and
- the integration of renewable and distributed generation, as well as
- to accommodate new types of demand, such as from electric vehicles.[14]

Metering system

According to directive 2006/32/EC, smart meters should be installed in EU Member States when an existing meter is replaced, when a new building is

[14] EC (2010)

connected to the grid, or when an existing building undergoes major renovations as far as this is technically feasible and economically reasonable.

The EU electricity directive also calls the member states to implement "intelligent metering systems" to assist the active participation of consumers in the electricity supply market. The directive requires at least 80% of the consumers to be equipped with intelligent metering systems by 2020.[15]

Reduce greenhouse gas emissions

In the strategy for limiting climate change the EU has committed to reducing its own emissions by at least 20% by 2020. The objective also calls for the conclusion of an international agreement which will oblige developed countries to reduce their greenhouse gas emissions by 30% by 2020. In the framework of this agreement, the EU would set itself a new objective of reducing its own emissions by 30% compared with 1990 levels. Reducing greenhouse gas emissions involves using less energy and using more clean energy.

Energy efficiency targets

In the Action Plan for Energy Efficiency (2007-2012) the EU has set the objective of reducing its energy consumption by 20% by 2020. To achieve these objectives efforts need to be made especially in respect to

- energy saving in the transport sector,
- the development of minimum efficiency requirements for energy-using appliances,
- awareness-raising amongst consumers about sensible and economic energy use,
- improving the efficiency of the production,
- transport and distribution of heating and electricity and also
- developing energy technologies and improving the energy performance of buildings.

Renewable Energy

In the Renewable Energies Roadmap the EU has set the objective of increasing the use of renewable energy sources in its energy mix by 20% by 2020. This objective

[15] EC (2009)

requires progress to be made in the three main sectors where renewable energies are used:

- electricity (increasing the production of electricity from renewable sources and allowing the sustainable production of electricity from fossil fuels, principally through the implementation of CO_2 capture and storage systems),
- biofuels, which should represent 10% of vehicle fuels by 2020, and finally
- heating and cooling systems.

The uses of renewable energies like wind power, solar and PV energy etc contributes to limiting climate change and secures the energy supply.

3 Smart Grid driving factors

Scarcity of non-renewable energy sources and climate change are the key drivers for the future grid development that underscore the need of the deployment of a Smart Grid. The increasing environmental concerns around the globe are driving the expansion of renewable energy on a larger scale. The widespread addition of wind, solar and other RES present operational challenges. A grid that can handle a generation mix with a high percentage of RES will become a necessity for those technologies to realize their full potential.

The table below offers a brief overview of certain drivers that are crucial to the deployment of Smart Grid technologies.

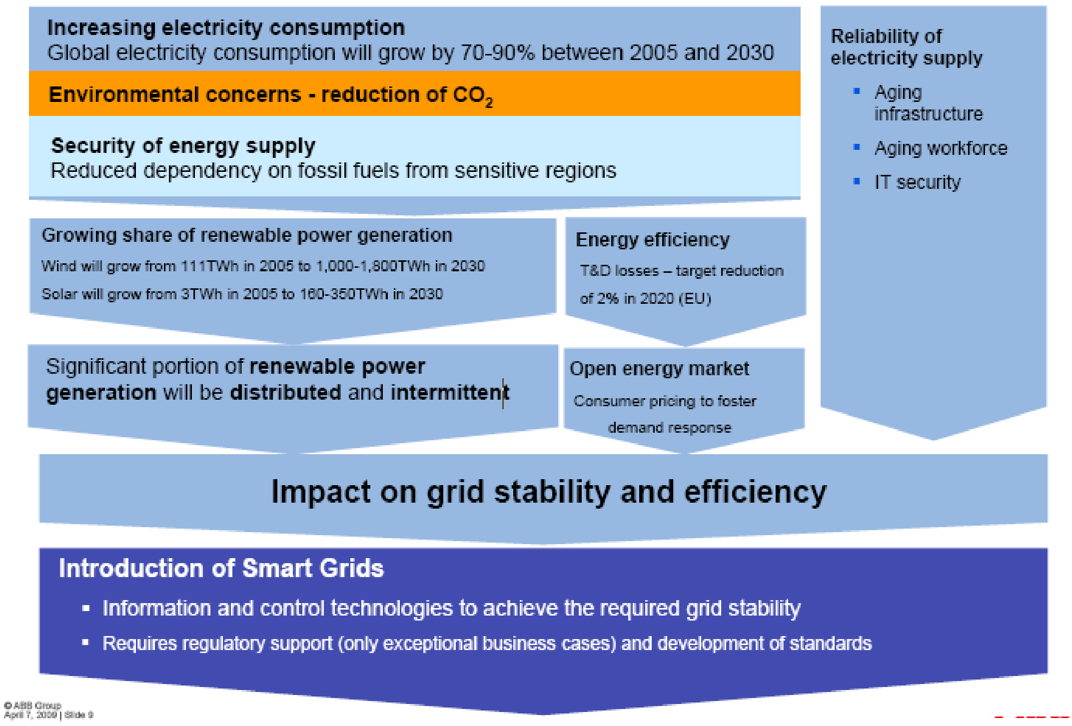

Figure 6 Drivers for the Smart Grid [16]

In the following section the key driving factors for the need of deploying the Smart Grids are discussed more in detail.

[16] ABB (2009)

3.1 Increasing electricity consumption

Electricity is the fastest-growing component of total global energy demand, with consumption expected to increase by over 150% under the ETP 2010 Baseline Scenario and over 115% between 2007 and 2050 under the BLUE Map Scenario 2010 of the IEA.

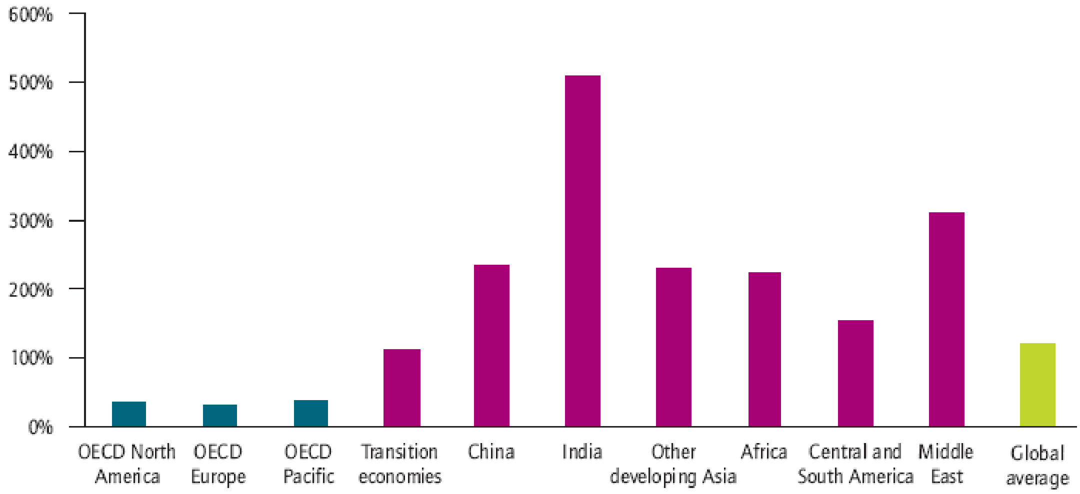

Figure 7 Electricity consumption growths 2007 to 2050 (BLUE MAP scenario)[17]

Growth in demand of OECD member countries is expected to increase much more modest than emerging economies and developing countries due to population growth and economic catching up. In OECD countries, where modest growth rates are based on high levels of current demand, Smart Grid technologies can provide considerable benefits by reducing transmission and distribution losses, and optimizing the use of existing infrastructure.

Smart Grids are becoming an important technology to increase the efficiency of the supply system in order to meet the growing electricity demand.

3.2 Environmental concerns

One of the greatest environmental challenges is the greenhouse gases contribute to climate change. There is an urgent need in reducing the CO2 emission. Several studies have indicated that Smart Grids can make a major contribution to CO2 emission reduction.

The ETP 2010 study demonstrates the many opportunities to create a more secure and sustainable energy future. Baseline scenario follows the reference scenario to

[17] IEA (2010)

2030 outlined in the World Energy Outlook 2009, assuming governments introduce no new energy and climate policies. In contrast, the BLUE Map scenario is target-oriented by setting the goal of halving global energy-related CO2 emissions by 2050 (compared to 2005 levels) and examines the least-cost means of achieving that goal through the deployment of existing and new low-carbon technologies. In the ETP 2010 baseline scenario the global CO2 emissions double, in the BLUE Map scenario abatement across all sectors reduces emissions to half 2005 levels by 2050. As shown in Figure 8 the increase in efficiency and RES are important instruments for reducing CO2 emissions.

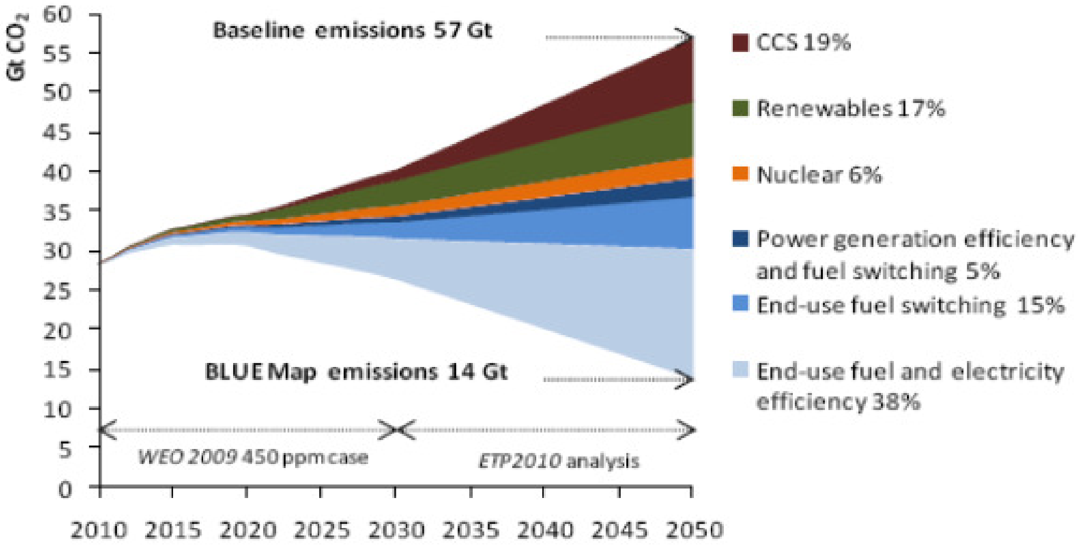

Figure 8 Key technologies for reducing global CO2 emissions (BLUE MAP scenario)[18]

The Smart 2020 study, measuring the global impact of Smart Grids, estimates an up to a 15 % reduction of BAU CO2 emissions in 2020 as shown in Figure 9.

[18] IEA/OECD (2010)

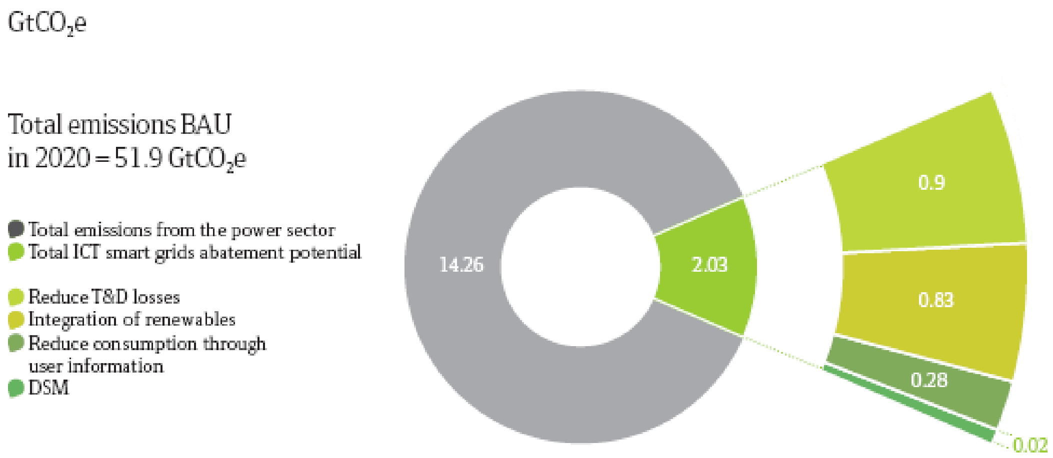

Figure 9 Global CO2 impact in 2020 (Smart 2020 study) [19]

The U.S study made by DOEs Pacific Northwest National Laboratory projects a potential reduction in electricity and CO2 emissions by 2030 attributable to Smart Grid by up to 12%. PNNL divides the impacts of a Smart Grid up into direct and indirect reductions: direct reductions being Smart Grid functions that produce savings in energy and/or emissions consumed or by reducing generation requirements whereas indirect reductions are related to Smart Grid functions producing cost savings (see Table 1). [20]

[19] GeSI (2008)

[20] PNNL (2010)

Mechanism	Electricity Sector Energy and Carbon Reductions*	
	Direct	Indirect
Conservation Effect of Demand Response Consumer Information	3%	-
Marketing/Outreach Synergy Between Demand Response and Efficiency Programs	-	0%
Measurement and Verification for Efficiency Programs	1%	< 0.5%
Smart Grid-Enabled Diagnostics in Residential and Small/Medium Commercial Buildings	3%	-
Conservation Voltage Reduction and Advanced Volt/VAr Control	2%	-
Load Shifting from Demand Response	< 0.1%	-
Support Additional Electric Vehicles (EVs) / Plug-In Hybrid Electric Vehicles (PHEVs)	3%	-
Reduced Need for Regulation and Reserves to Achieve 25% RPS of the electric sector:		
Solar Photovoltaic Integration and/or Wind Energy Integration:	< 0.1%	5%
Total Savings	**12%**	**6%**

Table 1 Direct and indirect impact of a Smart Grid (PNNL study)[21]

The EPRI report shows the potential to yield energy savings of 56 to 203 billion kWh in 2030, corresponding to a 1.2 percent to 4.3 percent reduction in projected retail electricity sales. By this scenario the annual carbon emission are annually reduced by 60 to 211 million metric tons CO2 corresponding to 2.7% to 9.6% of GHG emissions from electricity generation in 2009 as shown in Table 2.[22]

[21] PNNL (2010)

[22] EPRI (2008)

Emissions-Reduction Mechanism Enabled by Smart Grid		Energy Savings, 2030 (billion kWh)		Avoided CO_2 Emissions, 2030 ($Tg\ CO_2$)	
		Low	*High*	*Low*	*High*
1	Continuous Commissioning of Large Commercial Buildings	2	9	1	5
2	Reduced Line Losses (Voltage Control)	4	28	2	16
3	Energy Savings Corresponding to Peak Load Management	0	4	0	2
4	Direct Feedback on Energy Usage	40	121	22	68
5	Accelerated Deployment of Energy Efficiency Programs	10	41	6	23
6	Greater Integration of Renewables	--	--	19	37
7	Facilitation of Plug-in Hybrid Electric Vehicles (PHEVs)	--	--	10	60
	Total	**56**	**203**	**60**	**211**

Table 2 Smart Grid CO2 avoidance[23]

To summarize, Smart Grid helps to reduce the dependence on fossil fuels and lower the CO2 emissions by better and more efficient management of the grid and by facilitating the deployment of low carbon technologies such as renewables and electric vehicles.

3.3 Security of energy supply

Maintaining security of energy supply is of utmost importance in transmission grid operation and planning. Interdependencies of various grid components can bring a cascading series of failures that could bring our system to a complete standstill.

Security of supply can be increased by adding lines, storage and demand. Even under an extreme climate events effecting renewable energy with low wind or low solar during winter, excess wind power from another region can be imported. [24]

Remote monitoring and control devices throughout the system can create a "self-healing" grid, which can restore and prevent outages and extend the life of substation equipment and distribution assets. Through such automation, rising consumer expectations for power quality and reliability can be met in a time of growing electricity demand and an aging infrastructure and workforce.[25]

[23] EPRI (2008)

[24] Greenpeace (2011)

[25] EAC (2008)

3.4 Aging infrastructure

The aging infrastructure is another major concern. Large parts of the existing infrastructure dates back to the 1960s or even earlier and is reaching the end of its useful life.

As demand grows, infrastructure changes, distributed generation becomes more widespread, ageing distribution and transmission infrastructure will need to be replaced and updated. New technologies will need to be deployed and investment certainly is needed to maintain reliability and quality of power. Smart Grid technologies provide an opportunity to maximize the use of existing infrastructure through better monitoring and management, while new infrastructure can be more strategically deployed.[26]

3.5 Growing share of RES

According to the objectives set by the EU, the use of RES should be increased. In "Power Choices Pathways to Carbon-Neutral Electricity in Europe by 2050" report Eurelectric presents a scenario in which RES power generation increases 40% by the year 2050 as shown in Figure 10. The total electricity consumption in Europe is seen to be 4800 TWh and 1800 TWh will be produced by RES. Among RES technologies, wind power takes the lead, with onshore wind providing 35% of the RES contribution and off-shore wind 27%. Hydropower remains stable with for 23% of the total RES. Biomass fired electricity also increases, although in relative terms its share of RES power slightly decreases, while solar power also comes to a share of 13%. [27]

[26] IEA (2011)

[27] Eurelectric (2009)

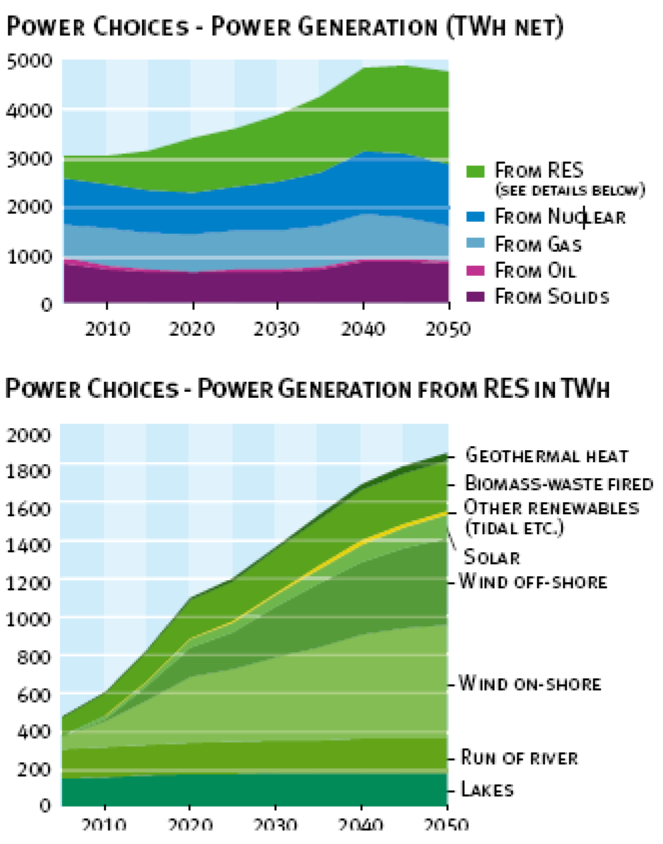

Figure 10 Total EU net power generation [28]

Also increasing use of RES is shown in the IEAs 450 scenario. The reference scenario is the same as BAU, in which the new rationalization projects to increase e.g. energy efficiency will not be done, so the use and generation of electricity will continue in same baseline.

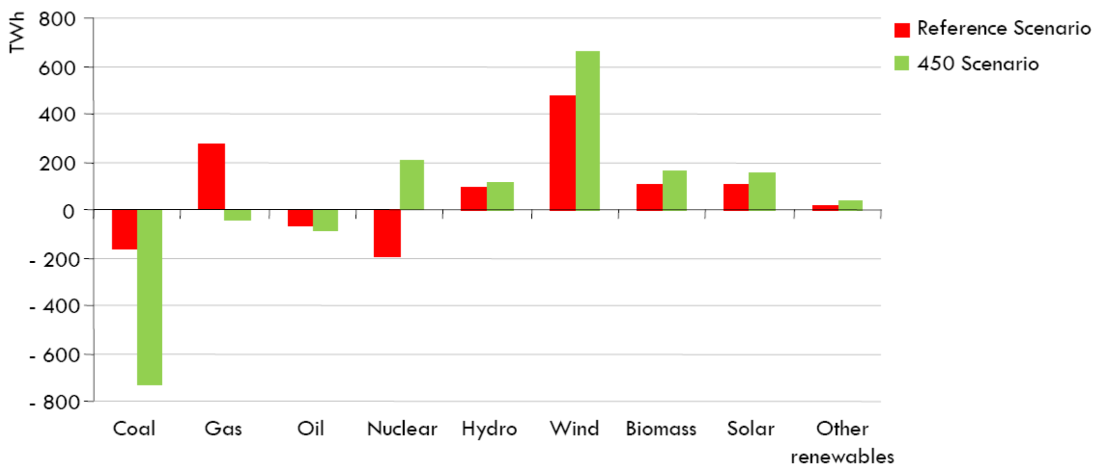

Figure 11 EU Power generation [29]

[28] Eurelectric (2009)

These scenarios show that RES are becoming a much greater importance in electricity generation. Intermittent energy sources such as wind and solar will put additional strains on the existing grids. Their intermittence must be counter-balanced with more intelligence, base load power generation and storage. The big challenge is to efficiently integrate this significantly growing amount of RES into the grid.

3.6 System adequacy

The considerations for meeting the needs of electricity consumers are significantly different from those for other energy commodities. First, large-scale electricity storage is available only in a few regions that have significant reservoir hydro resources. Second, electricity is traded on a regional rather than on a global basis. It is in this context that electricity production and consumption must be continually monitored and controlled. Smart Grid technologies can help to improve system adequacy by enabling more efficient system operation and the addition of regional energy resources to the electricity mix. The increased amounts of data gathered from a Smart Grid can show where operational efficiency can be improved and increased automation can improve control of various parts of the system, enabling fast response to changes in demand. The introduction of regional energy resources, including variable generation such as solar, wind, small hydro power plants, and combined heat and power, as well as dispatch able generation such as biomass, reservoir-based hydropower and concentrating solar power systems, will increase the amount of generation capability on the system. Smart Grids enable improved, lower-cost integration of these and other variable technologies that may require different electricity system operation protocols.[30]

3.7 Electrification of transport

The BLUE Map Scenario made by the IEA estimates that the transport sector will make up 10% of overall electricity consumption by 2050 due to the significant increase in EV and PHEV.

[29] IEA (2009)

[30] IEA (2011)

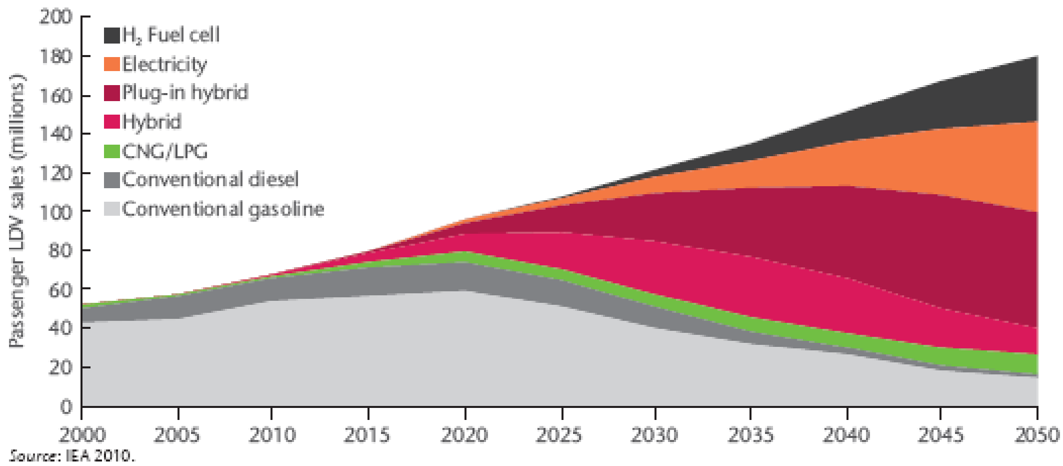

Figure 12 Annual light-duty vehicle sales by technology type (BLUE Map scenario) [31]

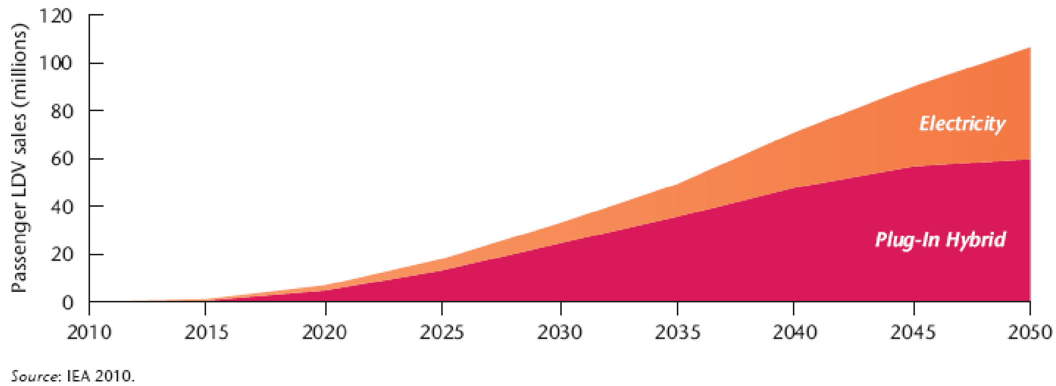

Figure 13 Annual global EV and PHEV sales (BLUE Map scenario) [32]

LDVs will increase dramatically until 2050. By 2030, sales of EVs are projected to reach 9 million and PHEVs are projected to reach almost 25 million. After 2040, sales of PHEVs are expected to begin declining as EVs (and fuel cell vehicles) achieve even greater levels of market share. The target is to achieve 50 million sales of both types of vehicles annually by 2050.

Electrification of transport is going to have a major impact on transport as well as on the energy sector over time. If vehicle charging is not managed intelligently, it could increase peak loading on the electricity infrastructure, adding to current peak demands, and requiring major infrastructure investment to avoid supply failure. Smart Grid technology can enable charging to be carried out more strategically when demand is low, making use of both low-cost generation and extra system

[31] IEA (2010)

[32] IEA (2010)

capacity, or when the production of electricity from renewable sources is high. Furthermore, Smart Grid technology could enable electric vehicles to feed electricity stored in their batteries back into the system when needed.

4 Smart Grid technology

Adequate grid architecture requires an array of “enabling technologies”. Many of these Smart Grid technologies are already used in other applications such as manufacturing and telecommunications and are being adapted for use in grid operations. Others are being adapted to meet the demand of the modern power grid.

In general, the driver of the Smart Grid technologies can be grouped into areas. The DOE identified five foundational key drivers as illustrated in Figure 14. [33]

- Integrated communications, connecting components to open architecture for real-time information and control, allowing every part of the grid to both ‘talk’ and ‘listen’
- Sensing and measurement technologies, to support faster and more accurate response such as remote monitoring, time-of-use pricing and demand-side management
- Advanced components, to apply the latest research in superconductivity, storage, power electronics and diagnostics
- Advanced control methods, to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event
- Improved interfaces and decision support, to amplify human decision-making, transforming grid operators and managers quite literally into visionaries when it come to seeing into their systems

The DOE further identifies the need for the Smart Grid to be green by “slowing the advance of global climate change and offering a genuine path towards significant environmental improvement.

[33] DOE (2008)

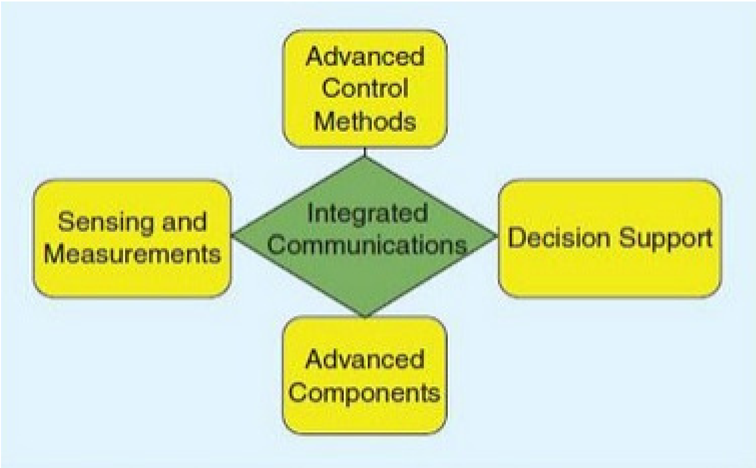

Figure 14 The five key technology areas identified by DOE [34]

4.1 Integrated communication

Integrated communication means high-speed, fully integrated, two-way communication technologies that make the grid dynamic and transactive for real-time information and power exchange. An open architecture will create a near plug-and-play environment. This facilitates an environment in which technologies from multiple vendors can easily interact and that securely connects grid components, customers, and operators, enabling them to talk, listen, and interact. Integrated communications are critical to enable the real-time, two-way exchange of data and information needed by the five operational processes. Today's communication systems do not support the bandwidth, latency, and reliability requirements of the Smart Grid or the next generation of asset optimization processes.[35]

Information provided by smart sensors and smart meters needs to be transmitted via a communication tool which is characterized by a high-speed and two-way flow of information. Different communication applications and technologies are involved. These communication services have been classified into groups by the EPRI. An overview of these groups is provided in Figure 15 as well as brief descriptions and examples.

[34] DOE (2008)

[35] NETL (2011)

An expanded view of different smart grid communication applications and technologies		
Core networking	▪ protocols needed to provide interoperable connectivity in a network that may vary greatly in topology and bandwidth	e.g. HTTP, TCP
Security	▪ security measures for consumer portal communications as portals directly deal with consumer information and billing processes	e.g. IPSec, HTTPS
Network management	▪ standard technologies for collecting statistics, alarms and status information on the communications network itself	e.g. Basic IP, SNMP
Data structuring and presentation	▪ "meta-data" for formally describing and exchanging how devices are configured and how they report data	e.g. HTML, XML
Power system operations	▪ several of the key applications for portals involve integration with distribution system operations, such as outage detection and power quality monitoring	e.g. DNP 3
Consumer applications	▪ electrical metering and various aspects of building automation	e.g. ANSI/IEEE C12
Network technologies		
WAN technologies	▪ the problem of how to reach the consumer site represents the most rapidly-changing area of portal technology, and the one that will have the most impact on its commercial viability	e.g. DSL, Cellular
LAN technologies	▪ technology making a portal distinct from being just a "smart meter" or "smart thermostat" is its ability to network with other devices locally	e.g. Ethernet, Wi-Fi

Figure 15 Overview of Smart Grid communication applications & technologies[36]

4.2 Sensing and measurement

The technologies will enhance power system measurements and enable the transformation of data into information. They will evaluate the health of equipment, grid integrity, and grid congestion. They will also support advanced protective relaying, eliminate meter estimations and prevent energy theft, and enable consumer choice and demand response. Such information enables consumers to make choices about whether to use electricity in response to information about electricity prices and demand, and can help provide relief when transmission lines are operating at or near capacity.

Many of the distribution assets are not currently instrumented today for key operational data such as watts, reactive volt-amperes, volts, amperes, and operational status. Additionally, health -monitoring data such as number of device operations, temperature, and other indications of degraded conditions are generally not available. Smart Grid sensing and measurement technologies will provide this information, giving the O&M process the information needed to reduce outages, address power quality issues, reduce losses, extend the life of assets, and reduce labor costs. [37]

[36] OECD (2009)

[37] NETL (2011)

Examples for sensing and measurement technologies are listed below:

- Advanced sensors
- Advanced metering infrastructure, including “smart” meters
- Phasor measurement units, monitors that sample voltage and current many times a second at a given location on the electricity grid to indicate grid stress and trigger corrective actions to maintain reliability
- Dynamic, real-time line-rating technologies measure the capacity of a transmission line in real time rather than basing allowable line loadings on earlier system studies that do not consider actual ambient conditions (i.e., static ratings). Thus, a line would not experience the overload-induced excess sag, which leads to tree contacts, nor would it be loaded too lightly, which results in potential lost wholesale opportunities. Dynamic ratings can increase the utilization of both transmission and generation assets[38]
- Near-real-time information can be provided to customer as well as operator. Today, very limited customer information is available, normally retrieved only on a monthly basis when the meters are read. Smart meters will provide near-real-time information about energy consumption and price to operators and customers [39]

Smart meter and Phasor measurement units are discussed more in detail in the following sections.

4.2.1 Smart meter

A smart meter is usually an electrical meter that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing purposes.[40]

The Ferraris disc or induction meter is the most widespread type of meter. It has been invented over a hundred years ago and is still in use. Usually, the old-style meters can only measure the total amount of electricity used over an entire billing period because they have to be read manually.

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[38] NETL (2011)

[39] NETL (2011)

[40] FERC (2008)

Today improved information technologies started a new generation of electricity metering technology called smart meters. As a result of increasing competition and improved energy efficiency metering has grown in importance and plays a crucial role in today's energy market.
Smart meters go far beyond from only recording of electricity consumption. It records the total electricity consumption and transmits this information to the utility. Bidirectional communications between the meter and the central system, load profile recording, multi-tariff metering and acquisition of supply quality data is enabled. Smart meters dispense with on-site readings, as the metering data can be remotely read and automatically transmitted to the system operator. This data is the base for the billing of the customer, the preparation of forecasts, supplier switching and much more.[41]

The big advantage of smart metering is the possibility to inform consumers in real or near real time of their actual energy use e.g. via a web portal or external displays. This new development also paves the way for the introduction of flexible tariffs and makes time-of-use (or TOU) prices possible. Different prices can apply at different times of the day which provides a new way of managing the electricity use.

Smart meters will also help to reduce peak demand by encouraging the consumer to think more about how and when to use electricity. The end user will be able to influence their electricity bills by adjusting the habit of electricity consumption.

The benefits of Smart Metering installations are numerous for many different stakeholders of the systems. The table below mentions some of the major benefits for utility stakeholders.

[41] E-control (2011)

Stakeholder	Benefits
Utility Customers	• Better access and data to manage energy use • More accurate and timely billing • Improved and increased rate options • Improved outage restoration • Power quality data
Customer Service & Field Operations	• Reduced cost of Metering reading • Reduced trips for off-cycle reads • Eliminates handheld meter reading equipment • Reduced call center transactions • Reduced collections and connects/disconnects
Revenue Cycle Services - Billing, Accounting, Revenue Protection	• Reduced back office rebilling • Early detection of meter tampering and theft • Reduced estimated billing and billing errors
Transmission and Distribution	• Improved transformer load management • Improved capacitor bank switching • Data for improved efficiency, reliability of service, losses, and loading • Improved data for efficient grid system design • Power quality data for the service areas
Marketing & Load Forecasting	• Reduced costs for collecting load research data
Utility General	• Reduced regulatory complaints • Improved customer premise safety & risk profile • Reduced employee safety incidents
External Stakeholders	• Improved environmental benefits • Support for the Smart Grid initiatives

Table 3 Benefit of smart metering for stakeholders [42]

4.2.2 Phasor measurement units

Phasor Measurement Units (PMU) is GPS based and measures the instantaneous magnitude of voltage or current at a selected grid location to provide a global and dynamic view of the power system, and automatically checks to ensure predefined operating limits are not violated. Offering wide-area situational awareness, phasors work to ease congestion and bottlenecks and mitigate or prevent from blackouts. Typically, measurements are taken once every 2 or 4 seconds offering a steady state view into the power system behavior. Equipped with Smart Grid communications technologies, measurements taken are precisely time-synchronized and taken many times a second offering dynamic visibility into the power system. Adoption of the Smart Grid will enhance every facet of the electric delivery system, including generation, transmission, distribution and consumption. It will energize those utility initiatives that encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand. It will increase the possibilities of distributed generation, bringing generation closer to those it serves. Solar panels on your roof will become more

[42] EEI (2011)

common than some distant power station. The shorter the distance from generation to consumption, the more efficient and economical it becomes. This system empowers consumers to become active participants in their energy choices and it will offer a two-way visibility and control of energy usage. [43]

4.3 Advanced components

Advanced components play an active role in determining the electrical behavior of the grid. These power system devices apply the latest research in materials, superconductivity, energy storage, power electronics, and microelectronics to produce higher power densities, greater reliability and power quality, enhanced electrical efficiency that produces major environmental gains, and improved real-time diagnostics. [44]

Examples for advanced components are:

- Advanced switches, transformers, cables, and other electrical devices
- Storage devices, including plug-in hybrid electric vehicles, as well as advanced batteries
- Grid-friendly, smart appliances, including air conditioners, clothes washers and dryers, and hot water heaters capable of delaying operation in response to price signals
- local electricity grids (micro grids) that can operate independently of the main electricity grid when needed

4.4 Advanced control methods

Advanced monitor and control (ACM) essential elements of the Smart Grid. Computer-based algorithms allow efficient data collection and analysis, provide solutions to the operators and are also able to act autonomously. For example, new substation automation systems have been developed that provide local information and that can also be monitored remotely. Whereas the substation information is only available locally in traditional Smart Grids, new developed subsystems are capable of making this information available in the whole grid to provide a more efficient power management. Furthermore, faults or drastic changes in current flow or total

[43] DOE (2008)

[44] DOE (2008)

interruption of an electrical circuit can be detected much faster than in traditional grids.[45]

These technologies will perform the following functions: [46]

- Diagnose and solve: the availability of real-time data processed by powerful high-speed computers will enable expert diagnostics to identify solutions for existing, emerging, and potential problems at the system, subsystem, and component levels
- Take autonomous action when appropriate: the Smart Grid will include significant advances in system protection and control by incorporating high-speed digital communication systems with advanced analytical technologies. Special protection systems will allow power transfers across the grid that would not otherwise comply with standard contingency criteria. Upon a change of status (e.g., a loss of generation and/or loss of a transmission line), a pre-programmed set of actions will be instantly initiated (e.g., wide area load-shed, generator re-dispatch, separation of interties, islanding) to maintain acceptable reliability margins while optimizing the affected assets
- Perform “what-if” predictions of future operating conditions and risks: fast simulation and modeling applications are examples of this

The Smart Grid will rely on local intelligence, automation, and decentralized control for selected applications, particularly those with primarily local impact. Centralized ACM will be utilized in other applications that involve a broader and more integrated impact. One of the overall objectives of ACM is to perform system and asset level analyses over multiple time horizons and take timely action to continuously optimize the overall operation of the system. [47]

4.5 Improved interfaces and decision support

Another key component area for Smart Grids is programs for decision support and human interfaces. In the future, the data volume in Smart Grids will increase tremendously compared to traditional grids. Thus, one of the main challenges is to integrate and manage the generated data and to prepare the data in a user-friendly way in order to support grid operators and managers decision. Improved interfaces

[45] OECD (2009)

[46] NETL (2011)

[47] NETL (2011)

and decision support will enable more accurate and timely human decision making at all levels of the grid. Tools and applications include systems based on artificial intelligence and semi-autonomous agent software tools, visualization technologies, alerting tools, advanced control and performance review applications, and as well as data and simulation. New methods of visualization enable integration of data from different sources, providing information on the status of the grid and power quality and rapid information on instabilities and outages. Geographic information systems provide geographic, spatial and location information and tailor this information to the specific requirements for decision support systems along the Smart Grid.[48]

[48] OECD (2009)

5 Smart Grid applications

The Smart Grid technologies that form the foundation of a new grid enable new Smart Grid applications. Those applications will change the way people use, buy, manage, and think about electricity.

A report released by GigaOm analyzes six key Smart Grid application trends that will help shape the industry landscape in the years to come. These are the six trends: [49]

1. Distribution automation (DA)
2. Data analytics
3. Demand response (DR)
4. Carbon management
5. Energy information display (EID) in home energy management
6. Electric vehicle (EV) smart charging

In the GTM Research survey it was found that distribution automation & grid optimization are ranked as the top Smart Grid applications. Figure 16 provides an overview of the most important Smart Grid application according to the GTM Research survey.

[49] Cnet (2011)

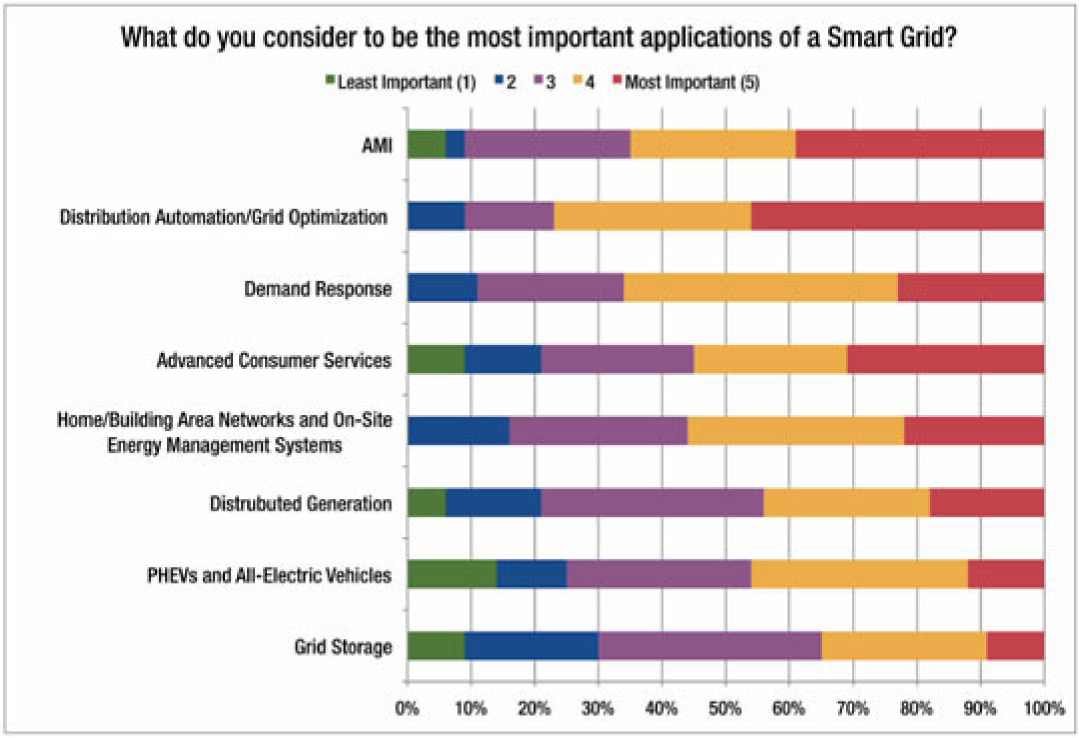

Figure 16 Overview of Smart Grid applications (GTM Research) [50]

This Pike Research report examines Smart Grid trends in Europe, and forecasts the size and growth of the market for Smart Grid technologies through 2020. It also forecasts the Smart Grid market by applications from 2010 to 2020. While smart meters are attracting most of the attention at the moment, transmission system upgrades will be the largest portion of investment between now and 2020, 37% of the total. Smart meters will be the next largest application category, followed by distribution automation and substation automation as presented in Figure 17.

[50] Greentech Media (2010)

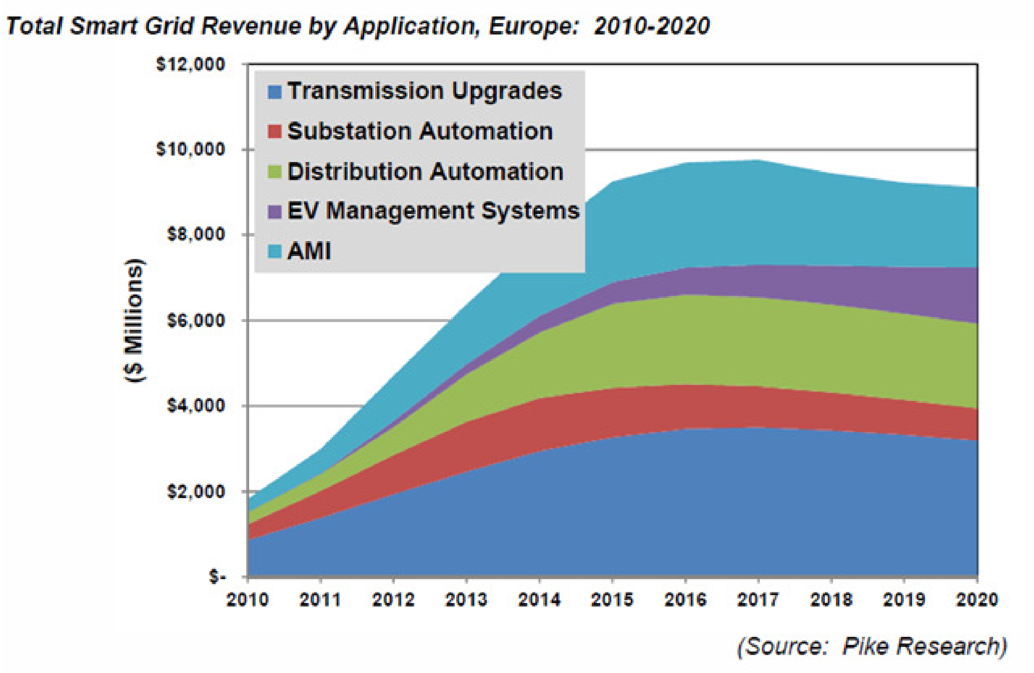

Figure 17 Total Smart Grid revenue by applications in Europe (Pike Research) [51]

In literature there is no common categorization of Smart Grids applications to be found. The following section categorizes and describes the most important and common Smart Grid applications in more detail.

5.1 Advanced Metering Infrastructure

Advanced metering infrastructure (AMI) or system (AMS) is the integration of smart meters, an integrated two way communications system, and utility consumer processes. It serves as the primary consumer interface to the electric system.

AMI and the information it provides to the customer service and operations processes will help reduce peak loads, improve the detection, diagnosis, and restoration from outages on their systems, and operate them more efficiently. It also simplifies the meter reading process and substantially reduces the number of labor hours required by the metering process.[52]

The devices process the information based on consumers' learned wishes and power accordingly. Price signals based on real-time-costs are given to "smart" home controllers or end-consumer devices mainly home's major energy-users like thermostats, washers and refrigerators. The house or office responds to the

[51] The Green IT Review (2011)

[52] NETL (2011)

occupants, rather than vice-versa. Because this interaction occurs largely automatically in the background, minimal human intervention is needed.

Visualization technology is another advanced metering system which is already used for real-time load monitoring and load-growth planning at the utility level. Such tools generally lack the ability to integrate information from a variety of sources or display different views to different users. This condition will grow even more acute as customer-focused efficiency and demand-response programs increase, requiring significantly more data as well as the ability to understand and act on that information.[53]

Implementing an advanced metering system or infrastructure programs is often considered as the primary component in Smart Grid efforts. Though the terms are not synonymous, the communications technologies and devices in AMI are key enablers of Smart Grid technologies. Advanced meters can better integrate “behind-the-meter” devices such as residential energy storage units, PHEVs, distributed generation, and various mechanisms for controlling or influencing load.[54]

AMI has developed over time, from its roots as a metering reading substitute to today’s two-way communication and data system. The combination of the electronic meters with two-way communications technology for information, monitor, and control is commonly referred to as AMI. Previous systems which utilized one-way communications to collect meter data were referred to as Automated Meter Reading (AMR) Systems. The evolution from AMR to AMI is illustrated in Figure 18 with lists of its stakeholders and benefits for each step in Smart Meter evolution. Not until the Smart Grid initiatives were established were these meters and systems referred to as smart meters and smart meter systems.[55]

[53] DOE (2008)

[54] EAC (2008)

[55] EEI (2011)

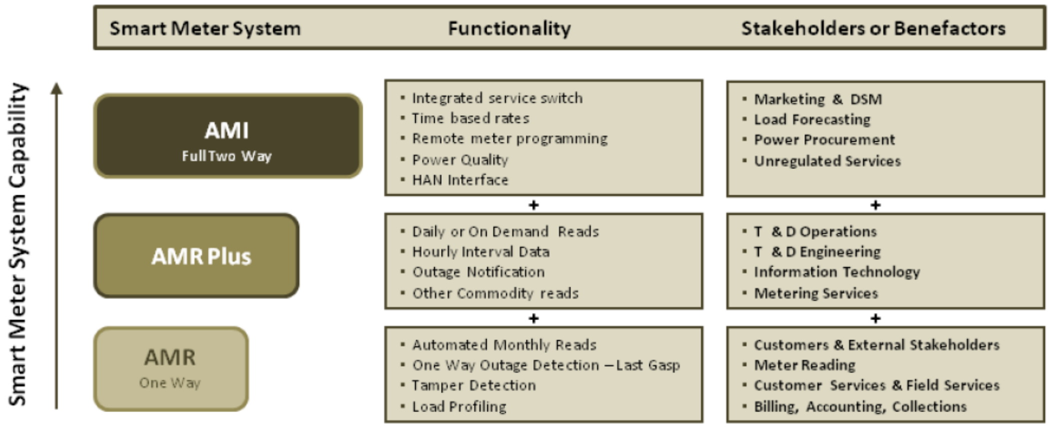

Figure 18 Smart meter technology evolution [56]

To summarize, AMI will provide a wide range of functionalities which are listed as follows: [57]

- Remote consumer price signals, which can provide time-of-use pricing information
- Ability to collect, store and report customer energy consumption data for any required time intervals or near real time
- Improved energy diagnostics from more detailed load profiles
- Ability to identify location and extent of outages remotely via a metering function that sends a signal when the meter goes out and when power is restored
- Remote connection and disconnection
- Losses and theft detection
- Ability for a retail energy service provider to manage its revenues through more effective cash collection and debt management

5.2 Demand Response

Demand response (DR) or Load Management in the electricity system is the mechanism by which end-users at the industrial, service or residential sector level alter consumption in response to price or other signals. It can both reduce peak demand, but also provide system flexibility, enabling the deployment of variable generation technologies. The fundamental goal of demand response is to reduce the peak load which occurs at certain times within minutes or hours in certain regions. The peak is characterized by a rapidly increasing load in real-time and requires

[56] EEI (2011)

[57] IEA (2011)

quick response from generating resources that are more cost intensive to operate. Reducing peak demand requires interaction between utilities and consumers' energy management and much wider use of time-differentiated electricity prices to ensure that consumers have a genuine incentive to adapt their consumption patterns. Demand at a system level is relatively predictable and ramps up and down slowly compared with variable generation.[58]

AMI and CS applications are expected to enhance the effectiveness of demand response on reducing peak load. Reducing load during peak load periods is a key tool for optimizing system assets. Demand response resources play a critical role in ensuring the reliability of the electricity grid; the Smart Grid will enable DR to be applied more broadly across the system. [59]

A 2008 FERC survey estimated that the potential demand response resource contribution from all U.S. demand response programs is to be about 5.8 percent of U.S. peak demands.[60]

Demand response programs are listed as follows: [61]

- Dynamic pricing without enabling technology where consumers respond manually to high prices at peak demand
- Dynamic pricing with enabling technology where consumers respond via automated devices to high prices at peak demand
- Direct load control where energy-intensive consumer devices are directly controlled by the utility during peak demand
- Interruptible tariffs where consumers agree to reduce demand to predetermined levels when called upon by the utility, in exchange for some incentive or rebate
- Other programs generally available to larger business consumers, such as capacity bidding, demand bidding, and aggregator DR services

[58] IEA (2011)

[59] NETL (2011)

[60] FERC (2008)

[61] NETL (2011)

5.3 Substation Automation

The substation was for decades one of the key locations for adding intelligence into the network, primarily at the transmission level. After many projects that demonstrate the value of pushing intelligence out to substations, utilities are typically establishing long-term transformation plans for their fleet of substations. This suite of intelligence usually includes: [62]

- Incorporation of intelligent electronic devices like digital relays, controllers, multi-function meters
- Substation Local Area Network and host processor
- Data concentrators and warehousing of real-time and event data
- Connectivity models and device attributes
- Communications to integrate substation level intelligence with grid operations and RTO applications
- User interfaces remote and local
- Condition monitoring sensors

Substation automation provides critical transmission level information to support analysis and optimization of transmission assets.

5.4 Distribution Automation

Distribution automation (DA) is an analysis and control application that monitors grid operational issues and dispatches controls to operate line-sectionalizing equipment to minimize impact of degraded conditions or actual outages. [63]

Distribution Automation solutions allow automatic management of grid generation, transmission, distribution and integration of distributed intermittent renewable energy sources like solar, wind, geothermal, etc. and new uses like PHEV. DA applications are improving system operation, reconfigure the system after disturbances, improve reliability and power quality, and identify and resolve system problems. Many applications can also be extended to a two way communication system with customer services, such as demand response and DER.[64]

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[62] NETL (2011)

[63] NETL (2011)

[64] Kapan (2009)

DA features an enormous opportunity to optimize energy efficiency of distribution networks, and improve the quality and reliability of the power supply. Two-way communications with the protection and control devices on the distribution portion of the Smart Grid is fundamental to achieving those energy efficiency and reliability goals leading to huge reductions in expenditure and wastage.

5.5 Distributed generation

Distributed generation (DG) is also known as distributed energy resources (DER), on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy. DER generates electricity from many small energy sources typically in the range of 3 kW to 10,000 kW. They contribute to the generation mix, support demand response to reduce peak load and improve reliability when the grid need their support. Currently, most of the electricity is generated in large centralized power plants mainly powered by fossil fuel, nuclear or large RES plants. The advantage is that those plants show very good economics of scale, whereas the drawback is the long distance electricity transmission as well as the negatively affect on the environment and their high costs. In the future, the challenge will be to efficiently and effectively operate this large number of distributed and diverse resources. Distributed generation reduces the amount of energy lost in transmitting electricity because the electricity is generated close to where it is used and it also reduces the size and number of power lines that must be constructed.

In general, these decentralized generation units produce heating and cooling energy as well as electricity. A successful operation of a virtual power plant requires the following technical equipment:[65]

- An energy management system that monitors, plans and optimizes the operation of the decentralized power units
- A forecasting system for loads that is able to calculate very short-term forecasts (1 hour) and short-term forecasts (up to 7 days)
- A forecasting system for the generation of renewable energy units. This forecast must be able to use weather forecasts in order to predict the generation of wind power plants and PV
- An energy data management system which collects and keeps the data that is required for optimization and forecasts, e.g., profiles of generation and loads as well as contractual data for customer supply

[65] IEC (2010)

- A powerful front end for the communication of the energy management system with the decentralized power units

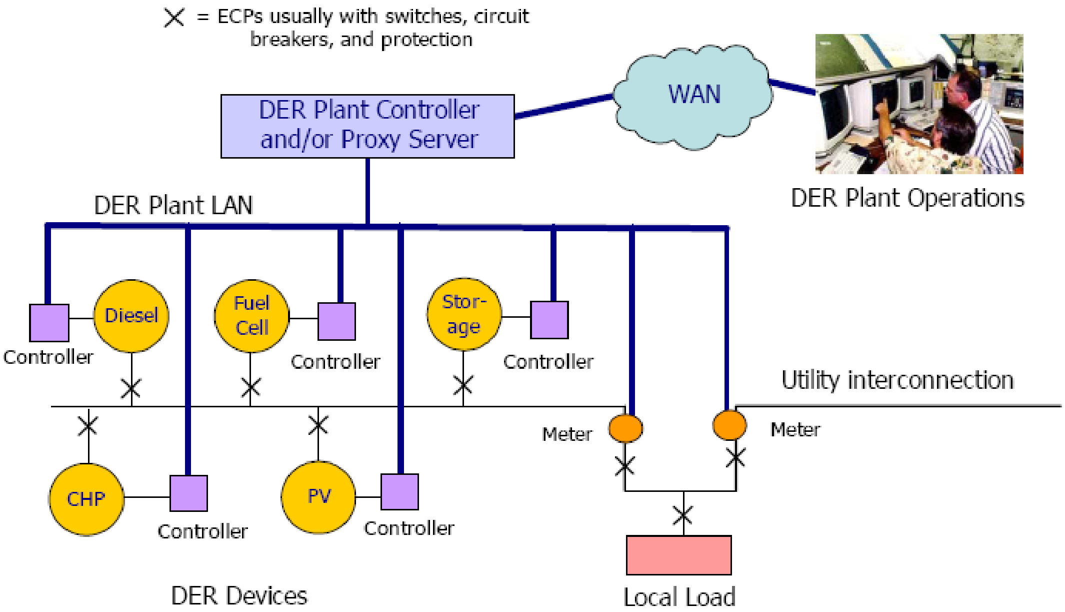

Figure 19 Example of the communication and control of a DER plant [66]

Another way to realize the potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a microgrid.

A microgrid is defined as a distribution system with distributed energy sources, storage devices, and controllable loads, that may generally operate connected to the main power grid but is capable of operating as an island.[67]
Microgrids are usually low voltage networks with DG sources, combined with local storage devices and controllable loads like water heaters and air conditioning. They have a total installed capacity in the range of between a few hundred kilowatts and a couple of megawatts. The unique feature of microgrids is that, although they operate mostly connected to the distribution network, they can be automatically transferred to islanded mode to provide a customized level of high reliability and resilience to grid disturbances. Within the main grid, a microgrid can be regarded as a controlled entity which can be operated as a single aggregated load or generator and, given

[66] IEC (2010)

[67] Kaplan (2009)

attractive remuneration, as a small source of power or as ancillary services supporting the network.[68]

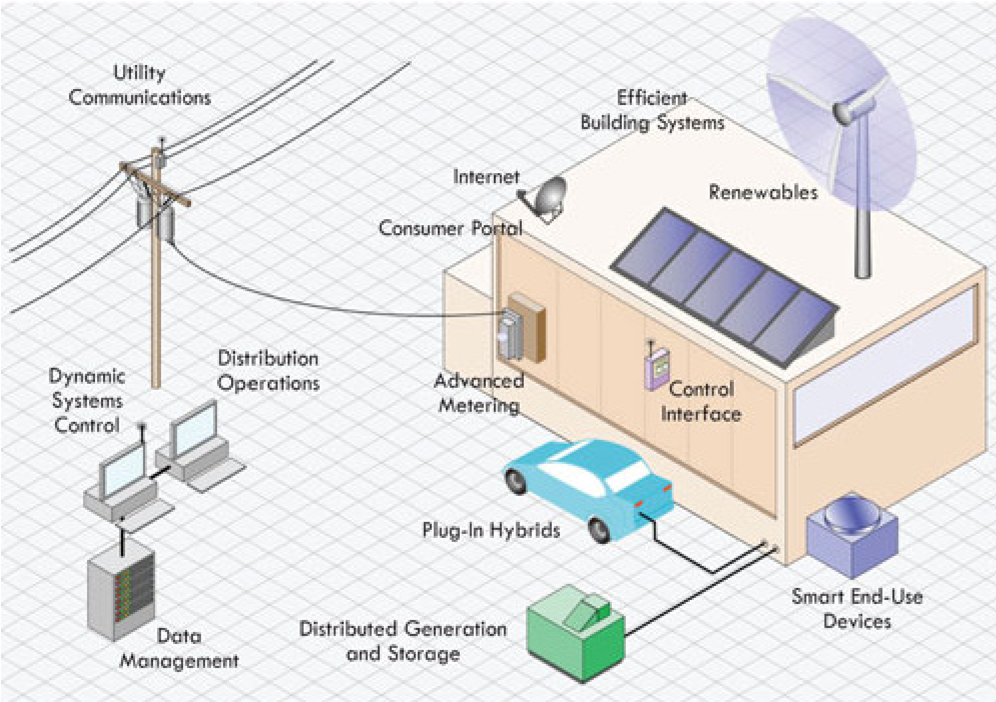

Figure 20 Microgrid on customer level [69]

Community microgrids represent a new level of intelligence and control methodology aimed at creating small control areas that optimize the local assets around the objectives of the community. Figure 21 illustrates the complexity of the community microgrid. [70]

[68] EU (2006)

[69] Galvinpower (2011)

[70] NETL (2011)

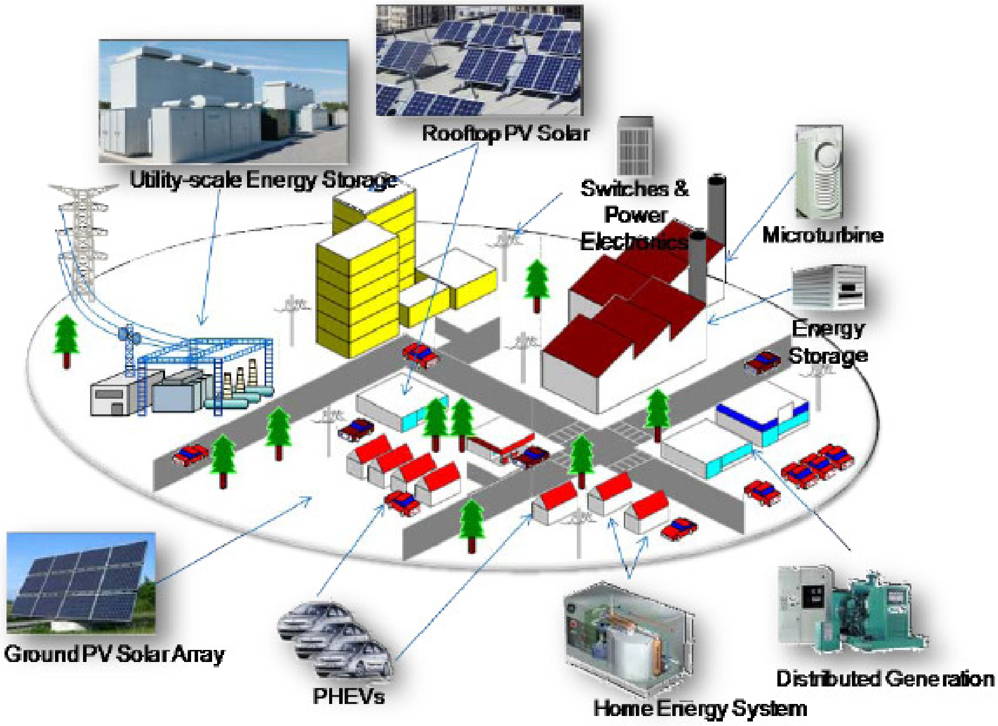

Figure 21 Community microgrid [71]

5.6 Home area networks

A home network or home area network (HAN) is an essential tool in the Smart Grids palette of offerings. It allows Smart Grid applications to communicate intelligently with multiple appliances in a home.

HANs are an extension of advanced metering infrastructure making a two-way communication between devices, users and the utility possible. Consumers can create HANs of smart appliances, thermostats, security systems, and electronics that are able to communicate with the grid and relay information back to the consumer.

Two-way communications facilities will allow appliances and security systems to initiate the conversation, notifying home and business owners of problems or safety alerts when they are away. The HAN implementation empowers the consumer to interactively manage these appliances or devices. The installation of intelligent appliances and in-home display units allow the electric utility to inform and motivate consumers to make energy efficient decisions based on time-of-use rate structures.

[71] Horizon Energy Group (2011)

HANs assist the utility in addressing peak energy demand with cost savings passed on to the consumer.

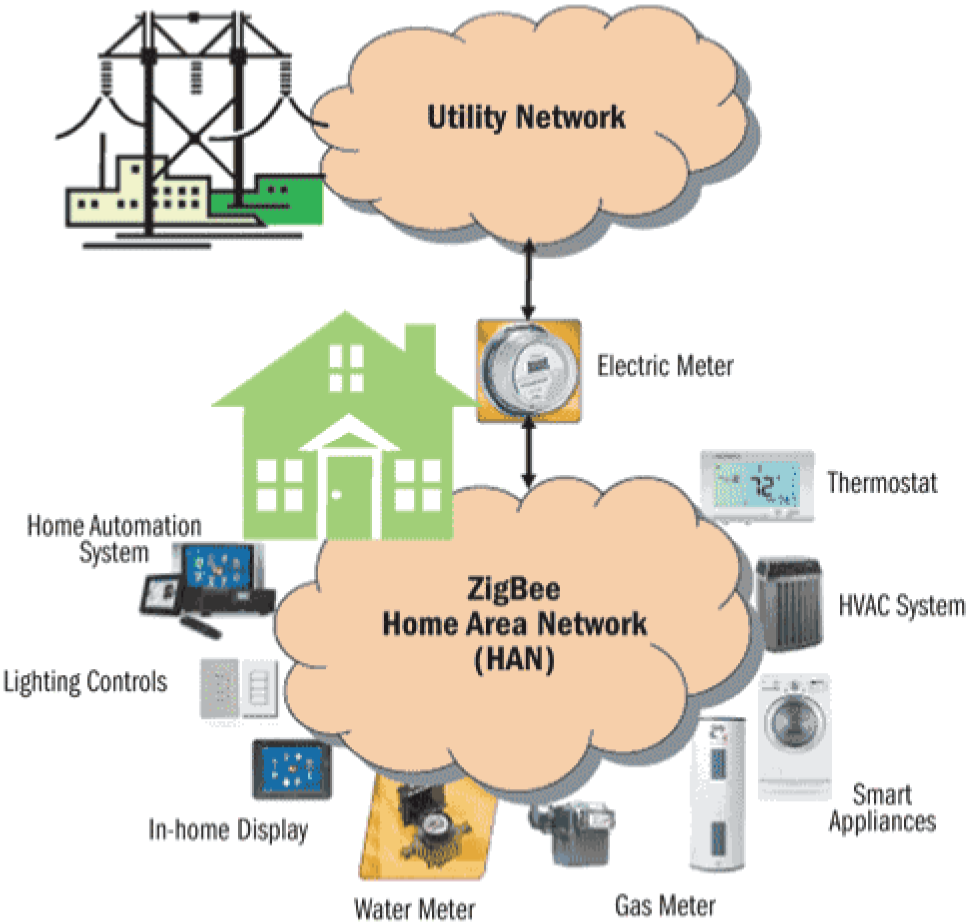

Figure 22 Home area network structure [72]

5.7 Distribution Management System

Distribution management systems (DMS) cover all the functions needed to efficiently operate a power distribution network from a control centre. Distribution networks are medium-voltage and low-voltage networks which distribute electrical power from a high-voltage network via substations and transformer stations to the consumers.[73]

Over the past few decades, management of the Energy Distribution Network has been progressively supported by Information Technology systems. The aim was to improve work-flow and optimize network operations and security. This has mainly resulted in the implementation of individual applications specific to each function and

[72] Earthfriendlyenergy (2011)

[73] IEC (2010)

functional group of the utility. Liberalization and deregulation force utilities to find new ways to improve supply quality and customer services and at the same time company profitability by saving costs in their business processes, while maintaining energy prices at a competitive level. A major solution to reach the additional company objectives will be through a better integration of their IT systems.[74]

Distribution networks cover an enormous area and employ an extremely large amount of electrical equipment. Operational requirements in such networks are multi-faceted and complex. This is why control technology calls for functions that precisely address these requirements and provide operational support. DMS serves as the integration mechanism for linking new Smart Grid applications with asset optimization applications. The key applications integrated within the DMS include the following features: [75]

- Common enterprise network electrical connectivity model - configuration controlled by the engineering design process and integrated with all other enterprise applications that require an up-to-date model to operate e.g. planning analysis tools, safety tagging, maintenance programs, crew dispatch
- Geographic information system (GIS) provides the locational dimension of assets and land base information
- Supervisory control and data acquisition (SCADA) provides primary monitoring of distribution assets and control signal infrastructure
- Customer Information System (CIS) is an application that contains customer-specific information
- Engineering Information System (EIS) contains engineering data, drawings, and records
- Advanced Metering Infrastructure (AMI) provides consumer usage information, power detection, and remote switching capability
- Outage management system (OMS) is an application for understanding the extent of outages and supporting the stabilization and recovery of the system from an outage
- Distribution automation (DA) is an analysis and control application that monitors grid operational issues and dispatches controls to operate line-

[74] IEC (2010)

[75] NETL (2011)

sectionalizing equipment to minimize impact of degraded conditions or actual outages

- Conservation Voltage Reduction (CVR) monitors and maintains feeder voltages closer to minimum levels by dynamically adjusting regulators and capacitor banks thereby reducing energy consumption and losses
- Maintenance applications and programs such as condition-based maintenance, asset health monitoring, and maintenance data and records
- Workforce Management System provides work status, location of field personnel, and work related information
- Distribution planning tools is an analysis applications that perform load flow analysis to identify strengths and weaknesses in the distribution system e.g. predicted future low voltage and overload conditions
- Advanced Network Applications provides functions that achieve optimum network utilization

Today's distribution grid operation is mainly characterized by manual procedures relying on the experience of an aging infrastructure. The great advantage of DMS is its capability to display multiple overlays from other applications to give operators and other users a complete context of various parameters. The deployment of DMS will enable a smart, self-healing grid by providing the following improvements:

- Reduction of outage occurrences and durations by applying advanced fault location and network reconfiguration algorithms
- Minimization of losses through improved monitoring
- Optimization of utilizing assets by management of demand and distributed generation
- Reduction of maintenance costs by online condition monitoring

5.8 E-Mobility

A Smart Grid is also necessary for plugging in the next generation of automotive vehicles, including plug-in hybrid electric vehicles (PHEVs). Such ancillary services are able to serve as a storage device. PHEVs take advantage of lower cost and off-peak capacity and can provide grid support during the peak periods. Renewable energy such as wind which often blows more at night when demand is low can then be borrowed back from the Smart Grid during the day when the demand is higher. An integrated communications infrastructure and corresponding price signals are necessary for an efficient handling of the increased load of plug-in hybrids and electric vehicles. [76]

It is evident that PEVs will increase the load on the grid in the future. The positively or negatively contribution to the electric system will depend upon how intelligent the electric system is implemented over the next decade. Smart charging devices will help manage this new energy device on already constrained grids and avoid any unintended consequences on the infrastructure. They allow PEVs to communicate with the utility, timing the charging to coincide with low prices during off-peak, low grid impact, and potentially low emissions periods. V2G takes this concept one step further by allowing PEVs to feed their power back into the grid to help stabilize voltage and frequency, reducing the need for spinning reserves and regulation services and thus avoiding emissions from electricity generating units that would otherwise need to provide these services.

E-Mobility serves the following functions:[77]

- Primary, secondary, tertiary reserve
- Manageable load
- Power system stabilization
- Power quality
- Load leveling and shedding
- Individual mobility (not relevant for Smart Grid)
- Energy conservation (increased efficiency compared to combustion engines)

5.9 Grid storage

Storage capacity is an essential method to balance supply and demand. Oversupply at one area can be stored at another, and this stored electricity can then be used as backup at any area in the grid, a long as transport capacity is available.[78]

Electric storage system technologies can be classified into two groups. The first group store electricity directly in electrical charges like capacitors that are highly efficient but have a low energy density and discharge typically in a short period of

[76] DOE (2008)

[77] IEC (2010)

[78] Greenpeace (2011)

time. The second group converts electrical energy to another form of energy that can be kinetic, potential, or chemical energy.

The most commonly used systems today work by converting electricity to kinetic like flywheel or potential energy e.g. pumped hydro or compressed air e.g. CAES and then discharging that energy back to the grid when needed. These systems have limiting factors such as lack of portability. Electrochemical energy storage systems, on the other hand, can efficiently store electricity in chemicals and then release it upon demand.

Electrical storage fulfills a number of functions in the grid including:[79]

- Serving as a spinning reserve
- Serving as a manageable load
- Power system stabilization
- Load leveling and shedding
- Reactive power support

Energy storage is a major element of Smart Grid. In the following sections the main storage systems are being discussed briefly.

5.9.1 Pump hydro storage

Pumped storages are the most widespread storage technology used in the world. They are in operation since more than one century and can be considered as traditional technology. Pump storage is a type of hydroelectric power generation that can store energy by pumping water up from a lower elevation reservoir to a higher elevation during times of low-cost, off-peak electricity. During periods of high electrical demand, the stored water is released through turbines. Losses in the pumping process make the plant a net consumer of energy overall, however the system makes income by selling more electricity during periods of peak demand, when electricity prices are highest. Pumped storage is the largest capacity form of grid energy storage now available. The technology is currently the most cost-effective means of storing large amounts of electrical energy on an operating basis but capital costs and appropriate geography are critical decision factors for building new infrastructure. Taking into account evaporation losses from the exposed water surface and conversion losses, approximately 70% to 85% of the electrical energy used to pump the water into the elevated reservoir can be regained when it is

[79] IEC (2010)

released. Pumped storage systems help control electrical network frequency and provide reserve generation along with energy management. Pumped storage plants can respond to load changes within seconds whereas thermal plants are much more inflexible to respond to sudden changes in electrical demand, potentially causing frequency and voltage instability.[80]

5.9.2 CAES

Compressed air energy storage (CAES) is a decades-old technology which takes excess energy from a power plant or renewable energy and uses it to run air compressors, which pump air into an underground cave or container where it's stored under pressure. When the air is released, it powers a turbine, creating electricity. Big utilities are starting to investigate this technology because it is one of the lowest-cost and simplest energy storage technologies.

5.9.3 Batteries

Lead acid batteries are the oldest, most mature form, of batteries for energy storage. The technology is relatively cheap and widely available but the chemistry has its barriers, including lower energy density and heavier weight.

Flow batteries are a decades-old technology that converts chemical energy into electricity. The electrolyte is usually stored in large external tanks, and the rate of how the power is stored and delivered can be managed. Another advantage of a flow battery is that it can be recharged quickly.

With lithium-based batteries much of the advancement in this sector is being done especially for the grid and for electric vehicles. Compared with the incumbent technology, lead acid batteries, lithium allows for faster charging, lighter weight, and higher energy density.

Sodium Sulphur or "NAS" batteries use simple ingredients: liquid sulphur and salt. They have been used on Japan's power grid for years.

The nickel–cadmium battery is a type of rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes.

[80] Greenpeace (2011)

The sodium or "zebra" battery uses molten chloroaluminate sodium as the electrolyte. They have been used in several EVs. The downsides to the Zebra battery include poor power density and the requirement of having to heat the electrolyte which wastes some energy and presents difficulties in long-term storage of charge.

5.9.4 Flywheels

Flywheels are large discs that spin in a vacuum and are sometimes used as backup power for an uninterrupted power supply (UPS), which are emergency power systems that turn on after a power outage before a generator kicks in. Flywheels have the benefit of needing little upkeep over a 20-year-plus lifetime and don't contain toxic chemicals like some batteries do. The amount of power delivered to the grid depends on how fast the flywheel spins. But flywheels have faced some hurdles in reaching mainstream commercialization including technology development, difficulty finding the right market and competition with batteries.

5.9.5 Fuel Cells

Fuel cells produce electricity through an electrochemical conversion, and can be quickly recharged by updating a fuel cell device with a new solution. Fuel cells have long been thought of as the holy grail of energy storage technology but have so far failed to make it to mainstream commercialization. They may fare better in the power grid market, since the need for rock bottom prices in the gadget and car markets has been one of their biggest barriers.

6 Challenges to deployment

The Pacific Crest Mosaic Smart Grid, surveying industry leaders with budgeting or technology section responsibility, named cost as the strongest barrier to Smart Grid projects. Technology immaturity is also a key barrier to Smart Grid projects but is rated a main barrier for fewer respondents.

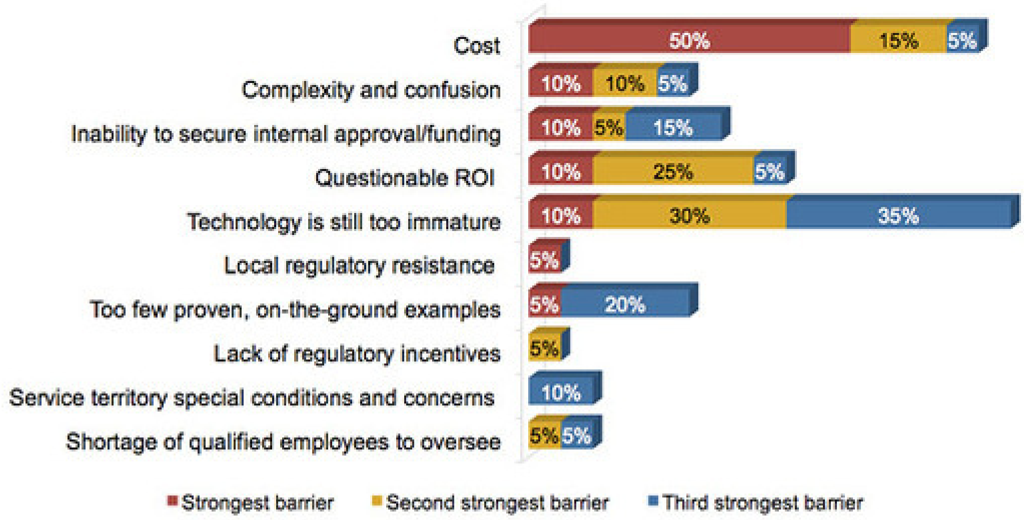

Figure 23 Barriers to Smart Grid[81]

The Smart Grid is broad in its scope and the potential landscape of challenges is also very large and complex. The fundamental issue is organization and prioritization to achieve an interoperable and secure Smart Grid.

The purpose of this chapter is to present the most significant barriers to achieving the principal characteristics of the Smart Grid and to offer some suggestions for addressing them so its vision can be realized.

6.1 Investment challenge

Grid modernization certainly cost money. The big question is of who is taking over the costs for the renewal of the electricity infrastructure. At present, there is a big gap between current and optimal investment. Mainly, grid operators and suppliers are expected to carry the main investment burden but the willingness to undertake any substantial investment might be limited. An optimal model for sharing costs and benefits along the value chain has to be developed. Clarity is missing on how to

[81] Smart Grid News (2009)

integrate the complex Smart Grids systems and how to choose cost-effective technologies, which technical standards should apply to Smart Grids in the future.[82]

In many cases, individual applications may not be cost effective in isolation, but where common infrastructure can be leveraged to accomplish a number of objectives, the value proposition can become compelling. Smart Grid investments often require a large upfront investment but future benefits may come in small incremental costs. Utilities and regulators may need to look at full service life cycle and benefits in order to fully justify investment. Some of the benefits may come back as social benefits and payback period may be longer than stakeholders would like.[83]

Intelligent electricity networks are a key component in the EU energy strategy, but substantial investments are needed to make them a reality. An overview of the distribution of Smart Grid project investments in the European Union is demonstrated in Figure 24. According to the European Commission, over 5.5 billion Euros has been invested in about 300 Smart Grid projects in Europe during the last decade. Around 300 million Euros has come from the EU budget. The investment costs of the Swedish smart meter roll-out with around 1.5 billion Euros with approx. 150 projects are not included in this illustration. Projects represented can span over more than one country and can include more than one category.[84]

[82] EC (2011)

[83] Kapan (2009)

[84] EC (2011)

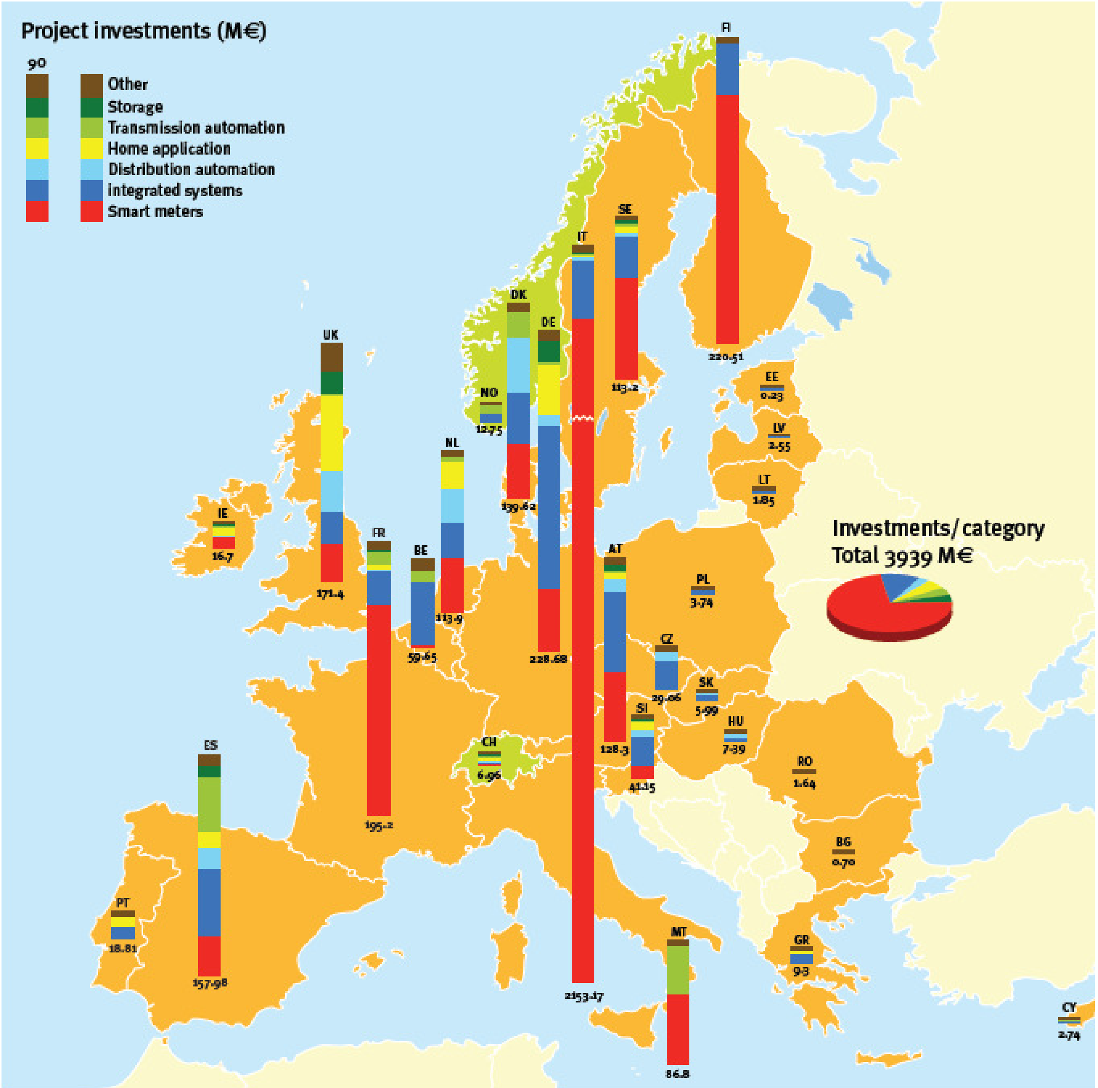

Figure 24 Distribution of Smart Grid projects in the European Union [85]

Future Smart Grid capital expenditures predictions heavily vary from source to source. According to a Greenpeace study by 2030, some 70 billion Euros investment in grid infrastructure is required to secure electricity supply 24 hours a day, 7 days a week with 68 percent renewable power in the mix. By investing another 28 billion Euros on expanding the grids by 2030, the constraining of renewable sources could be reduced to 1 percent. The total grid cost is limited to less than 1 percent of the electricity bill.[86]

The International Energy Agency estimates the total needed investments for Europe in the electricity grid to be 500 billion Euros until 2030 whereas the European

[85] EC (2011)

[86] Greenpeace (2011)

Technology Platform calculates the required investment in Smart Grids to be a total of EUR 390 billion by 2030.

KEMA estimates the investments of €1 trillion by 2030 needed to meet future demand. Demand growth of 2 percent means an additional of 1,250 TWh of power will be consumed. On the generation side, a replacement and expansion of 900 GW, and 500 GW of peak renewable energy sources will be needed by 2030. Transmission and distribution, a combination of ageing assets, system expansion and integration of RES and distributed generation is an investment of 500 billion Euros by 2030. Markets and regulations that support and enable the system will need over 20 billion Euros investment in data and information by 2030.[87]

Public policy plays a very important role in creating an investment environment in Europe able to attract Smart Grid investments. SAP addresses the current disincentives that need to be overcome as listed below:[88]

- Uncertainty over the regulatory framework, especially whether price regulation will allow for a reasonable return on investment
- Short-term vs. long-term: investments have to be undertaken now, while uptake by customers is still uncertain and full benefits will only occur in the long-run. This issue is especially important in energy markets that are already open to competition
- Lack of European standards that provide certainty, reduce the costs of technology through economies of scale, and ensure interoperability
- Investment inertia: the full benefits of Smart Grids will only be realized if all market players invest at the same time, which is difficult to coordinate; everybody is waiting for anyone else to take the first step
- Free riders: while the benefits of Smart Grids will be spread over the whole energy value chain, the investment burden lies on just a few players

Also, the European Commission perceives the importance to accelerate Smart Grid deployment and proposes to focus on the following points:[89]

- Developing technical standards
- Ensuring data protection for consumers

[87] KEMA (2011)

[88] SAP (2011)

[89] EC (2011)

- Establishing a regulatory framework to provide incentives for Smart Grid deployment
- Guaranteeing an open and competitive retail market in the interest of consumers
- Providing continued support to innovation for technology and systems

Therefore, the fundamental policy question is whether or not the current policy framework will overcome these disincentives. Addressing this question is urgent because Europe must exploit this unique opportunity to fund Smart Grid innovation and deployment as a core component of its power systems infrastructure in order to ensure an adequate, sustainable future electricity supply.

6.2 Technical challenge

There is a variety of technical challenges facing a Smart Grid. Some of the greatest are developing, implementing, and deploying the array of different technologies required to enable both sides to communicate in a cost-effective way. Most technologies are known, but their integration for example how well they work together is the key challenge for the success of the Smart Grid concept. [90]

Further technical barriers include standards, interoperability, cyber security and data privacy. Another major technical barrier is developing economical storage systems. These storage systems can help solve other technical challenges, such as integrating distributed renewable-energy sources with the grid.

6.2.1 Data Privacy

The transmission of sensitive private data among various players in Smart Grids has raised data privacy concerns. The main consumer protection issues associated with Smart Grid deployments include:[91]

- Privacy, ownership and security issues associated with the availability of detailed customer energy consumption data
- Customer acceptance and social safety net issues associated with new types of rates, especially dynamic pricing
- Consumer protection issues associated with remote disconnection functions made possible by smart grids

[90] DOE (2009)

[91] IEA (2011)

Customer data privacy, ownership and security issues are a leading concern of consumer and privacy advocates. Smart grid and smart meter deployments create large amounts of detailed customer-specific information, while energy providers gain a new medium for customer interaction. But an open and secure ICT infrastructure is a necessity of a successful Smart Grid implementation. Addressing interoperability, data privacy and security is a priority requirement to make the ICT infrastructure open and secure and reduce transaction costs among its users. It is essential to address these issues within the overall context of Smart Grid design and deployment planning. Otherwise there is a high real potential for some customers to react adversely or even be harmed.[92]

6.2.2 Cyber Security

In the past, communicating to field equipment was channeled through closed, proprietary communication infrastructures. Now, open and standard-based infrastructures are rapidly growing.

The Smart Grid offers great benefits with its openness and interconnection to participants, but it also implicates security challenges that must be addressed. The use of new ICTs can jeopardize reliability by vulnerabilities and has the potential for cyber attacks. Cyber security now must be a first-thought consideration and considered holistically. Effective security is not a set of bolt-on products to new or existing infrastructure. Secure development practices should be used to design and deliver the systems that will power the Smart Grid. Owners and operators must secure operational practices in order to help protect these vital services.[93]

Cyber security is being addressed by several collaborative international organizations. One recent US study summarized six specific challenges involved in securing the electric Smart Grid:[94]

- Aspects of the regulatory environment may make it difficult to ensure Smart Grid systems' cyber security
- Consumers are not adequately informed about the benefits, costs, and risks associated with Smart Grid systems

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[92] IEA (2011)

[93] Microsoft (2009)

[94] GAO (2011)

- Utilities are focusing on regulatory compliance instead of comprehensive security
- There is a lack of security features being built into certain Smart Grid systems
- The electric industry does not have an effective mechanism for sharing information on cyber security
- The electricity industry does not have metrics for evaluating cyber security

6.2.3 Storage technology

The ability to store electrical energy is limited. One of the most fundamental and unique limitations of electricity is that it can not easily be stored and then used at a later time. Although incremental progress is being made in energy storage research, the discovery of a disruptive storage technology would greatly accelerate grid modernization.

Cost-effective battery technology continues to be a challenge for PHEVs and EVs and local wind and solar resources. Serious considerations are discharge, battery life, size and weight. Additionally, incorporating battery power storage into current automobile frames will require manufacturing adjustments including systems to monitor the status of the battery as well as structural design changes to accommodate the battery itself.[95]

The Electricity Storage Association illustrates the estimated capital cost per cycle of various storage technologies before project financing costs, operation and maintenance costs, and replacement costs. As shown in Figure 25 the most existing technologies cannot meet the economic requirements with the exception of pump hydro storage and possible CAES. The high cost is related to insufficient performance and the high cost of raw materials and fabrication as well as the scale of production.

[95] DOE (2009)

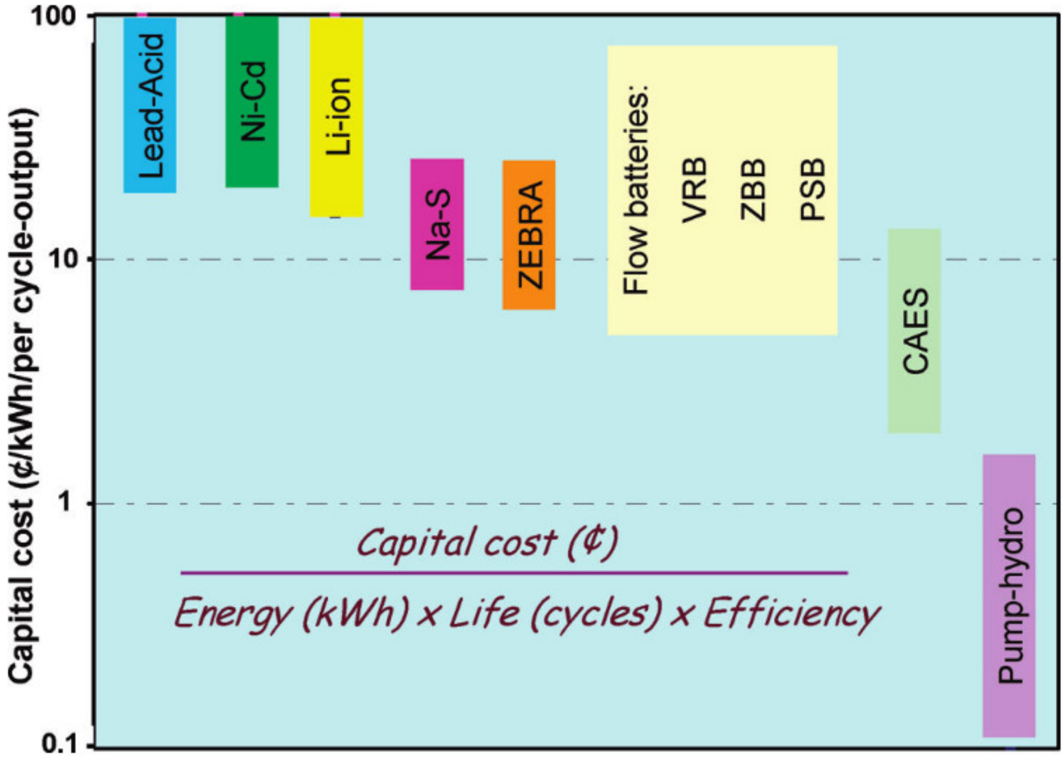

Figure 25 Comparison of varied electrical storage [96]

The energy storage technology especially in terms of batteries needs to improve. It is critical to bring down the cost and increase the reliability because without advanced batteries, electricity from wind and solar power must be used the moment it's produced because most commonly such as flywheels and pumped hydro and compressed air systems, have limiting factors.

6.3 Culture and Communication barriers

The successfully achieving of the Smart Grid vision depends on the involvement of all stakeholders educated in the Smart Grid vision, technologies, benefits and opportunities and united to accomplish it. More afford is need to communicate and educate the participants in this area.

On of the top challenges for the industry is overcoming the lack of education among consumer. The benefits of a modern grid have not been made clear to consumers but they need to understand the benefits a Smart Grid could bring, such as lower energy bills, greater energy efficiency and lower carbon emissions. Other potential components of the consumers' value proposition include:[97]

[96] ESA (2009)

[97] NETL (2007)

- More effective monitoring and control of energy consumption to reduce overall electricity costs
- Participation in future electricity markets for demand response, spinning reserve, energy, etc
- Enjoyment of future value added services that may be enabled by a modern grid

To involve the consumers is a required ingredient for grid modernization and consumer education is the first step in gaining their involvement.

6.4 Lack of Standardization and Regulation

“The biggest impediment to the smart electric grid transition is neither technical nor economic. Instead, the transition is limited today by obsolete regulatory barriers and disincentives that echo from an earlier era.” said Kurt Yeager, Executive Director of the Galvin Electricity Initiative and President Emeritus of the Electric Power Research Institute, in testimony before the House Committee on Energy and Commerce on May 3, 2007.

The electric power delivery system is very similar to the telecommunications network of the past. Some decades ago, one phone company was the monopoly provider of services across the countries, and it was illegal to plug other companies’ telephones and devices into that company’s network. Today, telecommunications choices and services are much greater thanks to legislation and technological advances that broke up the monopoly and later opened the door to competition in the telecommunications industry.[98]

6.4.1 Standardization

Standardization plays a key role in providing the ability of information sharing which will be required to enable the development of new applications for a successful future power system.

The major challenge is to integrate interchangeable parts from a variety of different providers worldwide. There is a big need for interoperability standards that will allow utilities to buy pieces of equipment from any vendor knowing that they will work with each other and with existing equipment at every level. Required is an interoperation at all levels in a given system, which goes beyond interfaces and one plug fitting

[98] EAC (2008)

with another. They not only need to speak the same language they also have to understand each other's processes. Instead of imposing detailed technical specifications at a global level we have to focus on key interfaces. Efficient standards for interoperability are creating a huge area of freedom and innovation for the benefit of manufacturers and the utilities. [99]

Updating your grid is going to be a huge task in itself, and there is always the temptation to do this in isolation. But in the future many national and regional grids, even if they are seemingly geographically isolated will need to be able to communicate with each other across borders and even across continents. By using international, consensus and building standards a built-in interoperability on a global scale will be developed. Since the investment into the Smart Grid is huge it is important to use standards that have been created under the same conditions and are monitored and updated through the same continuous processes.[100]

6.4.2 Regulation

Smart grids need smart regulation. Currently, the regulatory framework does not sufficiently encourage investments in distribution grids which cause the urgent need for action to remove regulatory constraints to investments. Important issues are the low achievable return on investment, missing investment incentives and the lack of consistency in national regulation policy.

A Eurelectric study showed that three quarters of the 45 European DSOs surveyed in 2007 have a lower return on invested capital than their WACC. The traditional regulatory framework has incentivised DSOs to reduce costs, including expenditure in areas such as R&D and skills renewal, whose benefits often extend beyond the lifetime of a price review period. This regulation is leading many DSOs to destroy, not create economic value. Therefore, smarter regulation is required and a revision of the regulatory financing model applied to DSOs is urgently needed. Such a model needs to be based on a clear-sighted, broad analysis of the benefits of DSO investment both in terms of customer service and environmental benefits, and to guarantee a fair long-term return on invested capital.[101]

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[99] IEC (2010)

[100] IEC (2010)

[101] Eurelectric (2011)

Also, the way of how utilities are compensated needs to be changed. An electric utility's revenue is tied primarily to the amount of power it sells. This business model was fine 50 years ago, in a world with seemingly unlimited resources and little evidence of climate change, but not today. Today, utilities have little motivation, to encourage customers to find ways neither to reduce demand nor to practice energy efficiency themselves. To encourage utilities to foster energy efficiency, we need regulations that establish new rate structures and business models. These will create incentives for utilities to earn revenue in ways that are not entirely linked to additional sales.[102]

Regulation will play a key role in incentivizing a smart allocation of resources by DSOs over the next decades. A balanced regulatory framework is needed that provides long-term incentives for efficient delivery on the one hand, including incentives for innovation, and on the other hand provides the necessary financial resources to allow DSOs to invest in R&D, demonstration and implementation of Smart Grids. But these investments may have little impact if they're not accompanied by new state-level regulations that give both utilities and customers strong incentives to better manage and reduce their electricity consumption. The challenge is to provide flexible regulation that leverages desired and developing technology through goal-directed and business-case-supported policy that promotes a positive economic outcome. A fair rate of return is an essential requirement for Smart Grid investments, along with the recognition that these investments which should be accepted in the regulatory asset base with the requirement of a shorter payback period. It is essential that this regulatory revision is in line with the needs of an energy-efficient power system and a low-carbon economy. Efficient national regulation is the key tool for driving the current development towards a highly modernized grid and regulators will be key facilitators in the process of modernizing the electricity networks.[103]

[102] DOE (2009)

[103] Eurelectric (2011)

7 Conclusion

Until 2050 the global electricity consumption is expected to increase by more than 115%, the global CO2 emissions will double and the European RES power generation is expected to increase by 40%. The transport sector is going to have a major impact on the energy sector by capturing a share of up to 10% of the overall electricity consumption by 2050. Also, the existing infrastructure dated back to the 1960s is reaching the end of its useful life and needs to be adapted to modern needs.
In short, the message is that an energy revolution is within reach. All these factors underline the importance of implementing a Smart Grid. There is no way around dealing with the ongoing rapidly changing electrical power landscape to achieve energy security, economic development and climate change mitigation.

Smart Grid is key enabler of mechanisms to bring energy savings and carbon emission reduction both directly through integration of more renewable energy and facilitation of PHEV adoption and indirectly through energy efficiency by maximizing demand response and load management, and minimizing use of peak loads. But the Smart Grid is more than one technology. The Smart Grid concept is an intersection of energy, IT, and telecommunication fields. The integration of smart technologies of many different kinds will be essential to a functioning Smart Grid.

We are still facing many different intertwined challenges. Financing remains a substantial challenge but there is also a variety of technical barriers. Some of the greatest are developing, implementing, and deploying the array of different technologies. Most technologies are known, but their integration and interoperability is a key challenge. Further barriers are the lack of standards and regulations, as well as cyber security and data privacy. Also, development of economical energy storage systems plays a critical role for the success of the Smart Grid concept.

Neither the government alone, nor the private sector alone, can accomplish the goal of modernizing the electricity system. Innovation for the energy systems and a smart system technology supported by international standards and regulations is the key to sustainability, reliability, and efficiency in energy supply. Realizing Smart Grids' potential will require a new level of cooperation between investors, consumers and especially governments acting as regulatory bodies. Collaboration is vital.

Abbreviations

ACM	Advanced control methods
ADEME	Agence nationale de l'environnement et de la maîtrise de l'énergie
AEIC	Association of Edison Illuminating Companies
AMI	Advanced metering infrastructure
AMR	Automated meter reading systems
AMS	Advanced metering system
Approx.	Approximately
BAU	business as usual
CAES	Compressed air energy storage
CCS	Carbon dioxide capture and storage
CHP	Combined heat power
CIS	Customer Information System
CO2	Carbon Dioxide
CVR	Conservation Voltage Reduction
DER	Distributed energy resource
DG	Distributed generation
DOE	Department of Energy
DSM	Demand side management
DSO	Distribution system operators
EAC	Electricity Advisory Committee
EC	European Commission
EEGI	European Electricity Grid Initiative
EEI	Edison Electric Institute
e.g.	For example
EID	Energy information display
EIS	Engineering Information System
EISA	Energy Independency and Security Act
EPBD	European Performance Building Directive
EREC	European Renewable Energy Council
ERGEG	European Regulators' Group for Electricity and Gas
EPRI	Electric Power Research Institute
ESA	Energy Storage Association
ETP	European Technology Platform

EU	European Union
EV	Electric vehicle
FERC	Federal Energy Regulatory Commission
GAO	Government Accountability Office
GeSI	Global e-Sustainability Initiative
GHG	Greenhouse gas
GIS	Geographic information system
GPS	Global Positioning System
GTM	Greentech Media
HAN	Home area network
ICT	Information and communication technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IIDS	Improved interfaces and decision support
LAN	Local area network
LDV	Light-duty vehicles
Li-ion	lithium-ion
LPG	Liquefied natural gas
Na-S	sodium–sulfur
Ni-Cd	nickel–cadmium
OECD	Organization for Economic Cooperation and Development
OMS	Outage management system
O&M	Operation & maintenance
PEV	Plug-in electric vehicles
PHEV	plug-in hybrid electric vehicles
PMU	Phasor Measurement Units
PNNL	Pacific Northwest National Laboratory
PV	Photovoltaic
RES	Renewable energy source
RTO	Regional transmission operator
RTP	Real time pricing
R&D	Research and development
SA	Substation automation
SCADA	Supervision control and data acquisition
TOU	time-of-use
TWh	Terawatt hours
U.S.	United States

UTC	Utilities Telecom Council
VRB	vanadium redox battery
V2G	Vehicle to grid
WACC	Weighted average cost of capital
WAN	Wide area network
ZEBRA	sodium aluminumchloride
ZBB	Zinc Bromine Battery

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