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The Smart Grid in Europe:

The Impact of Consumer Engagement on the Value of the European Smart Grid

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Thesis for the fulfillment of the

Master of Science in Environmental Management and Policy

Lund, Sweden, September 2011

IIIEE Theses 2011:33

Published in 2011 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
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ISSN 1401-9191

Acknowledgments

This space is too limited to thank everyone who contributed at some point to this work, but I want to thank the team at Green Tech Media, especially Rick Thompson and David Leeds for the opportunity to work with them on the European smart grid report while doing my thesis research. The report "The Smart Grid in Europe 2012-2016: Technologies, market forecast and utility profiles" is available online [1].

I am also grateful to Oksana Mont for her valuable feedback during my thesis work and to Andrius Plepys for his feedback and recommendations in the preparatory phases. I would also like to extend my special gratitude to Johan Soderbom, Maikel van Verseveld and everyone else I interviewed, for their contributions to my understanding of the European smart grid situation and its dynamics. Thank you also to my fellow IIIEE Master students and staff for a very memorable year in Lund. Last but not least, my gratitude goes out to Leonor Torres for keeping me ambitious and to my parents for their never-ending support.

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[1] http://www.greentechmedia.com/research/report/the-smart-grid-in-europe-2012

Abstract

Smart grid technology is promising significant increases in efficiency for the electricity industry, savings for end-consumers and associated reductions in CO2 emissions for society. Yet smart grids in Europe are developing slower than expected. This work describes the drivers and barriers for the development of the smart grid in Europe and investigates how to increase the value creation for utilities, consumers and society through the maximization of consumer engagement with smart grid technology.

Consumer engagement has a profound impact on the value of the smart grid for utilities and for society through estimated potential savings in construction of peak capacity of up to €9 billion per year from peak load shifting through demand response and up to an estimated €18.2 billion in annual savings from reduction in absolute power consumption. This study demonstrates that the business case for smart grids in Europe is much more obvious for society than for utilities; therefore, forward-looking regulators should drive the development of the smart grid in Europe by putting incentives and policies in place.

Using the theories of Regulatory Engagement, Affordances, Transaction Cost, Social Comparison and Diffusion of Innovation and reviewing results from numerous demand response pilot tests around the world, this thesis discusses best practices and develops recommendations for utilities and for regulators. It concludes that utilities, regulators and intermediaries should not just focus on technology or financial incentives, but more importantly should improve the classical marketing function in utilities, i.e. understanding the behavior and fulfilling the functional and emotional needs of different consumer segments. According to the author, lowering or eliminating transaction costs for consumers and strengthening social interaction, norms and values around energy use are key levers for increasing consumer engagement, which are largely overlooked by utilities and regulators.

Keywords: smart energy, smart grids, energy efficiency, consumer engagement, utility business case

Executive Summary

The power industry and regulators have hailed the smart grid as a key contributor to Europe's move towards energy independence and the reduction of greenhouse gasses, through its potential of increasing efficiency in the transmission, distribution and use of electricity. Investments in smart grid technology are forecast to grow very significantly over the coming decade. However, despite the considerable push provided through the EC's 20-20-20 mandate and promises of significant economic and environmental benefits, the smart grid is developing at different speeds around Europe. Therefore this thesis first investigates the drivers and barriers to smart grid development in Europe and aims to investigate how one of these factors - consumer engagement - can be maximized and thereby the value generated by the smart grid increased.

The development of the smart grid could be seen as an evolution from the old, centralized production and distribution of electricity to a modern network incorporating two-way end-to-end communication and largely decentralized automated management of generation, transmission and distribution. It incorporates technologies such as advanced metering (AMI), distribution automation (DA), integration of distributed and renewable electricity generation (DG/RES), advanced energy storage, electric vehicle (EV) charging infrastructure and ICT for systems management and data security, and enables applications such as demand response (DR) and energy management services and home automation networks (HAN), all of which are briefly described in this work.

This thesis demonstrates that the development of the smart grid in Europe is driven by a) the EC's 20-20-20 targets and policies in line with the Third Energy Package, b) issues of energy security and quality, induced by the move to renewables, as well as c) promises of economic benefits for utilities and society as a whole, consisting mainly of improvements in operational and user efficiency, reduction of peak power, reduction of absolute consumption levels and job creation and d) enabling technologies such as advanced metering infrastructure (AMI), electric vehicles and micro-renewables. The factors slowing down the deployment of smart grid technology include a) inconsistent policies and regulations in different EU member states, b) market distortions, the weak financial situation of some of the utilities and uncertainty regarding investment payback for the utility, caused by unbundling of transmission and distribution as well as uncertainty about lower peak load and consumption levels, c) technological challenges involving data safety, interoperability and integration of ICT and d) a lack of attention to consumer engagement, which in some cases has turned consumers against the new technology.

The smart grid will create monetary and non-monetary value for governments and regulators, for consumers, for utilities and network operators and for electricity retailers. This work specifically investigates the impact that consumer engagement has on the value of the smart grid for utilities and for society. It establishes that a fully rolled out smart grid in Europe has an annualized capital and operational expense of between €7.8 billion and €9.1 billion. Apart from generating savings in operational expenses and reductions in transmission and distribution losses, in conservation voltage and in societal costs of power outages and CO2 emissions, the analysis of monetary smart grid benefits conducted in this thesis concludes that peak load shifting through demand response is likely to generate estimated savings in construction of peak capacity of up to €9 billion per year. Furthermore, up to an estimated €18.2 billion in annual savings can be achieved from reduction in absolute power consumption. Both of these potential savings are highly dependent on the level of consumer engagement achieved. This study demonstrates that the business case for smart grids in Europe

is much more clear for society than for utilities. This explains why utilities have been somewhat reticent to make large investments in smart grid technology without having the regulatory support or certainty that the benefits of these investments would accrue to them. It also leads to conclude that forward-looking regulators should be proactive in putting incentives and policies in place, both at the consumer and at the supply side, to drive the development of the smart grid in Europe.

Despite the fact that considerably lower levels of electricity use per household in Europe (just over 4,000 kWh) compared to the USA (around 11,000 kWh) theoretically imply a lower potential for savings through demand response, European consumers, depending on their response to feedback and price mechanisms, can generate the very significant savings mentioned above. Consumer 'buy-in' with smart grid technology has been identified by utility CEO's as one of the key barriers to smart grid deployment. Therefore, this thesis further analyzed how to maximize consumer engagement with smart grid technology and thereby increase the value creation for utilities, consumers and society.

The challenge of increasing consumer engagement with smart grid technology is one of behavioral change. Therefore, this thesis reviews a review of the theories of Regulatory Engagement, Affordances (for which an expanded version is proposed to include the socio-environmental stimuli that influence and form individual actors' motivation and experience), Transaction Cost, Social Comparison and Diffusion of Innovation and assesses how their learning can apply to consumer engagement with electricity use. Comparing these theoretical conclusions with results from numerous demand response pilot tests around the world, this thesis provides best practices of different types of pricing and feedback schemes and offers recommendations for utilities and for regulators.

Utilities, regulators and intermediaries are recommended to not just focus on technology or financial incentives, but are encouraged to improve the classical marketing function, i.e. understanding the behavior and fulfilling the functional and emotional needs of individual consumer segments. It is recommended to focus initial efforts for consumer engagement on the segment of 'early adopters', because they will drive the posterior diffusion to other consumer segments. Feedback to consumers about their individual electricity consumption is most likely to result in persistent reductions if the feedback is given with high frequency over a longer period, preferably disaggregated to the level of individual appliances, accompanied by historic and social comparisons and actionable advice and incentives that underline the hedonic, rather than functional benefits.

Regulators and public bodies are recommended to improve communication about societal goals, encouraging individual consumers and utilities to align their goals and actions accordingly. I argue that, rather than focusing on technology, key levers for increasing consumer engagement are to be found in lowering transaction costs for consumers and strengthening social interaction, norms and values around energy use. These levers are largely under-utilized by utilities and regulators. In my opinion, EC policy would be more effective if it mandates the provision of timely, accurate, specific and comparative consumption feedback to end consumers, rather than mandating installation of smart meters, as is happening currently. As long as no set-and-forget technology or applications are available that would completely take over decision-making for consumers (thus eliminating transaction costs), forward-looking utilities and regulators that wish to increase the value creation from smart grid technology should put maximizing consumer engagement top of their agendas.

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Abbreviations

AMI	advanced metering
ACEEE	American council for an energy efficient economy
ANA	association of national advertisers
AMR	automated meter reading
CCS	carbon capture and storage
CCV	co-created value
CHP	combined heat and power
CORDIS	community research and development information service
CAES	compressed air energy storage
CPP	critical peak pricing
DR	demand response
DLC	direct load control
DG	distributed generation
DA	distribution automation
DSO	distribution system operator
EIA	(US) energy information administration
EPRI	electric power research institute
EV	electric vehicle
EV/PHEV	electric vehicle / plug-in hybrid electric vehicle
ETS	emissions trading system
EMS	energy management system
ESO	energy service providers
CENELEC	European committee for electro-technical standardization
CEN	European committee for standardization
EEGI	European electricity grid initiative
EEMO	European energy markets observatory
ENTSOE	European network of transmission systems operators for electricity
ESMA	European smart metering association
ETP	European technology platform
ETSI	European telecommunications standards institute
FDIR	fault detection, isolation and restoration
GPRS	general packet radio service
GHG	greenhouse gasses
GDP	gross domestic product
HVDC	high voltage direct current
HAN	home automation networks
HEM	home energy management
ICT	information and communication technologies
IEEE	institute of electrical and electronics engineers
IEE	intelligent energy Europe
IEA	international energy agency

CIRED	international environment and development research centre
JRC	joint research centre
LTE	long term evolution standard
MV/LV	medium voltage / low voltage
MDM	meter data management
MDMS	meter data management system
NGO	non governmental organization
OFGEM	office for gas and electricity market
OGEMA	open gateway energy management alliance
OECD	organization for economic cooperation and development
PTR	peak time rebate
PV	photo voltaic
PLC	power line communication
RF	radio frequency
RTP	real time pricing
RTP	real-time-pricing
RES	renewable energy source
RD&D	research, development & demonstration
SEM	single electricity market
SEDC	smart energy demand coalition
SG-ETP	smart grid European technology platform
SETIS	strategic energy technology information system
SCADA	supervisory control and data acquisition
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
TOU	time-of-use
T&D	transmission and distribution
TSO	transmission system operator
UNEP	United nations environment program
USDOE	US Department of Energy
V2G	vehicle-to-grid
VVO	Volt/VAR optimization
WEF	world economic forum

1. Introduction

The European electricity sector is going through the most dynamic phase of its existence to date. Market liberalization and unbundling, mandated by the EU's Third Energy Package (Morris, 2008), have caused a wave of mergers and acquisitions, as well as the emergence of new service providers. The strong regulatory push resulting from the EU's 20-20-20 targets has caused a boom in the installation of renewable power generation, as well as large-scale rollouts of smart metering and the implementation of distribution automation programs. Electric vehicle charging infrastructure is being developed and is starting to be deployed in almost all European markets.

Pan-European R&D projects are shaping the future of the European smart grid. Leaders and start-ups from the IT and communication sectors are teaming up with utilities for the development of systems that maximize the efficiency of utility resources. Consumer applications are being developed that promise significant savings in end-consumer usage of electricity. However, deployment of the smart grid is happening at different rates around Europe, depending on national regulatory agendas and embedded interests on the part of the utilities.

Literature analysis and this thesis demonstrate that one of the barriers for development of the smart grid in Europe is lack of consumer engagement, which has a potentially huge impact on the total value creation of the smart grid. However, this barrier is still relatively little understood. Regulators have largely focused on rollout of smart metering technology, rather than on changing consumer habits. Similarly, most utilities and technology suppliers have focused their research and pilot projects on technology development, rather than on incorporating behavioral science into the design of their services and products. This is despite recent examples of consumer backlash against smart meters in California, the Netherlands and Germany and despite consumer engagement and buy-in having been identified as the main concerns in surveys among electricity utility CEOs (Comverge, 2010).

Apart from Faruqui (2010), very few efforts have been made to quantify the potential value of the smart grid in Europe from the utility and societal points of view. On the qualitative side, efforts have been made by Darby (2006, 2010), Ehrhardt-Martinez (2010) and Faruqui (2009) to classify and quantify the results of trials to increase consumer engagement through demand response and feedback mechanisms. The impacts of consumer engagement for utilities and regulators are potentially significant and closely interlinked (although not always aligned), and it should be in the interest of utilities and regulators to understand how each can increase consumer engagement and thus maximize the value of the smart grid, which is the topic of this thesis.

1.1 Background

Electricity has been a powerful driver of economic growth and wellbeing worldwide. Electricity generation is forecast to grow from 18,800 TWh in 2007 to 35,200 TWh in 2035 (EIA, 2010). However, electricity consumption alone is causing 17% of anthropogenic greenhouse gas (GHG) emissions (IEA, 2004) and as such should be one of the main areas of focus for mitigation of climate change.

In the EU-27, gross electricity generation is expected to grow from 3,362 TWh in 2007 to at least 4,073 TWh in 2030, not even taking into account the possibility of significantly higher demand because of deployment of electric vehicles (EV) (Oettinger, 2010). Most of Europe's energy needs are supplied from fossil fuel resources, largely imported into the European Union.

Energy demand continues to increase, while fossil fuel resources are shrinking and set to steadily become more expensive. At the same time, climate change and pollution have become issues of concern to European citizens. Through EU Directive 2009/28/EC, the EU has set an ambitious 20-20-20 target for 2020, committing to increase renewables' share of energy production to 20%, increase energy efficiency by 20% and lower CO2 emissions by 20% compared to 1990 levels.

The smart grid is hailed by regulators and industry players as one of the key opportunities to save energy and lower CO2 emissions, but deployment of the smart grid seems slow, as has been reported by numerous observers, including Vikash (2010) and Giglioli (2010).

The smart grid is a complex concept, involving not only distribution of electricity, but also data generation and communication systems and complex management applications. It also involves a wide variety of players, from electricity producers, grid operators and electricity retailers to hardware and software producers, industry giants and start-ups, investors, regulators and 'prosumers' (consumer and micro-producer).

Ernst & Young (2010) recently identified ICT, Greentech and Electricity Utilities as leading growth areas over the coming ten years. It is the convergence of these three sectors that creates the smart grid, which makes this one of the most exciting sectors to emerge. The upgrading of old electricity grids with information and communication technology to modern 'smart' grids facilitates the integration of renewable energy and improves operational efficiency of the grids. It also enables savings in end-consumption of electricity and allows for shifting of demand load through the involvement of empowered consumers, thus reducing the need for construction of expensive extra peak capacity.

Energy efficiency measures generally have a lower GHG abatement cost than investment in nuclear or renewable power generation or carbon capture & storage (McKinsey, 2010). Smart grid technology and applications have the potential to increase the efficiency of electricity distribution as well as the efficiency of in-home electricity use. This is an incentive for policy makers, utilities and scientists to prioritize the development of the Smart Grid.

1.2 Research questions

The development of the smart grid is taking place at different speeds in different European member states and there seems to be a consensus that the development to date has not been progressing as fast as expected. The thesis aims to put together a comprehensive overview of the drivers and barriers that cause the development to be slower than expected and then zooms in on one of the key barriers, consumer engagement, to determine its specific impact on the smart grid value creation and investigate how consumer engagement with smart grid technology can be maximized.

The research questions therefore can be defined as follows:

Main research questions:

1. Why is the smart grid in Europe not developing as quickly as expected?
2. How can the development of the smart grid in Europe be facilitated by maximizing the impact of consumer engagement on the value of the smart grid?

To answer the second research question, it is necessary first to establish the total value that the smart grid in Europe could potentially represent and then determine what impact consumer engagement could have on the potential generation of value through smart grid technology.

Thus the sub-questions are:

a. What is the projected value of the smart grid in Europe?
b. What impact does consumer engagement have on the value of the smart grid in Europe and how can it be maximized?

1.3 Methodology and analytical framework

This thesis has been done in parallel with work that I have performed over the last 6 months with Green Tech Media (GTM) Research in New York, to forecast the estimated value of the smart grid in Europe over the next 5 years. While studying the business case for smart grids and the barriers and drivers to its development, I was struck with the industry's focus on technology and the lack of focus on the ultimate enabler of smart energy, the user. This thesis investigates this specific aspect: the impact of consumer engagement on the value of the European smart grid.

For GTM Research, between February and August 2011, I mapped the development and forecasted the European market for smart grid technology in a more than 130 page report titled "The smart grid in Europe 2012-2016: Technologies, Market Forecasts and Utility Profiles" (Van der Zanden, 2011).

To understand the smart grid technology, the drivers and barriers for its development in Europe and the role of consumer engagement for its further dissemination and value creation, I performed an extensive literature analysis and 13 personal interviews with industry players, policy makers and researchers/consultants. I also deepened my understanding of smart grid technologies through email correspondence with a 5 researchers and regulators as well as by starting a discussion on the IEEE Smart Grid Linked-in Blog [2], which generated 19 spontaneous contributions from industry insiders.

The drivers and barriers for smart grid development mentioned in the literature are generally of normative and qualitative nature. This compelled me to look into the economic drivers and barriers in more detail, by means of constructing the economic business case for smart grids from a utility and societal point of view. The quantitative value forecast of the investments that will go into smart grid technology over the coming years and the estimated benefits that these investments will generate required me to make key assumptions about the cost and rate of deployment of each of the technology components that constitute the smart grid. To support my assumptions, I gathered information from industry players, regulators and research- and consulting firms, through extensive literature review and the abovementioned personal interviews with 13 industry insiders and consultants. Both sources and methods are described in detail later in this chapter.

The market forecast included a comparison of the business case from the point of view of utilities and from the point of view of society, which in turn allowed me to highlight the value that is directly influenced by consumer's response to, or engagement with, smart grid technology, which is one of the focus areas of this thesis.

The thesis uses some of the high level findings of the GTM Research report. Since the details of the calculation of the market value forecasts and business case for smart grids in Europe are not the main topic of this thesis and the details of the report are confidential to GTM Research, I do not mention these details (cited in the GTM report authored by me) in the thesis, but I do utilize the main findings, analytical outcomes and conclusions of this work in the thesis.

Literature analysis

For a complete analysis of drivers and barriers, as well as to deepen my understanding of smart grid technologies and applications and support my assumptions for the smart grid market forecast, I reviewed both plans for implementation and reports of the real progress made to date. In order to collect information from different perspectives regarding the smart grid situation, information was solicited from three different sources: government/EU organizations, industry players/associations and research/consulting firms. The perspective of research and consulting firms (gained from interviews as well as literature review) was to provide an 'independent' perspective, since the information from the government/EU organizations is often normative and motivated by political goals, while industry players and associations typically follow their own commercial agenda that shapes their plans and forecasts.

The literature analysis was conducted entirely over the Internet and included the following:

- Documents from regulatory and government bodies (including EC, JRC-SETIS, SmartRegions, EEGI, UNEP, Smart Grids ETP) which describe the concept of the smart grid in the context of the EU 20-20-20 targets and provide road maps for development of the smart grid.

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[2] http://www.linkedin.com/groups/Differences-between-US-European-Distribution-

- Documents that define RD&D priorities and plans that enable the development of the smart grid in Europe (including JRC-SETIS, SET Plan, CORDIS, IEA).
- Plans and progress reports by industry associations and R&D consortia (including ESMA, EPRI, EEMO, IEA, ENTSOE, Smart Energy Alliance; CIRED, OGEMA, Eurelectric) to get a clearer picture of the priorities and steps the private sector is taking towards a smart grid.
- Documents from NGO, research- and consulting firms (reports and white papers from Greenpeace, Fraunhofer, WEF, KEMA, Bloomberg, Accenture, Capgemini, Atos, PWC, Zpryme, GTM Research) were very helpful in establishing the strategic 'big picture'.
- Presentations by technology/industry experts (including ABB, Schneider Electric, Siemens, eMeter, IBM, Toshiba, RWE, Enel, GDF Suez, Endesa, EDF, EDP, E.ON, NEFCO, CleanTech Group)
- Descriptions and evaluations of pilot studies and cost of technologies (including EnergyWatch, ESMA, EPRI, Europe's Energy Portal)
- Articles in industry and academic journals
- Websites and annual reports of the 15 main utilities in Europe.

Personal interviews and e-mail correspondence

To get different perspectives on the situation and test the findings of my own qualitative analysis of Europe's smart grid development, I conducted 13 in-depth interviews with industry insiders, such as higher management executives in charge of R&D, strategy and business development at utilities, suppliers of hardware and system developers, as well as consulting firms. The interviews aimed to better understand smart grid technology and the drivers and barriers for its deployment from different stakeholder perspectives, and to gather information and support the assumptions for my smart grid market forecast. I sent out 20 requests for interviews and ended up conducting 13 interviews, which generally lasted 40 to 70 minutes. In most cases, to orient the interviewee, I sent out a list of questions in advance. These questions were a mix of open and closed questions, covering the topics of general smart grid development, smart grid investment (including questions to help me estimate the cost and rate of deployment of the individual technology components that make up the smart grid), regulations and consumer engagement.

For further research leads, at the end of each interview, interviewees were asked to provide contacts of other potential interviewees, as well as any documents or white papers that they would recommend. The list of questions is attached in appendix B.

In order to structure my understanding of the forces that shape the business of electricity distribution, I used Michael Porter's 5-Forces framework (Porter, 1979), to which I added an additional force: socio-eco-political influences, that are particularly relevant in Europe because regulatory mandates constitute one of the strongest drivers behind the development of smart energy. Throughout the thesis, I refer to this expanded framework as the (5+1)-Forces model.

I used the S-curves model of technological development and diffusion, as proposed by Rogers (1963) in the Theory on Diffusion of Innovation, to explain the evolutionary rather than substituting nature of the smart grid. The S-curve model has been very useful in describing the evolution of whole industry sectors and broad concepts, such as the evolution of transportation modes over time, as described in Grübler (1998).

To answer the question of how to maximize the impact of consumer engagement with smart grid technology, I sourced from the Theory of Affordances, for which I actually propose an expansion, as well as (Regulatory) Engagement Theory, Transaction Cost Theory and Social Comparison Theory. I then compared the learning from these theories with the findings from several pilot tests on consumer response and engagement, as reported by S. Darby (2006, 2010), A. Faruqui (2009), Ehrhardt-Martinez (2010), as well as my own review of results of 24 consumer demand response pilot tests performed in Europe between 1982 and 2009.

1.4 Scope and limitations

The development of the smart energy in Europe is different from the USA, China or Japan. This study focuses on the European situation and on smart grids. It excludes the micro grids and super grids, as defined by Van de Putte (2011). Some analysts divide smart energy into smart generation, smart metering, smart grid and smart consumption. These four components are highly interrelated. My focus will be on the European smart grid, but for my analysis I will include aspects of smart generation, smart metering and smart consumption. Within the concept of the smart grid, I will focus on market development and consumer acceptance of smart grid innovations and applications, rather than on the technology development.

Ample literature exists, often generated by EU bodies or industry associations, in the form of normative plans for RD&D and rollout of the smart grid or its components. On the other side, studies exist focusing on issues or practical experiences related to specific components of the smart grid. These documents generally focus on smart grid technology and not on consumer acceptance of it. In my opinion, more attention could be given to analyzing the overall development of the smart grid in Europe and the factors that might speed up or slow down its development. This thesis focuses on consumer engagement with smart grid technology. Theories of consumer engagement are relatively new and various theories exist that touch upon this field, but no single, all-encompassing theory exists yet. The literature that exists reporting the results of practical tests to measure the response of consumers to specific smart grid technologies, is fragmented and because of geographic or technology differences often difficult to compare, despite good efforts by S. Darby (2006, 2009), A. Faruqui (2009) and Ehrhardt-Martinez (2010) to do so.

It should be noted that the smart grid is still to a large extent a concept, an evolution in progress, and that regulatory and competitive structures in the different European states vary. Limited public information is available on exact costs and benefits generated by the different components that make up the smart grid, and on the level of consumer acceptance of the concept. This thesis aims to give a macro analysis of the development of the smart grid in Europe and consciously avoids going into too detailed an analysis of distinct technology components or geographic aspects of the concept. This implies that this study does not reflect how the status and dynamics of development of the smart grid differs from one member state to the next, but it allows for a strategic analysis. The general conclusions in this thesis represent my analysis of the data encountered in literature and interviews. Specific situations might vary from country to country.

1.5 Thesis disposition

This thesis analyses the drivers and barriers for the development of the smart grid in Europe, describes and forecasts the development of the smart grid in Europe and investigates how the impact of consumer engagement on the value of the smart grid can be maximized. Chapter two gives a description of the various concepts, components, technologies and players that make up smart energy and specifically the smart grid. In chapter three, I discuss the insight into the key drivers and barriers for the evolution of smart grids in Europe. On the basis of these insights, chapter four presents an assessment of the value of the smart grid in Europe and shows the business case from the point of view of Europe's utilities, as well as from the point of view of society at large. This will highlight what potential impact consumers have on the value of the smart grid. With the help of a literature review of consumer behavior theories and empirical results from pilot tests, in chapter five I will make recommendations on how this impact can be maximized.

2. The Smart Grid

2.1 What is the Smart Grid?

To understand what is and what is not considered in this study, it is useful to look at Van de Putte's (2011) definition of the 3 types of intelligent grids: micro grids, smart grids and super grids.

- Micro grids often cover islands, small towns or districts, where the distribution network incorporates monitoring and control infrastructure and uses local energy generation sources. The objective of a micro grid is to supply local power needs as efficiently as possible.

- Smart grids balance supply and demand out over a region. They use advanced types of control and management technologies to efficiently distribute power and connect decentralized renewable energy sources and cogeneration to the grid.

- Super grids transport large energy loads between regions or countries with large supply and large demand, using HVDC technology based interconnections.

This document excludes micro grids and super grids and focuses on smart grids only.

Most existing electricity transmission and distribution systems in the world were put in place 30-50 years ago. They organize one-way distribution of electricity from large central generation plants to the end users. The old grids suffer from significant losses of electricity in transmission (loss range in Europe 2-4%) and distribution (loss range in Europe 4-9%) (Majstrovic, 2010). There is also an important inefficiency related to peak demand. Demand varies, but capacity and generation are normally kept at peak demand level, leaving vast amounts of electricity unused. Moreover, the addition of highly intermittent electricity from renewable sources to the current grid presents important challenges for the management of the grid and the quality of electricity it delivers.

Significant opportunities exists to increase the grids efficiency by modernizing its operation, feeding in electricity from decentralized renewable sources and by interlinking multiple grids, moving electricity around to where it is required, as well as by adjusting demand to match supply of electricity. To achieve this, grids must enable the measurement, communication and management of demand and supply throughout the grid. Based on two-way communication of real-time electricity consumption, utilities and grid operators can manage their operations more efficiently, and consumers can adjust their consumption patterns to take advantages of lower prices in times of excess supply of electricity. Figure 1 shows a comparison of the current and the future smart grid.

Figure 1: Comparison of 'old' and 'modern' grid

	Current Grid	Smart Grid
Communications	None or one-way; typically not real-time	Two-way, real-time
Customer interaction	Limited	Extensive
Metering	Electromechanical	Digital (enabling real-time pricing and net metering)
Operation and	Manual equipment checks, maintenance	Remote monitoring, predictive, time-based maintenance
Generation	Centralized	Centralized and distributed
Power flow control	Limited	Comprehensive, automated
Reliability	Prone to failures and cascading outages; essentially reactive	Automated, pro-active protection; prevents outages before they start
Restoration following disturbance	Manual	Self-healing
System topology	Radial; generally one-way power flow	Network; multiple power flow pathways

Source: Research Report International

The U.S. Department of Energy in 2008 identified seven defining traits of what a smart grid will do (USDOE, 2008):

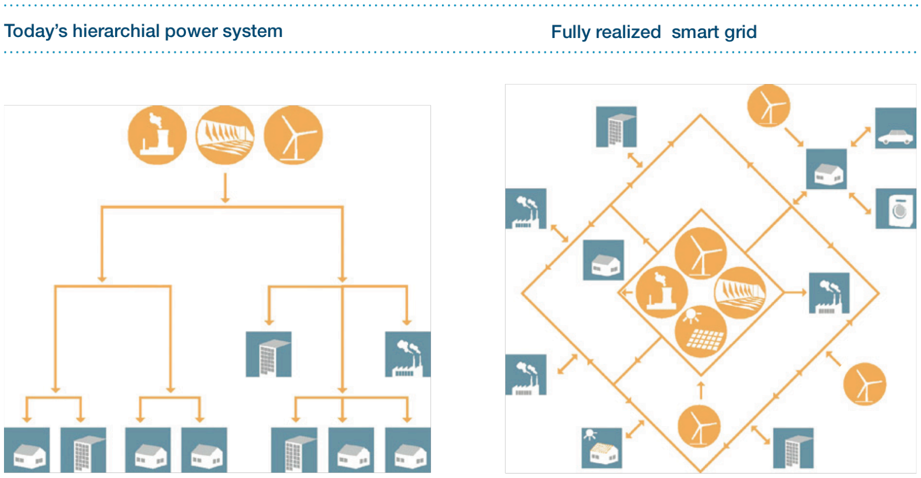
1. Optimize asset utilization and operating efficiency.
2. Accommodate all generation and storage options.
3. Provide power quality for the range of needs in a digital economy.
4. Anticipate and respond to system disturbances in a self-healing manner.
5. Operate resiliently against physical and cyber attacks and natural disasters.
6. Enable active participation by consumers.
7. Enable new products, services, and markets.

The European Technology Platform on Smart Grids, defines the smart grid as "an electricity network that can intelligently integrate the actions of all users connected to it -

generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies"

The physical architecture of the electricity grid will change from a one-way, generation centered electricity grid, to an interconnected, two-way electricity and communication network, able to incorporate multiple distributed generation sources, as shown in figure 2.

Figure 2: Fully networked, bi-directional 'smart' grid.

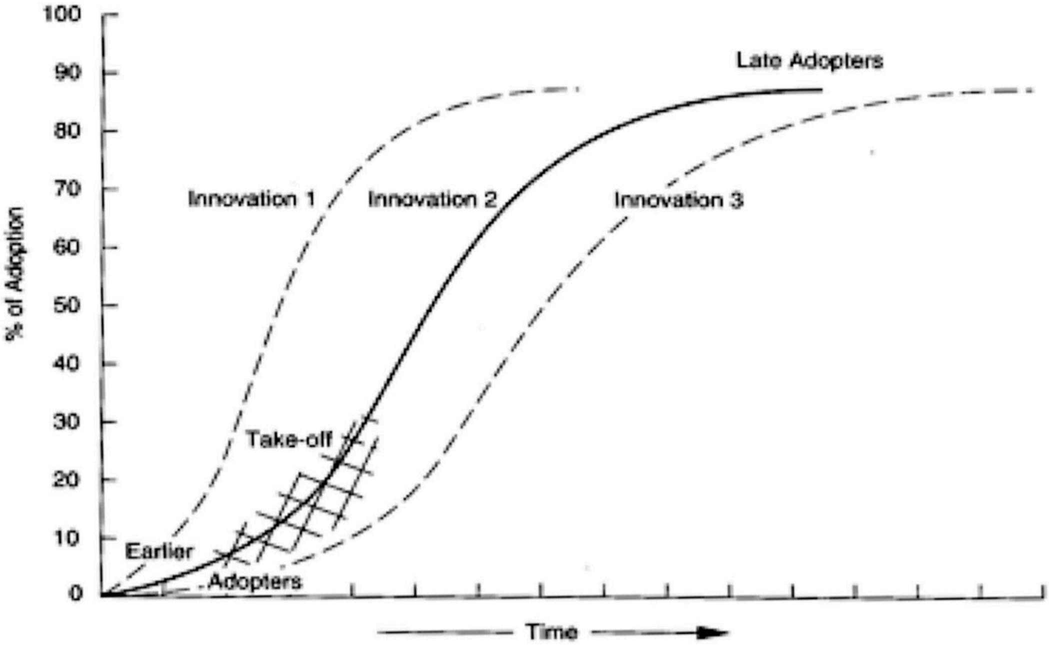


Source: Towards a smarter grid – ABB White Paper 2009

2.2 Evolution rather than substitution

In "Diffusion of Innovations", Rogers (1963) describes how diffusion of innovation usually takes the form of an S-shaped curve, as depicted in Figure 3. Innovations do not evolve on their own, but their diffusion may depend on interaction with existing practices and technologies. The S-curve represents the technological life cycle, from low diffusion in the early R&D discovery phase and pilot tests, to wider acceptance once the new technology is proven and produced at bigger scale and lower cost, to complete rollout and eventual substitution by other technologies. Various technologies may coexist and the diffusion of one technology may build on the basis of another technology.

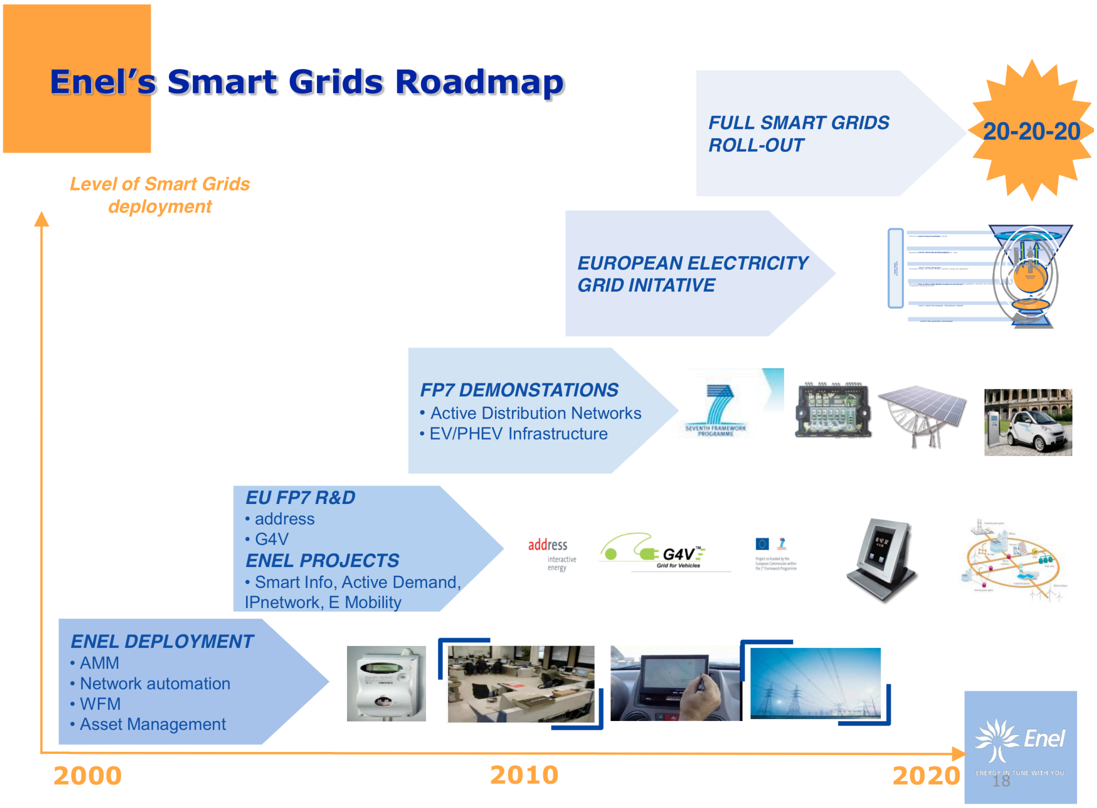
Figure 3: S-Model of diffusion of innovations.



Source: Rogers: Diffusion of Innovations (1963)

Rather than a radical substitution of the old grid by a modern grid, the development of the smart grid should be seen as an evolution, the gradual 'smartening' of the existing grid by adding various new technologies (digital metering, communication, distributed renewable generation, advanced storage, electric vehicles, etc.) and applications (demand response, distribution automation, energy management systems, etc) eventually leading to smart homes and smart grids. The diffusion of these technologies and applications is also expected to follow overlapping S-curves, as the penetration of one technology, such as smart metering, will enable the development and diffusion of the next technology, such as active demand or integration of micro-renewable power generation. Similarly, an electric vehicles (EV/PHEV) charging infrastructure will facilitate the diffusion of EV/PHEV and in turn enable storage capability through vehicle-to-grid (V2G) technology. Figure 4 shows how Italian utility Enel is planning the introduction of new technologies and applications on the road to a fully functioning Smart Grid.

Figure 4: Enel's subsequent technological innovations on the way to full Smart Grid capability



Enel's Smart Grids Roadmap

Level of Smart Grids deployment

FULL SMART GRIDS ROLL-OUT

20-20-20

EUROPEAN ELECTRICITY GRID INITATIVE

FP7 DEMONSTATIONS
- Active Distribution Networks
- EV/PHEV Infrastructure

EU FP7 R&D
- address
- G4V

ENEL PROJECTS
- Smart Info, Active Demand, IPnetwork, E Mobility

ENEL DEPLOYMENT
- AMM
- Network automation
- WFM
- Asset Management

2000 2010 2020

Enel

ENERGY IN TUNE WITH YOU

18

Source: Enel, Paola Petroni, 2010

2.3 The components that make up the Smart Grid

2.3.1 Electricity supply chain

The electricity supply chain can be divided into 7 steps:

Figure 5: Smart Electricity Supply Chain

Source: Van der Zanden

A generation plant produces the electricity, which is transformed and transmitted by the transmission system operator (TSO) over high-voltage transmission lines. The TSO is responsible for balancing the supply and demand. From there, electricity is distributed by the distribution system operator (DSO) over medium or low voltage power lines to substations, where it is transformed again for final delivery. In the past, resellers and supply companies would buy electricity from the DSO and develop the commercial deals with end customers. Smart metering is allowing smart energy services companies to develop new business models and services dedicated to reduction of end user electricity consumption.

To stimulate competition, the EU Third Legislative Package in 2009 mandated unbundling of generation, transmission and distribution. The objective was for these steps in the value chain not to be owned by the same company, but only 15 of the 41 European transmission system operators (TSO) have been fully separated from electricity generation and retail (PWC, 2010). Only the UK, the Netherlands, Austria, Hungary, Poland and the Nordic region (with the exception of Denmark) have a reasonably open competitive environment. In the European states where the generation/transmission, distribution and retail of electricity is unbundled completely or to some extent, the customer is 'owned' by the electricity retailer, who in turn buys electricity from the network operator, who in turn is supplied by the generation/transmission company. The customer is free to change energy supplier at any time (Moray, 2010).

2.3.2 Physical, communication and application layers

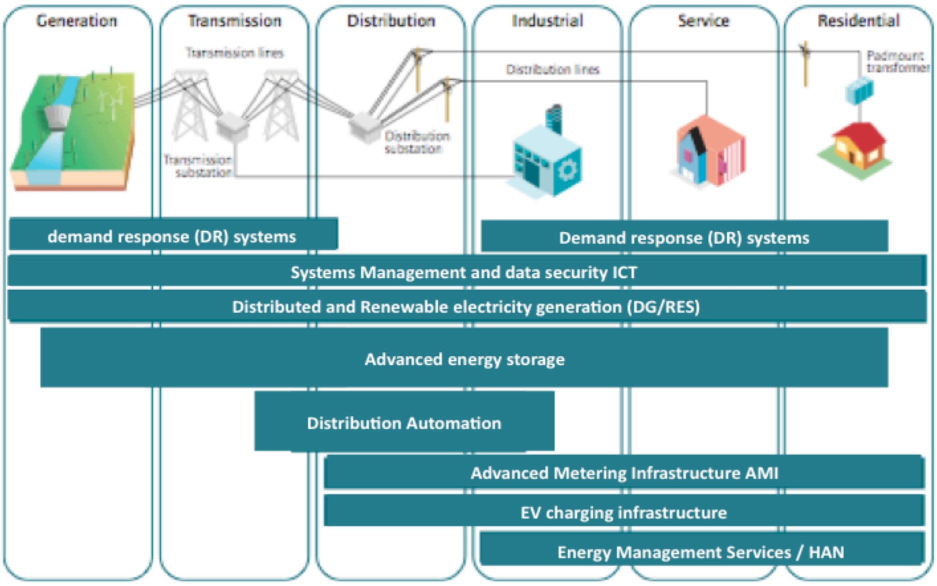
To arrive to a fully intelligent grid, generation and communication of real-time data regarding demand, supply and network status are required throughout the grid. Management systems and applications are required to turn the data into operational and asset management decisions for the operators, as well as consumption decisions for end customers, thus increasing the efficiency of the whole value chain.

Until now, most utilities and grid operators have sensors, meters and data communication systems in place to monitor the transmission and some distribution parts of the grid, but very limited information is generated about the consumption patterns at the point of end-consumption. As an important step towards solving this data gap and stimulating transparency and competition in the electricity sector, the European Union set a 2020 deadline for an 80% rollout of smart meters with two-way communication and remote control capability, through Energy Services Directive 2006/32/EC (Art. 13) and the Directive on internal markets 2009/72/EC (Annex I).

A fully-fledged smart grid normally incorporates the following components, shown in Figure 6:

- Advanced metering Infrastructure (AMI)
- Demand response (DR) systems
- Energy management services / Home automation networks (HAN)
- Distribution automation (DA)
- Distributed and renewable electricity generation (DG/RES)
- Advanced energy storage
- Electric vehicles (EVs) charging infrastructure
- Systems management and data security ICT

Figure 6: Electricity system and smart grid components



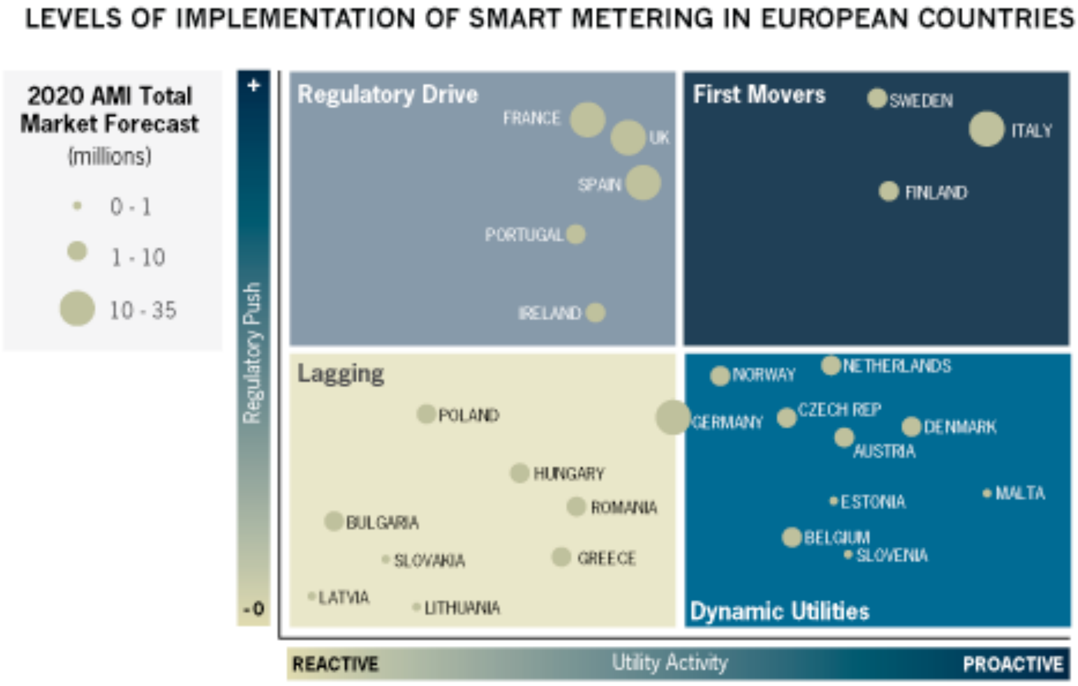
Source: adapted from IEA – Technology Roadmap: Smart Grids, 2011

2.4 Advanced Metering Infrastructure

Smart Meters form the basis of the intelligence of the new smart grid. The two-way information generated by advanced metering allows distribution system operators, energy retailers, energy service providers and final customers to improve their business efficiency and service performance, avoiding investments in expansion of networks and generation. Smart metering will allow utilities to offer consumers real-time or dynamic pricing, rather than static pricing. Dynamic pricing has shown to have the potential to significantly reduce peak power consumption (Faruqui, 2010). Smart metering is also a crucial capability for the integration and management of decentralized renewable energy production.

Influenced by regulations or actively pushed by utilities, some countries, like Sweden and Italy, already achieved 95%-100% penetration of smart meters, whereas other countries are just entering the stage of pilot tests. (Shargal and ESMA 2009). Figure 7 gives an overview of how far along the road of smart metering the various European states are and whether deployment is driven by utility initiatives or regulatory pressure.

Figure 7: Levels of implementation of smart metering in European countries.



Source: GJ van der Zanden / GTM Research.

However, the smart meter on its own will not save energy. It is simply an 'enabler', a tool that allows for better energy management. Any smart-meter rollout involves not just the meter manufacturers but also communications companies, advanced metering infrastructure (AMI) program management, meter data management systems (MDMS) and system integration. According to research by ZPryme (Rodriguez, 2010), less than half of the market potential of AMI is made up of the meters, the rest going to the supporting technology. It remains to be seen if the smart meter market space will be occupied by clean tech start-ups or software, telecom, IT or utility giants. Big players in the European smart meter arena today are Echelon, Landis+Gyr (Switzerland), Itron, Elster (Germany), Iskraemeco, Xemtec, and Hortsmann.

The key capability for enabling more efficient management of electricity generation, distribution and use, is the communications and applications layer. It consists of meter data management systems (MDMS), advanced metering infrastructure (AMI) program management, consumer interface soft- and hardware and systems integration technology, that unifies all the different types of appliances and data sources that are connected to the grid. As a result, the industry is seeing a strong rise in joint projects and strategic alliances between hardware (smart meters), software (management systems) and communication technology players.

A key issue is the interoperability of smart meters, to accommodate the communication between the vast amounts of different applications and appliances that are coming on the market. With exception of the UK, where GPRS and private RF systems have been the preferred communication technology in pilot tests, most European countries seem to prefer power line communication (PLC), because of lower cost and better reliability and control (Giglioli, 2010), as well as regulatory challenges for RF communication. The

European Commission has instructed the European Standards Organization (CEN/CENELEC/ETSI) to develop shared standards, expected by the end of 2012.

2.5 Demand Response

Electricity consumption in the EU-27 is expected to grow 1,8% per year to 2020 (Enerdata, 2009). Under a business-as-usual scenario, with steadily increasing demand for energy, peak demand will reach even higher levels. After 2013, the power generation sector in Europe will be subject to 100% CO2 auctioning, while required to reduce its emissions by more than 200 Mt CO2 until 2020 (Harrison & Chestney, 2011). This poses a strategic imperative to reduce peak electricity and increase efficiency. Instead of heavy investments in more generation capacity, investing in demand response (DR) to curb peak electricity requirements represents a significant opportunity for energy savings and CO2 emissions reductions.

In the broadest sense, demand response (DR) stands for the communication between utility and end-customer concerning their electricity use and price changes in the market. DR applications allow consumers to reduce or shift their electricity consumption at times of high prices, or allow utilities to reduce a customer's consumption at times when total demand in the system is nearing peak supply. Smart meters and energy boxes are essential in DR, because they enable information feedback through in-house displays, automated direct load control and two-way communication, based on frequent meter reading. The more expensive Smart Energy Boxes allow for direct centralized control and scheduling of appliances and decentralized generation facility management.

Based on detailed metering, the electricity suppliers will be able to offer differentiated pricing: Time of Use Pricing (TOU), Critical Peak Pricing (CPP), Real-Time-Pricing (RTP), Direct Load Control (DLC), and Threshold Consumption/Load.

Faruqui (2010) found conclusive evidence that households respond to higher prices by lowering usage. The size of the response depended on a number of factors, including geography, the size of the price increase and the support of enabling technologies, such as programmable communicating appliances and gateway systems that allow remote control. Various studies, most of them done in the USA, reviewed by Faruqui showed a potential for peak load reduction through demand response of up to 44%. Potential for demand response in Europe is generally considered to be lower than in the USA and industry players generally calculate within a range of 5% to 15%. Chapter 4 will cover this issue more in-depth. According to Torriti (2009), most Demand Response in Europe over the coming decade will be developing in Italy, France, Spain, the Netherlands and Greece.

2.6 Energy Management Services / HAN

Some energy services companies are already supplying energy management services to the commercial and industrial sector, but home automation networks (HAN) have had a slow uptake. One of the reasons for this is the lack of a common communication standard for HAN devices.

Meanwhile, broadband and wireless telecom companies, home security firms and traditional home automation vendors are entering the market. They are adding home energy management capabilities to their existing products, with the potential of supporting time-based pricing and demand response features as utilities make them available.

In Europe, new HAN applications are being piloted by utilities such as Germany's Yello Strom, who partnered with Google a.o. to offer customers the possibility to monitor and remote control their electric appliances (Giglioli, 2010).

Microsoft and Google launched web-based energy information display products, Microsoft Hohm and Google PowerMeter, free to consumers two years ago. Their aim seemed to be to sell the aggregate consumer information and access to consumers to the utilities. However, both companies exited the home energy management market in 2011.

2.7 Grid Optimization / Distribution Automation

In OECD countries, an estimated 7% of electricity generated is lost in transmission and distribution (which make up an estimated 30% of electricity cost), because of equipment failure, outages, load inefficiencies, voltage variation, feeder losses, etc. (Busquin, 2003). Optimizing the efficiency of grid operations is therefore a major contribution towards energy efficiency and mitigation of CO2 emissions.

The Electric Power Research Institute (EPRI) defines distribution automation (DA) as "A set of intelligent sensors, processors, and communication technologies that enables an electric utility to remotely monitor and coordinate its distribution assets, and operate these assets in an optimal manner with or without manual intervention."

Using the sensor technology, communication infrastructure and IT that the smart grid entails, utilities will be able to optimize the reliability, operational efficiency and security of their grid and improve their asset utilization. With information being generated in all corners of the grid and processed in real time, the smart grid will be able to sense and automatically react to any disturbances in the grid. It will be able to re-route power around disturbances or congestions without impacting the end-user's experience.

Typical DA applications are investment in modern distribution switchgear, Volt/Var optimization (VVO), fault detection, isolation and restoration (FDIR), dynamic load distribution and feeder protection systems and control. In Europe, the dominant technologies of communication for DA purposes are expected to be broadband over power line and public network technologies, such as LTE standard or RF. Consensus in the industry is that the technology available today should be capable of accommodating the present and future needs of automated distribution systems and that deployment should therefore potentially be swift. Despite this, however, automation of distribution networks in Europe remains at a low level of development, with the exception of Italy, that made significant investments to improve grid reliability and quality of service (Giglioli, 2010).

Apart from the opportunity of lowering losses in transmission and distribution, demand for DA will be spurred by the integration of plug-in electric vehicles and distributed generation. Unlike demand response technologies, return-on-investment in grid optimization does not depend on consumer acceptance and is therefore seen by many utilities as a more predictable investment in efficiency improvement. Also, investment in grid communication technology is cheaper than AMI deployment and could therefore be considered a 'lower hanging fruit' on the road to improved efficiency of the energy system. Because of these reasons, investments in DA technology are likely to experience significant growth over the coming years.

Major players involved in distribution automation in Europe are Telvent, Powersense, ABB, GE, Schneider Electric and Siemens, now being joined by ICT specialists like Cisco and Oracle.

2.8 Distributed and Renewable Electricity Generation

Whereas on a traditional grid, power generation was centralized and transmission and distribution were one-way, the metering capabilities and two-way communication of smart grids enable the production of electricity in numerous, decentralized locations. The growth of renewable power production, micro- or large scale, such as the offshore wind parks, is increasing the need for a smart grid that is able to balance these intermittent resources.

Distributed generation allows electricity to be produced by utilities or by individuals, closer to the point of consumption, thus reducing energy transmission loses. It helps utilities to meet peak power needs more easily and diversify the range of energy resources, lowering the cost of distribution and increasing the reliability of the power flow (Roehr, 2010). Distributed generation also enables a more efficient use of waste heat from combined heat and power plants (CHP) and the possibility of smaller scale, modular expansion of capacity reduces capital risk. (Busquin, 2003).

Distributed generation is a driver behind the reduction of electricity costs for consumers and increases the use of renewables. Power production in distributed locations can be small scale and individual 'prosumers' (consumers that also micro-produce) have the option to resell their production to the utility. This is completely changing the relationship between utilities and consumers.

The development of DG is driven by environmental concerns, deregulation of the electricity market, diversification of energy sources/energy autonomy and energy efficiency, while barriers are mainly technical constraints, such as design procedures, limitations on rural network capacity, fault level restrictions in urban areas and a lack of interconnection standards (ENERDGnet, 2003). Recently, increasing difficulties in obtaining planning permission, especially for wind turbines, has also become an obstacle in some countries. Various EU countries, such as Germany and Spain, have installed specific incentives and tax policies to promote DG development.

According to Capgemini (Lewiner, 2008), to meet 2020 EU targets, the volume of renewable energy generation connected to the grid is expected to triple from 150 GW to 450 GW. Small and medium size enterprises that specialize in ICT and electricity marketing are expected to benefit most from the new market and business opportunities created by the integration of distributed electricity generation.

2.9 Advanced Energy Storage

The intermittent, unpredictable nature of renewable power puts different stresses on the physical grid than conventional power. The load fluctuations must be managed through automated distribution technologies, highly flexible conventional power generation or storage. The increasing penetration of renewable electricity generation sources is driving the need for energy storage. Energy storage enables utilities to supply peak demand with lower generation capacity and facilitates the integration of renewable energy sources into the grid. Future applications could include time-of-use energy cost management for the commercial and industrial segments and transmission and distribution deferral for utilities.

Grid operators with access to hydropower can store power by pumping up water behind dams and releasing it to generate power at times of high demand. Countries with no access to hydropower are experimenting with power storage in CHP plants, home heat pumps or EV batteries. Other technologies for storage include fuel cells, sodium sulphur (NAS) batteries, compressed air (CAES), flywheels and molten salt. New developments are in lithium ion batteries, ultra capacitors and flow batteries. No ideal storage solution has been developed yet and this area is being watched with great expectation.

In Denmark, Dong Energy and Better Place are conducting tests to use EV batteries as storage for excess wind power.

2.10 Electric Vehicles

The development of electric transportation and the smart grid go hand-in-hand. Deployment of electric vehicles (EV) will be an important means to reduce society's CO2 footprint, but also provides a very promising alternative as electricity storage capacity, feeding power back into the grid if necessary (V2G).

However, especially in the early stages of deployment, it is expected that electric cars will exist in clusters. If they all charge at night, it could place enormous stresses on local transformers, and it is likely that investments need to be made in transformer upgrades. In order not to increase peak power demand because of electrical cars, the battery loading patterns should be carefully planned. EV power demand could be managed through 'smart charging' programs, making use of flexible pricing incentives. Another application that is being developed is 'smart billing', that allows the EV to be charged at different locations at the cost of the vehicle owner and not the property owner. Both smart charging and smart billing require a high level of communication between customer, electric car and utility, for which sophisticated software is required.

In its World Energy Outlook 2010, IEA predicts sales of EVs to reach 3 million per year by 2020 and 20 million per year by 2035, while it expects PHEVs sales to grow to 8 million by 2020 and over 60 million by 2035. A more conservative forecast by AT

Kearney (Rodriguez, 2010) expects EVs to represent 1,2% of all 89.4 million vehicles sold by 2020. Germany's E-Mobility Plan has a target of 1 million EVs on the road by 2020, while the UK is aiming for 1,7 million EVs and France is aiming for 2 million EVs. By all means, because of the sheer size of the global car market and the foreseen steady growth of PHEVs and EVs, it may be expected that Vehicle to Grid (V2G) will become one of the key applications of the future Smart Grid.

The EU has started a number of R&D projects such as G4V and Green eMotion, to speed up integration of PHEVs and EVs into the electric grid and develop an ICT platform for interoperability.

France (EDF) and Germany (RWE and E.ON) are the front-runners in Europe in the development of e-Mobility. All three companies have done extensive pilot tests and have developed EV charging stations and EV-charging station communication technologies. Small Dutch start-up Epyon has developed the first high speed charging station, with 50 KW capacity.

2.11 Systems Management and Data Security

With power generation becoming more decentralized and unpredictable, systems becoming more and more interdependent and millions of end-points generating data that needs to be processed, security issues are not only physical anymore.

Utility-wide integration of the new systems, technology, applications and information, essential for the optimal functioning of the grid, will require advanced utility control systems. Existing energy management systems (EMS) and supervisory control and data acquisition (SCADA) systems will have to be integrated with distribution management systems (DMS) and new applications such as meter data management (MDM). The enormous amounts of data that will be generated in the smart grid through AMI and grid optimization systems will require more sophisticated control systems, that turn the data into useful information for utilities to manage their performance (Leeds, 2009). As different pieces of data will be used in different systems and modules throughout the grid, standardization and interoperability will be key.

This is an enterprise wide challenge that affects utilities complete systems' architecture. It is therefore expected that IT blue chips such as IBM, Accenture, Oracle or Telvent, in collaboration with systems providers such as ABB or Siemens, will take a leading role in this development (Leeds, 2009).

An additional data related issue that has arisen with the smart grid is that of cyber security and data privacy. The discovery of the Stuxnet worm in 2010 underlined the need for increased data security. Consumer privacy concerns are also affecting the rollout of smart meters in countries such as the Netherlands and Germany.

3. Smart Grid Drivers and Barriers

Policy makers and private sector are pouring billions into this highly dynamic sector. However, regulatory challenges, quickly changing technology and new entrants make it difficult for market actors, investors and not in the least end customers to decide where to put their money for the longer term. My research discovered the following driving and inhibiting factors for the smart grid's development, which are shown in Figure 8 and discussed hereafter.

Figure 8: Drivers and barriers for the development of the smart grid in Europe.

BARRIERS

POLICY AND REGULATION
Variation in regulations exist amoung various EU member states, as does uncertainty over the new market model.

MARKET UNCERTAINTY AND DISTORTION
- Many technologies have only been tested on a pilot scale and savings estimates are uncertain.
- Regulatory uncertainty about who invests and who reaps the benefits. Will the Smart Grid accelerate the birth of a new service-based business model?

MARKET UNCERTAINTY AND DISTORTION CONTINUED
- Investment in renewable power still largely dependent on government incentives.

TECHNOLOGY BARRIERS
Challenges with respect to interoperability, data security and technological skills.

LACK OF CONSUMER INVOLVEMENT
Identified by utility execitives as the biggest barrier to smart grid value creation.

DRIVERS

ENVIROMENTAL TARGETS
EU's 20-20-20 target

EU MANDATES AND POLICIES
- Unbundling of electricity generation, transmission and distribution.
- Rollout of smart meters to 80% of EU households by 2020.

EFFICIENT AND RELIABLE ELECTRICITY SUPPLY
- Growth and integration of power supply from renewable resources.
- Interconnected pan-European electricity market.
- Increase the resilience of the grid and avoid losses and outages.

ECONOMIC DRIVERS
- Expectation of increasing electricity wholesale cost.
- New energy technologies and the convergence of the power, and ITC industries create new jobs and business opportunities.

Increase Return-on-Assets for Utilities:
- Reduction in operational.
- Avoidance of peak power capacity.

Societal benefits:
- Reduction of the economic cost of power interruptions.
- Reduction in customer's electricity bill.
- Reduction in CO2 emissions.

TECHNOLOGY DEVELOPMENT
Electric vehicles (EVs), energy storage, domestic Mirco Combined Heat and Power (MicroCHP), residential photovoltaic (PV) systems and advanced metering infrastructure (AMI) are all pushing the evolution of the Smart Grid forward.

Source: GJ van der Zanden / GTM Research

3.1 Smart Grid Drivers

The development of the smart grid in Europe is highly motivated by EU environmental targets and policies, the need for a more efficient and reliable electricity supply, and, of particular significance, the business case that it represents for utilities and systems suppliers.

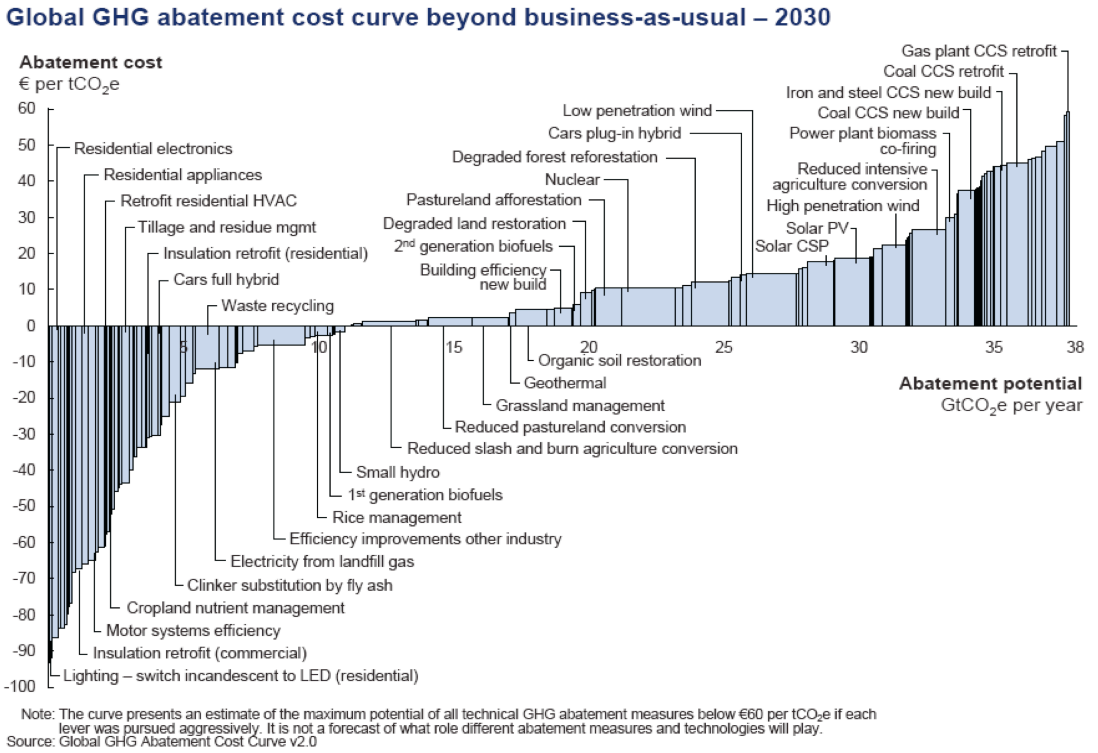
3.1.1 Environmental considerations, policies and stimulus funds

The scientific community is largely agreeing that anthropogenic climate change is posing serious threats to our existence. Worldwide electricity consumption is expected to almost double by 2035. It is causing 17% of anthropogenic GHG emissions (IEA, 2004) and therefore has become one of the main areas of focus for the mitigation of climate change. This is driving policy makers, private sector and consumers to embrace renewable energy sources, look favorably upon electric transport and energy efficiency measures.

The EU's 20/20/20 targets require a 20% reduction in CO2 emissions, 20% of electricity generated from renewable energy sources and a 20% increase in energy efficiency by 2020. Europe is seeking to reduce its CO2 emissions, but at the same time reduce its dependence on imports of fossil fuels and stimulate the competitiveness of its industries. Pressured by national CO2 emission targets and the looming of full carbon taxing from 2013, individual utilities are planning to reduce their carbon footprint. Ironically, the focus here is often on generation of 'clean' electricity and development of Carbon Capture and Storage (CCS) technology, rather than reduction of consumption through the involvement of end consumers via demand response and HAN applications. Large hydro and nuclear and even natural gas are being presented as 'clean', without taking into account other environmental impacts of these alternatives.

Energy efficiency measures have a much lower GHG abatement cost than investment in nuclear or renewable power generation or carbon capture & storage (CCS), as is evident from Figure 9, published by McKinsey in 2009. Smart grid technology and applications have the potential to increase the efficiency of electricity distribution as well as the efficiency of in-home electricity use. Most of these energy efficiency measures are located in the left hand of the GHG abatement cost curve. This is an incentive for policy makers, utilities and scientists to prioritize the development of the Smart Grid.

Figure 9: Cost and potential comparison of different GHG abatement measures.


Global GHG abatement cost curve beyond business-as-usual – 2030

Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

In its communication "Smart grids: From innovation to deployment" (2011), the European Commission estimates that *"Smart electricity grids should reduce CO2 emissions in the EU by 9% and the annual household energy consumption by 10%. They also help to ensure secure functioning of the electricity system and are a key enabler of both the internal energy market and integration of vast amounts of renewable"* energy. The directives following from the 20/20/20 targets, as well as funds for greenhouse gas (GHG) reduction, are shaping national policies and constitute a major driver behind the development of the smart grid in Europe. An EC Task Force was formed to work on recommendations with respect to policy and regulatory directions as well as the roles and responsibilities of the actors involved in the EU-wide implementation of the Smart Grid.

In its Third Energy Package of 2009, which promotes cross-border trade and collaboration, the EU mandated unbundling of transmission and distribution from generation of electricity, with the objective of stimulating competition. The same Third Energy Package mandated a rollout of smart meters to 80% of European homes by 2020. Germany and France opposed the unbundling of transmission and distribution of electricity, which resulted in a weak regulation, in which transmission system operators (TSO) are allowed under certain conditions to remain integrated with the utility. In fact, unbundling is not happening across the board in all markets – in 2009, only 15 of the 41 European transmission system operators were fully separated from production and retail. More than half of the Member States allow distribution system operators (DSO) to remain vertically integrated (PWC, 2010). It continues to be difficult for foreign competitors to enter the German and French markets, but most other markets are opening up to competition, providing a strong stimulus for utilities to innovate and invest in efficiency improvements.

Even though all European national markets started a process of liberalization in the late 1990s, due to market fragmentation and weak interconnections, the national market leaders typically still dominate their former monopoly market. According to a study by Ringel (2003), if the markets are liberalized, but there is a delay in creating a fully functional single European market, this is likely to create market distortions and imperfections that are counterproductive to the economic efficiency of the sector.

The Energy End-Use Efficiency and Energy Services Directive (2006/32/EC) that is currently being revised by the European Commission calls for metering that accurately reflects the final customer's actual consumption and provides information on actual time-of-use data. I expect this directive to be even more effective in reducing consumption than the mandatory rollout of metering, because of the demand response options and consumer engagement gains that will be encouraged through the dissemination of more detailed information.

The rollout of smart meters is happening at different speeds in various EU member states, largely depending on the national regulatory situation and utility initiatives, as was depicted in Figure 7. Network operators and utilities are arguing that the creation of an all-encompassing regulatory framework is key for the speed of deployment of the smart grid. They claim that this regulatory framework needs to involve a wide range of market actors and address market issues, such as impact on competition and changes in the industry and the way consumers use energy. It has also been argued that tariff setting can provide operators with incentives to invest in smart technology.

3.1.2 The need for security and quality of supply

Europe imports 53% of its energy requirements, mainly in the form of gas and oil. Renewable sources of energy and storage capacity, as well as significantly increased efficiency that will be achieved through grid optimization and demand response will make Europe less dependent on imports. At the same time, the modernization of today's old-fashioned grids is overdue. The introduction of smart grid technologies will provide a more reliable electricity infrastructure and increase the security and quality of supply.

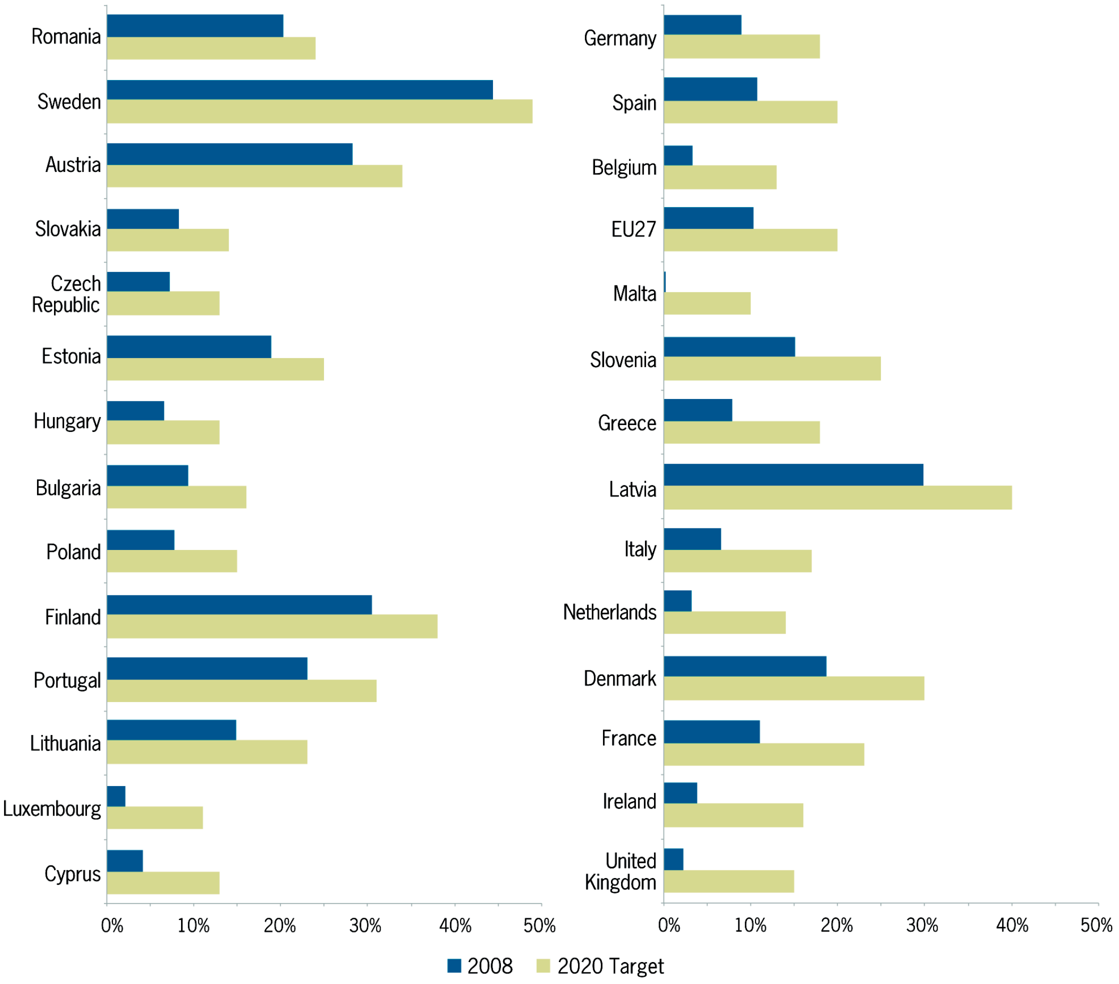
Over 50% of Europe's renewable energy sources today consist of hydro, which is highly controllable and can act as storage for other renewable energy sources. Wind and solar power generation are considered uncontrollable inputs and integrating their intermittent power presents a significant challenge to today's grids. On- and offshore wind power has captured most European investment in renewables over the last several years and is now by far the largest 'clean' renewable source (large hydro is controversial in sustainability circles because of the significant impact on upstream and downstream bio-habitats). Meeting the EU target of 20% renewable power generation by 2020 could cut fossil fuel imports by 200 million tons of oil equivalent (mtoe) per year. This directive (2009/28/EC) has been translated into legislation and varying national targets in the individual member states, as is shown in Figure 10.

Several governments, such as in Denmark, Germany, Spain and the UK, have grasped the opportunity of smart energy to create employment and competitive domestic industries for renewable power generation technology or e-mobility. This form of state intervention has proven effective on numerous occasions, as described by Jenkins et al. (2010).

Another political benefit of supporting renewables is that local power generation from renewable energy sources stimulates the local economies, rather than sending money abroad for the purchase of fossil fuels.

Government support remains one of the key drivers for renewable energy deployment – rising from $57 billion in 2009 to $205 billion in 2035(Oettinger, 2010). Up to now, the EU seems to have placed more emphasis on integration of renewable and distributed energy sources and the development of e-mobility, but it is expected that technologies and applications to improve energy efficiency will gain priority going forward (Woods, 2011).

Figure 10. Renewable energy in final energy consumption – 2008 status and 2020 target

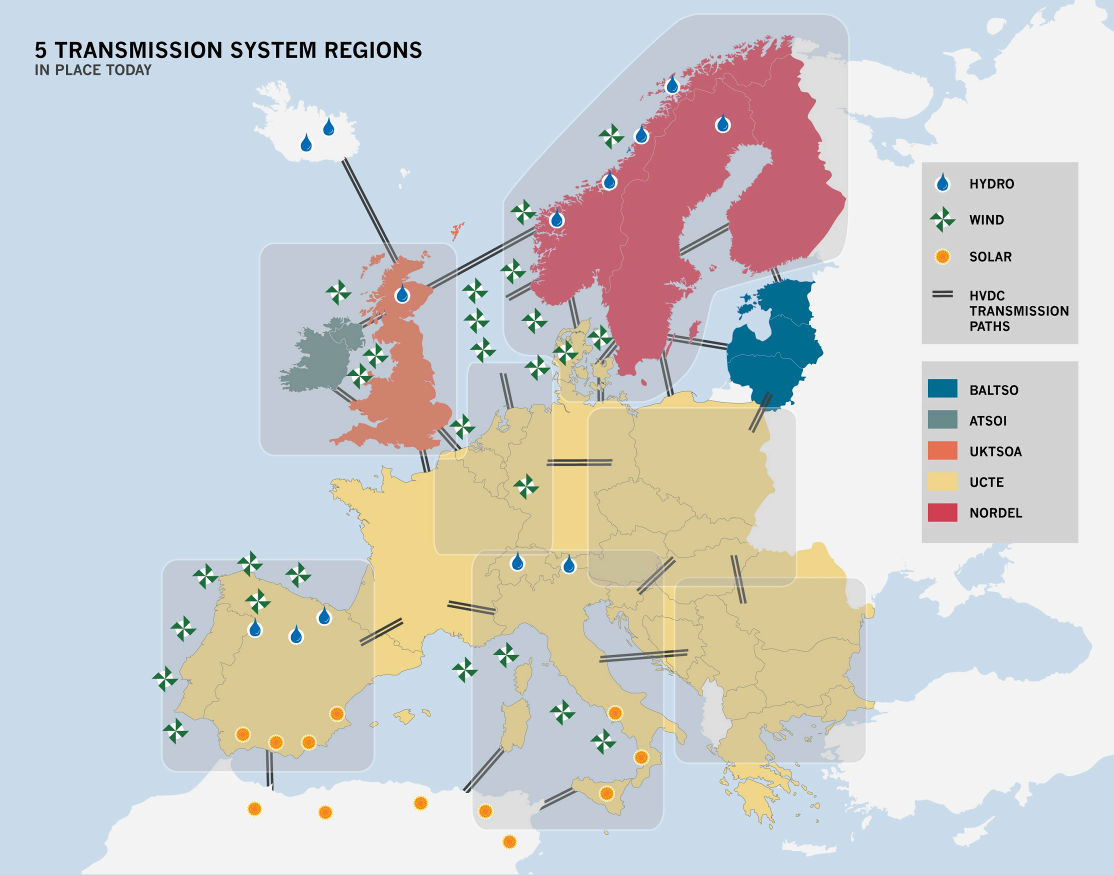


Source: Europe's Energy Portal / Green Tech Media

Visions of a European "Super grid"

Just for the maintenance and expansion of its electricity grid, Europe is expected to invest in excess of €500 billion in power transmission and distribution before 2030 (IEA, 2008). Upgrading the existing grid has been delayed due to a lack of regulatory framework and the fragmented nature of the transmission system operators (TSOs). Delays have also occurred because of public resistance to the construction of new high voltage lines, as has been a subject of public debate in Germany this year. In recent years, TSOs organized themselves into the European Network of Transmission Systems Operators for Electricity (ENTSOE). This facilitates pan-European decision-making. In its 10-year Network Development Plan, ENTSOE is giving a high priority to investments in HVDC connections to improve the integration of the European electricity market. This integration project is not unlike the 'Tres Amigos' connection project in the U.S. Europe currently has five Transmission Systems that will be connected through 'Electricity Highways' (to be commissioned by 2020), especially in the Baltic area, interconnections in southwestern Europe, and central-eastern and southeastern Europe. HVDC connections will also be made to the offshore wind energy fields in the Northern Seas and large-scale solar power generation planned in northern Africa. Figure 11 gives a future vision of Europe's interconnected Super grid.

Figure 11. Future vision of the European HVDC interconnected Super grid, integrating large offshore wind fields in the northern seas and solar generation in North Africa.



Source: GTM Research

Smart grid technology will help shave peak loads and reduce losses and outages, which cause significant losses to GDP. Thanks to early investment in distribution automation and SCADA systems, but also because most MV/LV cabling is underground, the reliability of the electricity supply in Europe today is considerably better than, for example, the U.S., where the average duration of an interruption in 2007 was 240 minutes, with an average annual frequency of 1.5. However, Europe's reliability is still well below that of Japan, where the average outage lasts 4 minutes (Tokyo boasting the world's most reliable power supply, with an average of 2 minutes outage time per customer per year and a frequency of 0.05 times per year); see Figure 12.

Figure 12. International comparison of reliability indices (2007)

Country/City	SAIDI*	SAIFI**
Tokyo	2	0.05
Netherlands	33	0.3
Germany	23	0.5
Denmark	24	0.5
France	62	1.0
Austria	72	0.9
UK	90	0.8
Italy	58	2.2
Spain	104	2.2
Unites States	240	1.5

**SAIDI: System Average Interruption Duration Index; gives the average number of minutes per year that the supply to a customer is interrupted.*

***SAIFI: System Average Interruption Frequency Index; gives the average number of times per year that the supply to a customer is interrupted.*

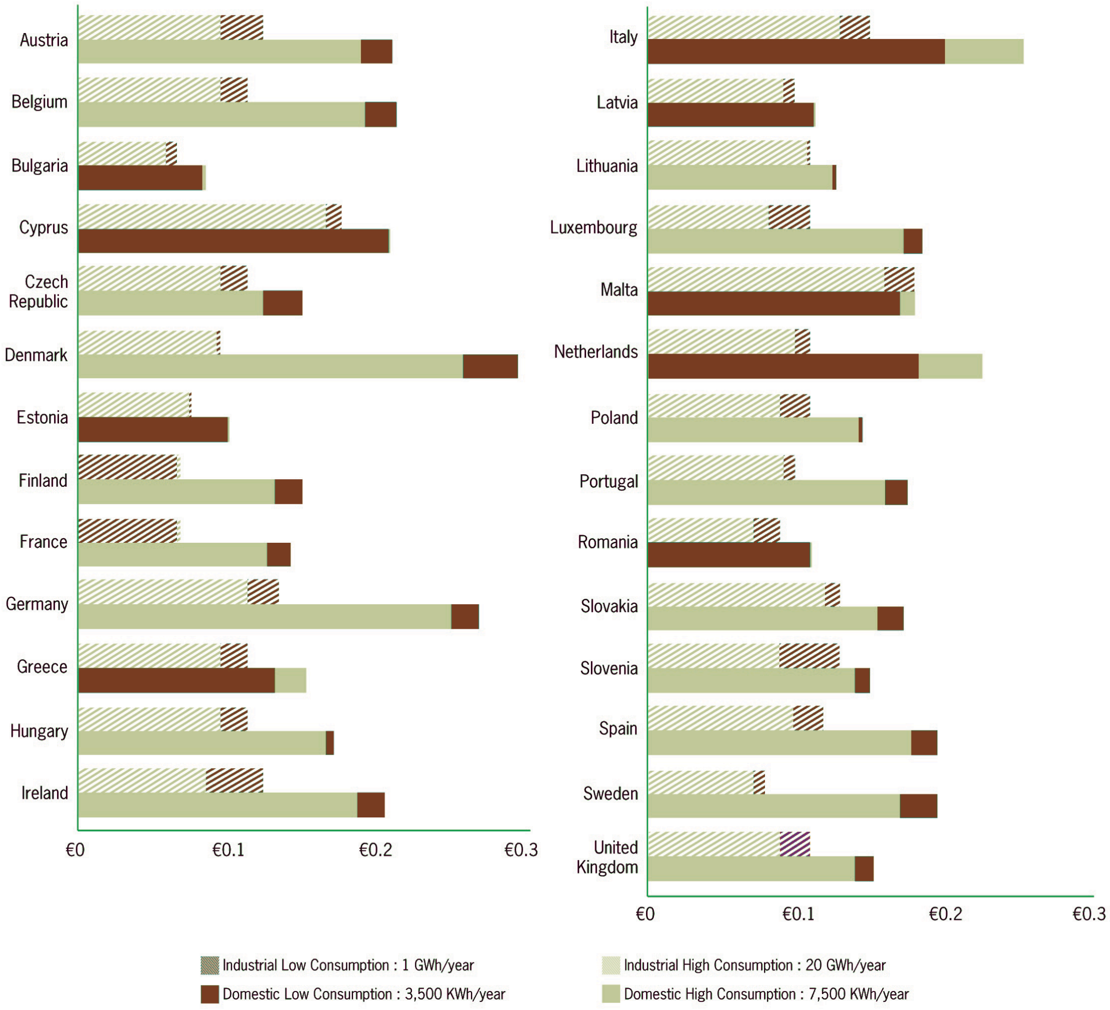
Source: GTM Research/Council of European Energy Regulators 2008

3.1.3 Economic drivers

The upward pressure on electricity costs, the potential for efficiency improvements, as well as the potential for reduction in peak- and absolute power consumption and opportunities for job creation all are important economic drivers behind the development of the smart grid.

In the long term, electricity prices are influenced by economic cycles, political decisions and capacity expansion or closures. A very clear indication of this is the 20+% surge in electricity prices all over Europe in April 2011 as a reaction to Germany's decision to idle seven nuclear reactors, a third of the country's capacity, in the wake of Japan's nuclear crisis (Blass & Wiesmann, 2011). At the same time, consumers are feeling the impact of the economic crisis, which normally could be expected to make them more sensitive toward opportunities to save money on their electricity bill. Increasing wholesale prices and pressure on margins are forcing utilities to focus on increasing their operational efficiency. Eventually, it may be expected that increased wholesale costs will translate into higher retail prices for electricity. By the year 2050, EPRI estimates that the average electric bill will probably go up by about 50% if the smart grid is deployed. If not, the average electric bill could go up by almost 400%. This trend will motivate consumers to adopt more energy efficiency measures and accept smart grid technologies such as demand response (DR) and home energy management (HEM) systems.

Figure 13. Electricity rates per KWh for households and industrial customers in selected European markets, for high volume and low volume consumers.



Source: Europe's Energy Portal / GTM Research

Because of increased competition, electricity retail prices in Europe have remained reasonably stable since 1995 (Hewicker, 2005, Dromacque, 2011). At the same time, wholesale prices have been rising steadily, except for the recent crisis years, and the burden on utilities from energy and environmental policies has increased significantly. An example of this is the recent Nuclear Tax in Germany, which will burden nuclear power producers with an additional €2.3 billion per year. On average, the network charges make up 29% of the consumer electricity prices in Europe; taxes, levies and surcharges make up about 24%, but these shares vary significantly among different EU member states (Dromaque, 2011). These non-energy charges to a large extent explain the differences in retail prices in the different member states, as shown in Figure 13. It is interesting to note that because of these taxes and levies, Denmark has the highest household electricity rate in Europe. This has encouraged the country to develop a culture of eco-innovation, which has turned the country into one of the leading examples of energy- and eco-efficiency in the world.

The most substantial benefits from smart grids for utilities are to be found in the considerable operational savings and the potential for peak load avoidance. This increases the asset utilization of generators, as well as transmission and distribution companies. As can be seen in more detail in chapter 3: Utility and Societal Business Case for Smart Grids, I estimate the economic savings for European utilities of a full scale Smart Grid to be in the range of €22 billion to €29.3 billion per year. Total annualized capital and operational expenditures for a fully operational European smart grid are estimated between €7.8 and €9.1 billion per year. While this should seem to prove an obvious business case for utilities, the same Smart Grid technology could enable consumers to reduce their electricity consumption by up to an estimated €18.2 billion. This reduction in utility income makes the business case for utilities much less obvious and explains why some have been hesitant to roll out smart metering without the EC mandate.

At a societal level, however, the case for smart electricity is clear. Apart from the savings on the part of utilities and the reduction in consumers' electricity bills, there would be a reduction in the cost to GDP of outages, which are now estimated to total close to €30 billion per year. I conservatively estimate a potential reduction of losses to GDP of €12 billion. A more efficient electricity system would also result in avoidance of carbon tax of approximately €0.45 billion per year.

The business case analysis explains why utilities have not been that eager to invest in smart metering, while also showing why regulators and legislators were keen on the smart grid becoming a reality on the basis of societal benefits alone. To capture the full societal savings potential of the smart grid, however, we believe regulators and legislative bodies should focus on maximizing consumer engagement, not just smart meter deployment. A mandate for the sharing of timely consumption information with consumers would seem to be the most effective approach; progress in the discussion of EC directive 2006/32/EC suggests that this method soon may be widely implemented. European policy and development of the smart grid are to a certain extent mirroring U.S. development and could draw important lessons from it. The smart grid in the U.S. was conceived with the consumer in mind, foreseeing savings through smart meters and demand response, but excessive focus on technical development alienated consumers to the point of generating a consumer backlash. As a result, U.S. utilities are now again focusing on engaging consumers and maximizing consumer benefits, sharing more information with the customer and customizing product offerings. Smart European utilities will see an opportunity to focus on consumer satisfaction early on and engage consumers in the process of mutual value creation.

Growth in demand for electricity is driving an even higher growth in peak demand, which under the current scenario is increasingly costly. Measures to reduce electricity demand are cheaper than building extra peak generation capacity. Findings from Faruqui (2010) indicate that depending on consumers' acceptance of critical peak pricing (CPP) tariffs and consumer interfaces, reductions in peak demand of up to 44% could be achieved and that with the help of demand response, the need for investment in expensive peak power plants could be reduced by up to €67 billion.

The renewal and re-invention of the power sector will create jobs and business opportunities. Apart from its 20/20/20 targets, through its mandates, directives and subsidies, the EU hopes to stimulate European industry in the development of world-class innovative energy technologies. The European Commission estimates the EU's target of 20% renewable energy by 2020 to create about 2.8 million new jobs and increase GDP by 1.1%(Kvarnbaek M., 2009).

3.1.4 New technologies

Advances in information and communication technology (ICT) have lowered the costs of grid-related ICT solutions, making the smart grid an economically feasible possibility, as the ability to communicate with millions of endpoints (meters and other grid assets) is now economically viable for the first time.

Renewable electricity generation technology is quickly gaining efficiency, to the point where wind energy is almost cost-competitive with fossil fuels and industry experts predict PV to be cost competitive before the end of the decade, maybe as early as 2013 (Ernest & Young, 2011). Empowered consumers can become 'prosumers' through decentralized micro-generation. At the same time, virtually all car manufacturers are making inroads with electronic vehicles.

Electric vehicles (EVs), integration of generation from distributed and renewable energy sources (DG and RES), integration of local 'micro grids' and advanced electricity storage, and domestic micro combined heat and power (MicroCHP) all require a smart grid to become operational, and therefore their development and the development of the smart grid mutually enhance one another. Significant amounts of public and venture capital, as well as interest and joint projects from the IT, telecom and energy industries, are driving innovation in smart grid-related technology, creating opportunities for new products and advanced consumer services.

Public-private bodies were set up with the task to develop standards for the interoperability of smart grid devices. Efforts to agree on international communication and interoperability standards have not been successful yet and it seems that market forces will determine which standards will prevail.

RD&D funding for the smart grid is coming from EU side, as well as national governments and industry. Research and technology development among the member states is coordinated through the Strategic Energy Technology (SET) Plan, to which the members of the Smart Grids European Technology Platform (SG-ETP) provide relevant input. The objective of the SET plan is to accelerate the development and deployment of cost-effective, clean technologies in Europe.

Government support is also aimed at the technology research phase and pilot projects, especially in smart energy technologies (McCrone, 2010). Despite the crisis, Europe invested €8.5 billion in clean energy RD&D in 2009 and important RD&D budgets remain in place:

- The Seventh Framework Program for Research and Technological Development (FP7) is a EU research funding program with a budget of €50.5 billion for the 2007-2013 period. It covers a wide range of areas related to energy efficiency.
- The SET Plan has earmarked €2 billion over the 2010-2020 period for the plan's smart grid initiative, the European Electricity Grids Initiative (EEGI), focusing on system innovation rather than technology innovation. The budget is split between research €600 million and demonstration €1390 million.
- Intelligent Energy Europe (IEE) is one of the main funding tools in the arena of energy research. Its main focus is on energy efficiency and renewable energies and has a budget of □ €727.3 million for the financial period 2007-2013.
- The office that regulates the gas and electricity markets (OFGEM) in the UK has made GBP500 million available for smart grid related RD&D and Italy decided to grant specific pilot projects an additional 2 to 3% return-on-investment.

Despite the fact that EU funded RD&D programs have considerably helped European smart grid players, f.e. in the definition of interoperability standards and communication protocols, Kerr (2010) claims that a lot more needs to be spent on public clean energy RD&D to achieve the desired 'Blue Map' outcome in CO2 levels by 2050. He claims that the global annual RD&D gap across all clean energy technologies is in the range of US$40-90 billion, of which US$5-10.5 billion corresponds specifically to smart grid research.

Judging from the priorities set in the EU's FP7 R&D plans, it is expected that technologies and applications to improve energy efficiency as well as the development of e-mobility will gain priority going forward.

3.2 Barriers for Smart Grid deployment

Despite these strong drivers, the rollout will likely not be as quick as might be desired. Factors holding back the development of the smart grid include: inconsistent and unsupportive policies in different member states; high upfront capital costs and uncertainty about who will reap the benefits; technology issues around interoperability and data security; the new skills required for systems integration; and the limited awareness among consumers of the potential benefits that the smart grid will have for them.

3.2.1 Policy and Regulation

Regulations and infrastructure situations vary widely around Europe. In some cases, policies or incentives stimulate power generation, encouraging consumption rather than savings. In some states, energy suppliers are responsible for the installation of smart meters; in others, the grid operator is responsible. Some markets, like Poland, maintain regulated tariffs, making it difficult for utilities to offer customized pricing schemes or demand response. In still others, such as Sweden, regulatory incentives have led to large-scale deployment of smart meters, but differences between the daytime and nighttime cost of electricity are relatively small due to the abundance of hydro storage, reducing the incentives generated by dynamic pricing. There is uncertainty about regulation of the new market model and how costs and benefits will be distributed amongst the actors.

The unbundling of power transmission from distribution, as per the Third Legislative Package of 2009, is also limiting the development of the smart grid, because power transmitters and distributors have potentially conflicting smart grid interests. Grid operators are more interested in ways to maximize grid management efficiency, rather than consumer data. Electricity suppliers would be interested in learning more about consumer habits in order to come up with new services for end users.

3.2.2 Market uncertainty and distortions

A significant barrier to deployment of the smart grid is the financial disincentive for utilities. Smart grid-enabled residences might generate a reduction in sales of electricity of up to €18.2 billion. A new business model of energy service provider could replace the old-fashioned role of power producer and vendor. This model of energy service providers (ESOs) is already working successfully with commercial and industrial clients in countries such as France.

The modernization of the electricity grid requires enormous investments and the question is how these are going to be financed. Despite a large number of pilot projects around Europe, there is still a lack of clarity about the full economic opportunity that the smart grid represents. Also, environmental and ancillary benefits are not factored into the business case. It is unclear to what extent these benefits will accrue for actors other than the investing party. The unbundling of distribution and retailing of electricity, as mandated by the EU, has created more uncertainty about who should carry the costs of investment in smart meters or HAN: the distributor, retailer or consumer. Liberalization of the markets is underway, but parts of the electricity supply chain still remain regulated. The increased competition makes it more difficult for utilities to raise tariffs to recuperate the extra capital expenditures for smart grid technology or investment in renewables. Utilities are looking at government for support and are asking regulators to agree on clear definitions of how the costs and benefits of investments in smart grid technology will be distributed among the different actors (McCrone, 2010). Governments are mandating increased energy efficiency and integration of renewable energy sources, but at the same time have to make sure this happens at a competitive cost, so as not to affect the competitiveness of their domestic industries.

Upfront capital and operating costs of new technologies are still high in the early phases of deployment, resulting in a long payback time. The risks inherent in new technologies increase the cost of capital for investors. Renewable power generation, in particular, has felt a negative impact from the financial crisis (Mercom Capital, 2011). Renewables still depend on state subsidies to make the return-on-investment competitive with that on electricity generation from conventional sources. Governments in various states, like Germany and Spain, have been encouraging the installation of renewables through generous feed-in tariffs and subsidies. The economic crisis, however, has reduced member states' budgets and weakened the financial position of utilities, resulting in less financial support for the rollout of smart grid technologies. Moreover, the weakened financial position and depressed share prices of many utilities make it likely that merger and acquisition activity in the sector will go up (Lewiner, 2008). As a result, several of Europe's biggest utilities are divesting to restore their financial position (Capgemini, 2009). A regulatory framework and clear distribution of risk and return between customers, utilities and government agencies will facilitate investment in smart grid technology.

3.2.3 Technology Barriers

The rapid pace of the development and integration of IT and communication technologies in the electricity sector has given rise to serious challenges with respect to interoperability, data security and technological skills.

Many of the new technologies are proprietary and lack agreed-upon standards or have not been proven on a large scale. Key issues for smart grid technology are agreements on common standards and communication protocols, for all technology and applications to have full interoperability. To overcome this barrier, the EU started a number of initiatives to develop interoperability standards, based on an open protocol, that now coexist with the proprietary standards.

The lack of viable technologies for electricity storage to date (apart from pumped hydro) is making efficiency measures and management systems in all other parts of the smart grid more relevant. Advanced storage, however, is hailed as the ultimate solution for the electricity sector.

Significantly more data traffic will require significant capacity for data management. Problems have been reported of ‘worms’ affecting data transmission and in some countries, such as the Netherlands, consumer claims about privacy violations led the government to change the mandate for smart meter installment from an obligatory one to a voluntary one. Concerns about cyber insecurity and data privacy need to be addressed quickly to reduce the risk of consumer backlash.

Another barrier for swift progress toward the implementation of the smart grid is the fact that many experienced utility engineers are nearing retirement age and ‘new’ engineering skills are needed in the areas of power electronics, communication and data management. Systems integration is key and will require joint efforts between the IT, energy and telecommunication sectors.

At the same time, electric mobility poses an important challenge to the electricity grid. Charging of large amounts of electric vehicles would significantly increase overall electricity demand - Enel estimates additional demand of 23 GWh per day in Italy (Calenco, 2010) - and could put strains on local network capacity, requiring smart charging solutions and possibly substation upgrades.

3.2.4 Lack of Consumer Involvement

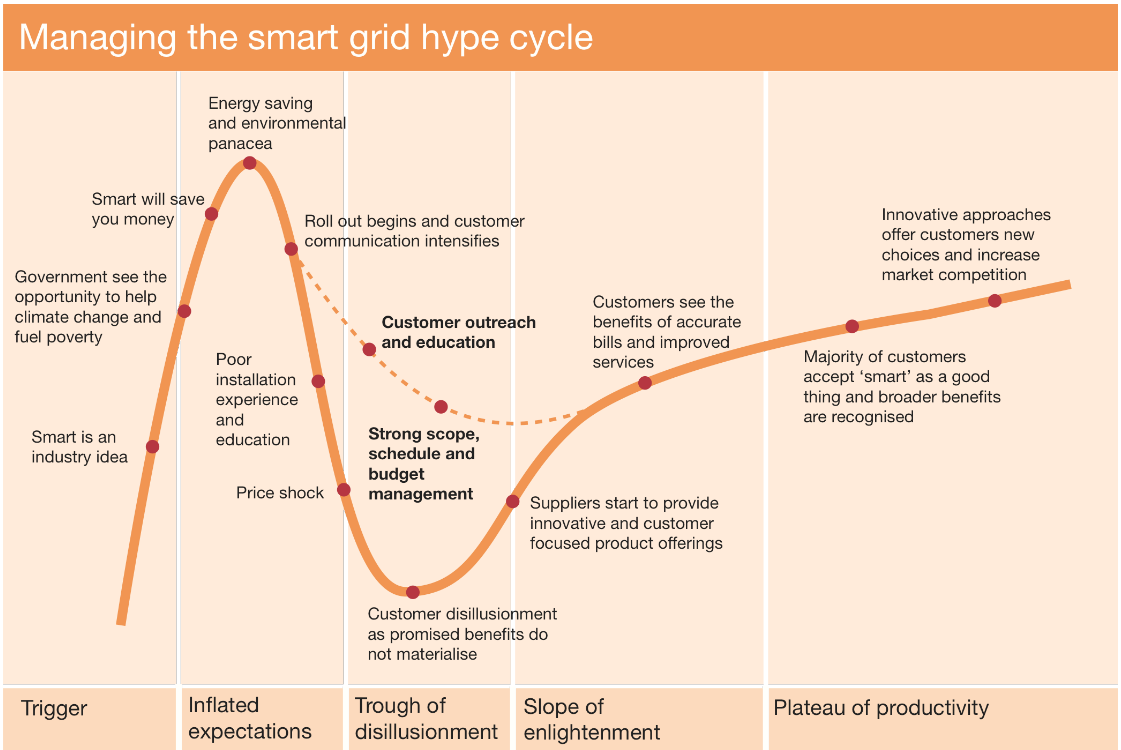
European consumers are increasingly aware of the need to reduce GHG emissions through improved energy efficiency and reduced consumption of fossil fuels. There is an increasing understanding that fossil fuels are becoming more expensive and that technologies and applications will need to be introduced to improve energy efficiency.

However, there is also still widespread ignorance in society about how the electricity market works. European consumers are habituated to utilities’ lack of transparency in billing methods, as well as to having access to a limited number of product and service options. Surveys in various countries have shown that European consumers also generally have a very limited understanding of what the smart grid is and how it could create value for them. In some markets, like Germany, recent price rises have turned public opinion against the utilities, which are often seen as representing the fossil-fuel based industry dinosaurs. Positive involvement of consumers with electricity is considered a key success factor for materializing the potential gains of the smart grid and the lack of involvement is worrying. A survey by demand response provider Comverge (Young, 2011) showed that utility executives identify 'consumer education and awareness' and 'consumer buy-in' as the biggest barrier to smart grid adoption.

The above underlines the importance of making the smart grid as consumer-centered as possible while paying attention to personal privacy issues. Tasks such as in-depth market analyses and carefully considered product/service design, as well as education and communication to consumers to maximize acceptance of new smart technologies, seem often to be overlooked by utilities.

Involving consumers in managing their electricity use more efficiently will be a key success factor for utilities that wish to embrace the opportunities of the smart grid. Consumer outreach and education can help utilities avoid the 'trough of disillusionment', as shown in Figure 14, and significantly accelerate consumer acceptance and deployment of smart grid technologies.

Figure 14: Smart grid expectation cycle



Source: PWC 2010

4. European Smart Grid: Utility and Societal Business Case

4.1 Forecasts of investments in the European Smart Grid

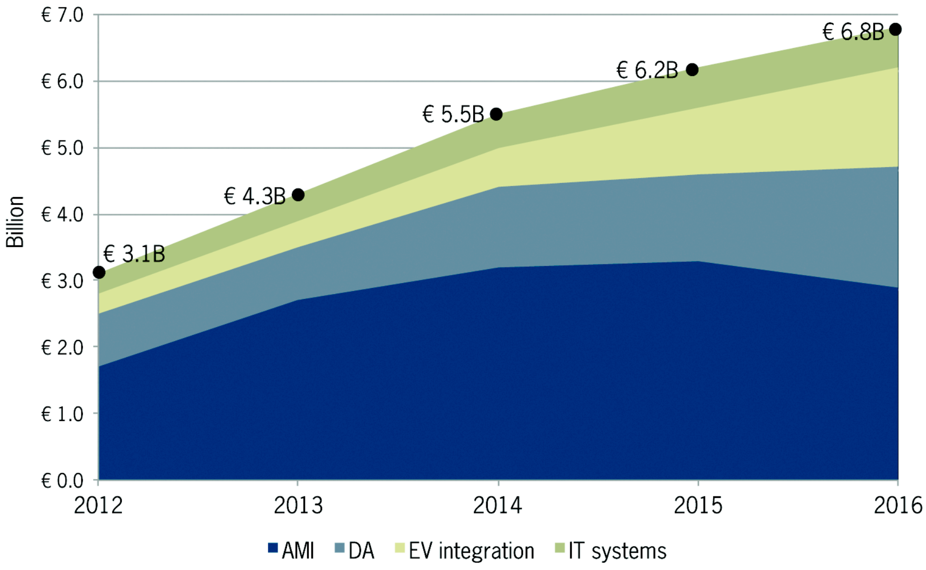
According to estimates by the Smart Energy Demand Coalition (SEDC), an association of the mayor European utilities, the estimated investment that is required to have the Smart Grid in all of Europe by 2030 amounts to about €120 billion and it would allow European users to save up to €31 billion per year (Euractiv, 2010).

Investment bank Goldman Sachs forecasts that spending in Europe on transmission, distribution and metering systems could reach $187 billion through the next 30 years (Roumeliotis, 2010). Booz & Company estimates that until 2020, €90 billion will be invested in Smart Grid related technology (Adam, 2010). In a different study by Faruqui et al. (2010), the total cost of installing smart meters in the EU are estimated at €51 billion, generating operational savings of between €26-41 billion and reducing the need for peak power infrastructure by between €14-67 billion, much depending on the level of acceptance of dynamic pricing schemes and demand response by end-consumers.

The bulk of the investments that are expected to go in to the European Smart Grid over the coming years will go into the following areas (Van der Zanden, 2011):

- Advanced Metering Infrastructure
- Distribution Automation
- Integration of Electric Vehicles
- IT Systems and Integration

Figure 15. GTM Research European smart grid market forecast 2012-2016 (€ millions)



Source: GTM Research

It is beyond the scope of this thesis document to show the fine details of my own calculation or its assumptions, but over the 2012-2016 period, I forecast total Smart Grid investment in Europe to grow from €3.1 billion to €6.8 billion, largely driven by the massive rollout of smart meters, as mandated by the EC, and ongoing distribution automation, mainly in the form of automation of secondary substations. Towards the second half of the decade, very ambitious EV penetration plans in Germany, UK, France, Spain and Italy, will translate into significant investment in EV charging infrastructure, which is likely to become one of the main areas of Smart Grid investment after 2020. GTM research's European Smart Grid forecast for 2012-2016 is presented in Figure 15.

4.2 The Business Case for Smart Grids

As is evident from the previous chapter, estimates of total investment required to make the smart grid an operational reality, are quite disparate. In part, this is depending on whether investments in expansion and maintenance of transmission and distribution networks, that are necessary irrespective of the move towards smart electricity, are considered part of the smart grid investments or not. But the lack of real-life experience and pilot projects is contributing to the uncertainty. What is clear is that the enormous investments required for upgrading the existing network to a modern Smart Grid, promise important benefits for many stakeholders that go beyond increased energy efficiency, penetration of renewables and reduction in CO2. Figure 16 attempts to summarize the main benefits for the different groups of stakeholders.

Figure 16: Benefits of the Smart Grid for different Stakeholders

Government and Regulators	**Utilities and network operators**
• A highly effective carbon abatement investment option. • GDP growth and green-collar job creation. • Increased transparency stimulates competition. • Rationalization of telecom and energy infrastructure investments.	• Change from commodity provider to higher-value service provider • Operational and capital savings from improved outage management, peak shaving, etc. • Increased hosting capacity for DG/RES and EV. • Contribution towards corporate sustainability and carbon goals
Consumers	**Electricity retailers**
• Energy bill and carbon savings • Greater transparency, control and choice over energy consumption • Better customer service	• Opportunities to develop new products and services • Ability to alter consumers' interaction with energy • Improved understanding of

• Increased availability of clean technologies, such as electric vehicles and micro-generation	consumer behavior

Source: adapted from World Economic Forum – Accelerating Smart Grid Investments, White Paper 2009

The business case for smart grids in Europe is different from that which exists in the U.S. The U.S. has historically had much more frequent meter reading and higher network losses and outage costs than Europe, and as such, automated meter reading (AMR) and distribution automation (DA) present higher savings potential in the U.S. than in Europe. Electricity consumption in the U.S. is also significantly higher than in Europe, providing a much higher potential for savings through demand response (DR) programs there. Furthermore, the unbundled status of many European utilities complicates the business case because the savings generated by some investments might not directly accrue to the investor. However, European regulators have realized the huge societal benefits that smart energy could generate and have emerged as key supporters of the technology's deployment. Because the modernization of Europe's electricity grid is overdue anyway and many of the upgrades would be 'smart' by default -- and not in the least because electricity prices are expected to trend upwards over the coming decade(s) – there is still a compelling business case for the smart grid in Europe.

I estimate the annualized present value of total European smart grid capital and operational expenditures to be between €7.8 and €9.1 billion (Van der Zanden, 2011). A fully rolled-out smart grid is expected to generate important benefits for utilities across Europe, as well as for society as a whole, as visualized in Figure 17.

Salient benefits include:

- Reduced losses in transmission and distribution, mainly due to the decreased prevalence of theft, equipment malfunction and unbalanced feeder lines. On the basis of Europe's total electricity consumption of about 3500 TWh and an average electricity price of 0,12€ per KWh, a simple calculation shows that the savings potential from reduced transmission and distribution losses in Europe from the current 8% to 6% would amount to about €8.4 billion. (See column 3)
- More precise management of conservation voltage could allow for a reduction in conservation voltage. While conservation voltage reduction is a bigger issue in U.S. radial systems, I estimate the savings potential in Europe to be 1% to 2%, which would save another €4.2 billion to €8.4 billion per year (column 4).
- Operational savings, consisting mainly of the elimination of meter reading costs, faster detection and repair of power outages, capability of remote connect/disconnect and minimization of power theft. According to studies undertaken by Ahmad Faruqui of the Brattle Group (2010), European utilities could achieve operational savings of between €2.2 billion and €3.5 billion per year from smart metering alone (column 5). The operational savings estimates in Faruqui's study are largely based on the reported savings realized by Italian utility Enel, which has the largest roll out of smart meters to date. Savings in field operation costs and from reduction of theft are relatively large in Enel's case and are likely to be smaller in other European markets. A study by Eoin Lees Energy

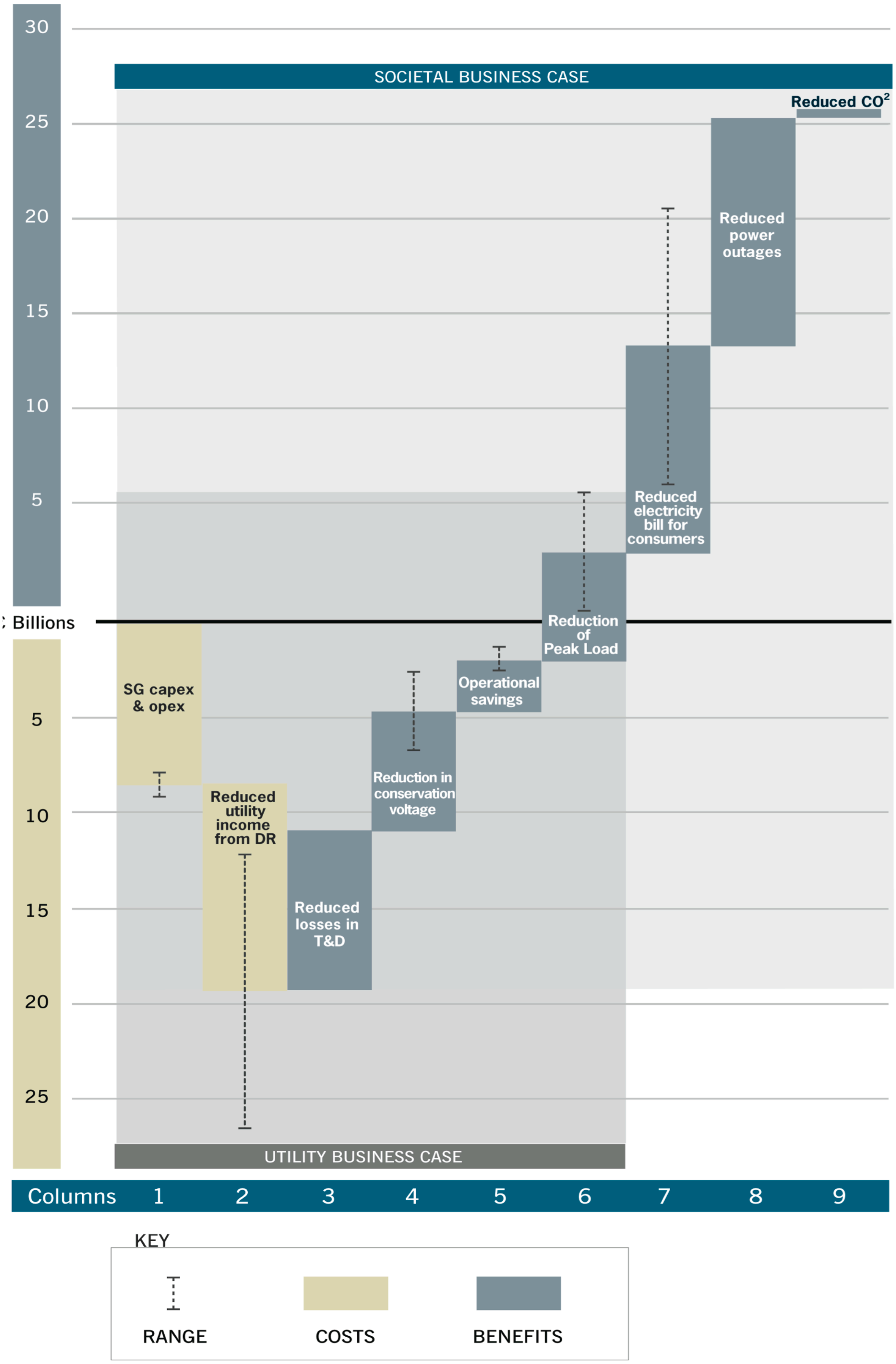
(2007) in the U.K. assessed the operational benefits more conservatively, at about 10% of the initial capital costs of the AMI.

- Reduction of peak load through demand response. In most parts of the EU, 5% to 8% of installed capacity is idle for 99% of the time. Growth in demand for electricity is driving an even higher growth in peak demand, which under the current scenario is increasingly costly. Peak power capacity is more expensive, more inefficient and more polluting than the power capacity used to generate base demand. Measures to reduce electricity demand are cheaper than building extra peak generation capacity. Based on a value of avoided cost of capacity of €87/kW-year, as determined by the Single Electricity Market committee (SEM), the total value of avoided capacity costs (generation capacity, transmission and distribution capacity and avoided energy costs) is around €0.6 billion per year for each 1% of peak load reduction achieved through demand response (Faruqui, 2010). Pilot tests in various parts of Europe and elsewhere have shown potential for demand response to fall across a rather broad range, from 0% to 25%, with commercial and industrial customers showing, respectively, 60% and 50% lower response levels than households. It is generally agreed that DR in Europe can reduce peak load between 5% and 15%, corresponding to between €3 billion and €9 billion per year (column 6). Reported reduction potential from DR in the U.S. is higher, around 20%. This is mainly because electricity use in many parts of U.S. is higher than in Europe, due to the wider presence of district heating/cooling and passive solar buildings in Europe, as well as the increased prevalence of more energy-efficient housing.

- Automated load following resulting from smart grid technology will greatly facilitate integrating EVs and renewables. In fact, the presence of a smart grid is an essential prerequisite for EV and RES integration. The benefits of automated load following for the purpose of EV and RES integration have therefore not been explicitly included in our valuation model.

The above benefits to utilities amount to an estimated total of between €22 billion and €29.3 billion annually. However, smart metering is also likely to unleash a reduction in consumers' electricity bills, estimated to be between €3.6 billion and €18.2 billion (column 7), depending on location, feedback models, penetration of air conditioners, etc. This makes the business case for utilities less obvious and rather uncertain, given the fact that both savings from reductions in peak load capacity, as well as the reduction in revenue from DR, are both highly dependent on consumer engagement with the new technologies and pricing schemes.

Figure 17. Utility and Societal business cases for full rollout f smart grid technology



Source: Van der Zanden / GTM Research

The uncertainty of the business case for utilities explains why utilities have been somewhat reticent to make large investments in smart grid technology without having the regulatory support or certainty that the benefits of these investments would accrue to them. Investments in improved consumer feedback and demand response are ambiguous for utilities, as DR allows for load shifting, which improves the utilities' asset utilization and defers capital investment in generation capacity, but at the same time, it reduces their income because of likely reductions in absolute levels of consumption.

The societal benefits of a full rollout of smart grid technology in Europe, however, include an additional €16 billion to €30.6 billion in savings (the addition of columns 7, 8 and 9). This makes the societal business case for smart grid deployment quite convincing and underlines the need for European regulators and utilities to agree on ways to share costs and benefits between utilities, customers and government entities to ensure that the development of the smart grid will not be slowed down because of uncertainties regarding the business case on the part of the utilities.

- Smart grid deployment will facilitate the reduction of electricity bills through demand response. Various trials in different parts of Europe have shown that depending on supporting technology, type and frequency of feedback, as well as climate and other contexts, a reduction of 2% to 10% in electricity bills can be achieved through demand response. According to Eurostat (2008), the average European household spends about 761€ per year on electricity, as per the data presented in Figure 18. A 10% reduction in consumption through smart metering applications could therefore result in direct savings of €76 per year, which is equal to more than half the price of installing a smart meter. Assuming that there are 240 million households in the whole of Europe, 2% to 10% would correspond to an estimated €3.6 billion to €18.2 billion in savings on the customer's side (column 7). This reduction in revenue for the utilities constitutes a barrier that may prevent them from aggressively rolling out metering and demand response programs.

- The total cost to GDP of power disturbances in Europe, as described previously, is estimated to be close to €30 billion per year. Distribution automation, including fault detection, isolation and restoration (FDIR) capability, could significantly reduce outage times, perhaps by as much as 80%. A conservative estimate of a 40% reduction would be valued at €12 billion (column 8).

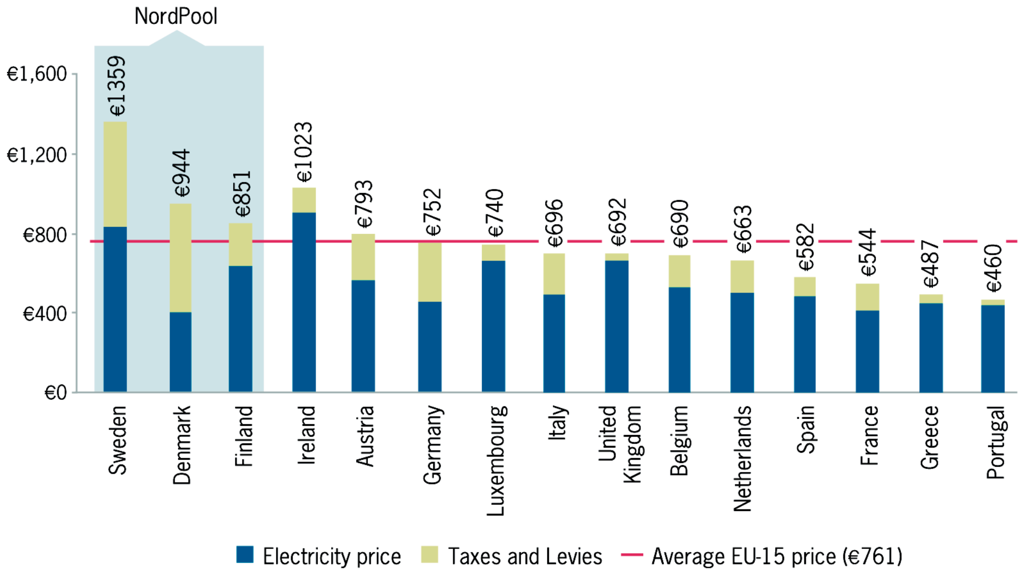
- In the period of peak capacity adjustment, the relative over-capacity will result in lower electricity prices in the short term. This effect has not been taken into account for our calculation.

- Reductions in CO2 emissions of up to 30 Mt/year are feasible with a fully operational smart grid, according to the European Commission's Strategic Energy Technologies Information System (SETIS). Assuming a price of €15/ton within the EU's Emission Trading Scheme, this would correspond to €0.45 billion per year, assuming no change in the mix of energy sources used (column 9).

- The renewal and re-invention of the power sector will create jobs and business opportunities. Apart from its 20/20/20 targets, through mandates, directives and subsidies, the EU hopes to stimulate European industry in the development of world-class innovative energy technologies. The European Commission estimates the EU's target of 20% renewable energy by 2020 to create about 2.8 million new jobs and increase GDP by 1.1% (Kvarnbaek, 2009).

- In addition to the giant technology firms, all sorts of firms in the power, renewable, appliance and auto industries can use the smart grid to interact with their customers, leading to numerous opportunities for the development of new applications and value generation.

Figure 18: average annual electricity bill in various European markets



Source: Eurostat, 2008

Figure 18 reveals another interesting insight with respect to the potential for demand response. The markets with the highest average electricity bill are in Scandinavia and are supplied by the NordPool electricity market. The high share of hydroelectric power and storage capacity in NordPool, however, significantly reduces the need for peak load shaving. Similarly, the much lower penetration of air conditioners and higher presence of district heating/cooling in Europe when compared to the U.S. implies a lower potential for DR and peak demand reduction. At the same time, lower electricity bills in the center and south of Europe are arguably too small to provide consumers with a strong incentive for reductions. This makes the value proposition for demand response in Europe considerably less than in the U.S. It is less for reasons of peak load reduction that DR is being considered in Europe than for load shaping, in order to facilitate the influx of renewable power into the grid.

A comparison of the benefits to utilities and to society of full smart grid deployment shows a mixed case for utilities. Potential peak load reduction is significantly higher if a high level of consumer engagement (i.e., a high percentage of demand response participation) can be achieved, but the simultaneous reduction in income due to decreased demand is a deterrent to utilities. The business case for society as a whole is more obvious. This explains why most utilities were hesitant to move ahead with smart metering rollouts until they were mandated by the EC. Now that an AMI rollout is mandated, it clearly seems to be in the interest of utilities to invest in maximizing consumer impact on load shifting for peak reduction. I therefore expect DR activity in Europe to pick up significantly over the coming five years, and I see copious opportunities for home energy management vendors, especially in the U.S. and Japan, where demand response and home energy management have been a focus area for a longer period of time.

As will be discussed later, consumers in various parts of the world have shown resistance against smart metering because of increased consumption bills (PG&G California), privacy (Netherlands) and health concerns (California, Germany). Utilities and regulators must make sure to get consumer buy-in for smart grid technology. An important part of this is making sure that the business case for consumers makes sense. Today's unengaged consumers will be asked to pay for part of the investment in smart grid technology and at the same time will start incurring transaction costs if they are asked to start interacting with their consumption feedback. Especially in today's difficult economic climate, it is essential that regulators and utilities convince customers of the economic and other benefits that smart grid technology will bring them, to justify the extra costs that consumers will incur. Lowering transaction costs for consumers will be key in this process.

4.3 Timing

All plans in Europe are synchronized to 2020, when an expected 80% of households should have smart meters installed and Europe should have reached its 20/20/20 goals.

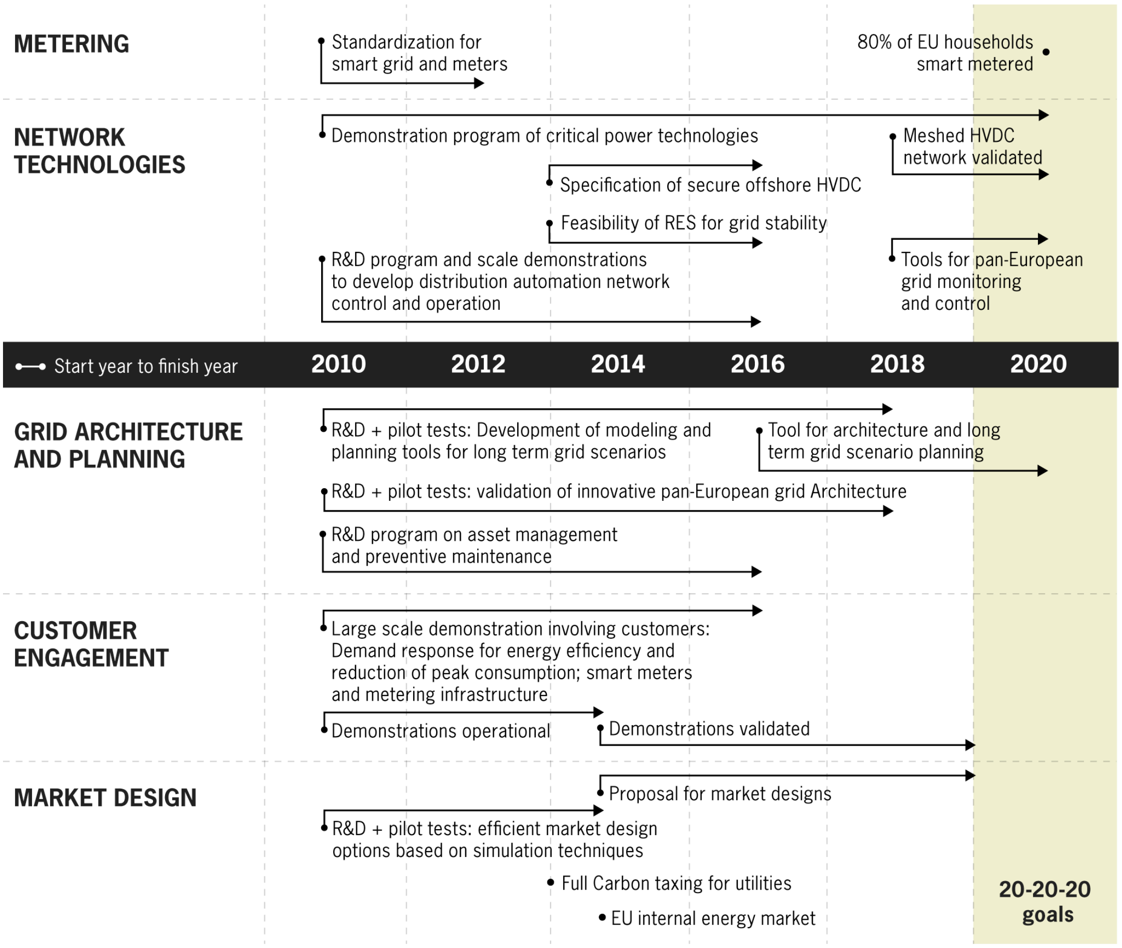
Smart meter rollouts have been delayed in some markets because of lack of interoperability standards or insufficient regulatory frameworks, as well as consumer concerns about privacy, such as in Germany and the Netherlands. Initial efforts to agree on interoperability standards did not succeed, but efforts are now being made to reach agreed-upon standards by the end of 2012.

In 2013, carbon taxing will come into effect in Europe, further speeding up the need to integrate renewables. Even though an EU-wide carbon tax is still being drafted and needs to be approved by all EU member states (a recent version of a Carbon Tax law in France was blocked by the National Constitutional Court), an agreement is likely, as most individual states have already set national energy taxes above EU minimums. According to the current draft, EU member states would be obliged from 2013 on to set minimum rates of CO2 taxes at €20 per ton for fuel for transport and heating. The taxes would not apply to electricity companies that trade carbon in the European Emissions Trading Scheme (ETS), where the price of CO2 is currently around €15 per ton. However, whereas through 'grandfathering' under the old European cap-and-trade scheme, electricity producers had been assigned too many allowances, these allowances are set to be reduced to zero by 2013, which will probably force an increase in the cost of emission allowances under ETS, thus providing a strong incentive for utilities to increase their use of low carbon or renewable sources.

Another goal of the EC is to have a fully integrated internal energy market operating by 2014.

A timeline of EC smart grid R&D objectives and policy targets is represented in Figure 19.

Figure 19 Timeline of EC smart grid R&D objectives and policy targets



Source: SETIS / GTM Research

5. The impact of consumer engagement

Europe's consumers are arguably among the most aware in the world of the need to reduce GHG emissions through improved energy efficiency and reduced consumption of fossil fuels. Compared to the U.S., where average household electricity use is close to 11,000 kWh per year, EU household electricity use is relatively minimal, averaging at just over 4,000 kWh. However, the average electricity bill in the EU is similar to the U.S.: €761 versus US$1250 (approx. €892) per year. One of the key drivers behind the higher energy efficiency in the EU is the cost of electricity, which is over twice as expensive in Europe as it is in the U.S., providing a strong incentive for saving. In absolute terms, however, this means that the potential for peak load reduction and reduction of electricity use in Europe is more limited than in the U.S.

There is an increasing understanding in Europe that fossil fuels are becoming more expensive and that technologies and applications will need to be introduced to improve energy efficiency. Generous feed-in tariffs and other incentives to install micro-renewables have already converted over a million consumers into active 'prosumers' in

Spain, Germany, the U.K. and other markets, allowing consumers to sell electricity back to the utility.

However, there is also still widespread ignorance about how the electricity market works, and in some markets, like Germany, recent electricity retail price increases turned public opinion against the utilities. This mirrors events in the U.S., where consumer backlash against smart metering has plagued PG&E's US$ 2.2 billion rollout of 10 million smart meters. PG&E promoted the smart meters as a means to lower electricity bills, but when bills went up in some specific cases, consumers revolted, laying a fertile base for later claims by consumer groups that the radio emissions from smart meters would constitute a health risk. These health claims led the State of Maine to allow consumers to opt-out of smart metering until the health issue had been clarified. In the Netherlands, consumer privacy concerns led the government to change the mandatory rollout of smart meters to a voluntary rollout. Research by T-Systems and The Economist Intelligence Unit in the U.K. recently showed that 54% of the population do not believe the government's claim that smart metering will generate energy savings of GBP7.3 billion over the coming 20 years (GBP23 per household per year); instead, most expect bills to go up. Fully 70% of respondents were not willing to incur upfront costs of smart meter installment, even with the promise of later savings. A Pike Research survey (Gohn, 2010) of US consumers showed that 20-30% savings on the electricity bill are required to get a significant (around 40% resp. 70%) share of consumers interested in demand response and smart appliances. Consumers are the enablers of a large part of the smart grid's potential savings, but they will expect economic and other rewards for their involvement.

Positive involvement of consumers with electricity use and service selection is considered a key success factor for realizing the potential gains of the smart grid. To many industry observers, the current lack of involvement is worrying. Utility executives on both sides of the Atlantic identify 'consumer education and awareness' and 'consumer buy-in' as the biggest barrier to smart grid adoption (Young, 2011). Consumers are the enablers of a large part of the smart grid's potential savings. While different consumer groups may be motivated by different facets of the technology, such as environmental concerns, convenience, etc., they will also expect economic incentives for their involvement. As transparency and competition in the European electricity sector increase, society at large will benefit through more competitive, tailor-made price and product offers, but utilities need to put consumer engagement higher on -- if not top of -- their agenda, rather than forcing the technology on unengaged consumers.

Some European utilities are starting to realize that smart metering rollouts are not only about technology, but are also very much about the process of rollout and the level of engagement achieved with consumers. Denmark's SEAS-NVE paid careful attention to this aspect to the point of training installers in how to talk to customers in their homes. As a result, the utility's complaint rates dropped significantly and customers now save an average of 16% on their power bills.

An important barrier to consumer engagement in Europe is the fact that in some European markets TOU tariffs are not allowed, and in others, consumers must actively be persuaded to change from today's flat rates to dynamic pricing schemes. Consumer research in California showed that 'opt-out' schemes with TOU pricing as the default pricing scheme are much more effective than opt-in schemes. Research by Momentum Market Intelligence (2003) indicated that 80% of consumers would remain on dynamic pricing if this was the default offering, while only about 20% would choose this scheme on a voluntary basis.

As was clear from the smart grid business case presented in chapter 4, a very significant part of the value proposition of the smart grid depends on actions taken on the consumer end. Through demand response mechanisms, either induced or automated, it is possible to achieve that consumers reduce or shift their consumption to off-peak periods. Various tests around the world have generally shown reductions in peak load generally in the range of 0% to 25%. In Europe, where potential for demand response is lower than in the USA, industry analysts generally use 5% to 15% as an acceptable estimate for potential peak load reduction. Whereas load shifting by consumers allows for peak load reduction, it does not necessarily reduce overall consumption, but depending on the type of feedback, an absolute reduction in consumption can be achieved. On the basis of tests performed in Europe, Faruqui (2010) assumes that an absolute reduction of consumption levels in the range of 2% to 10% is reasonable. Figure 20 gives an idea of the economic impact in Europe of each percentage point reduction in consumption.

Figure 20 Estimated impact of reduction in consumption on utility and consumer cash flows

Reduction	**Peak Load:** Deferred capex in peak generation capacity (€ billion)	**Absolute reduction:** Reduction in Consumer Electricity Bill (€ billion)
1%	0.6	1.8
2%	1.2	3.6
3%	1.8	5.5
4%	2.4	7.3
5%	3	9.1
6%	3.6	10.9
7%	4.2	12.8
8%	4.8	14.6
9%	5.4	16.4
10%	6	18.2
11%	6.6	20.1
12%	7.2	21.9
13%	7.8	23.7
14%	8.4	25.5
15%	9	27.4

Source: A. Faruqui / GTM Research

The wide range in reduction achieved in various demand response tests indicates the huge potential for value creation through consumer engagement: At a European-wide level, the tests seem to indicate possible savings from avoidance of peak load capacity of €3 billion to €9 billion and savings in consumer electricity bills, ceteris paribus, of €3.6 billion to €18.2 billion. These ranges more than justify a serious effort to try to understand how consumer engagement with electricity can be maximized, which is the objective of this thesis.

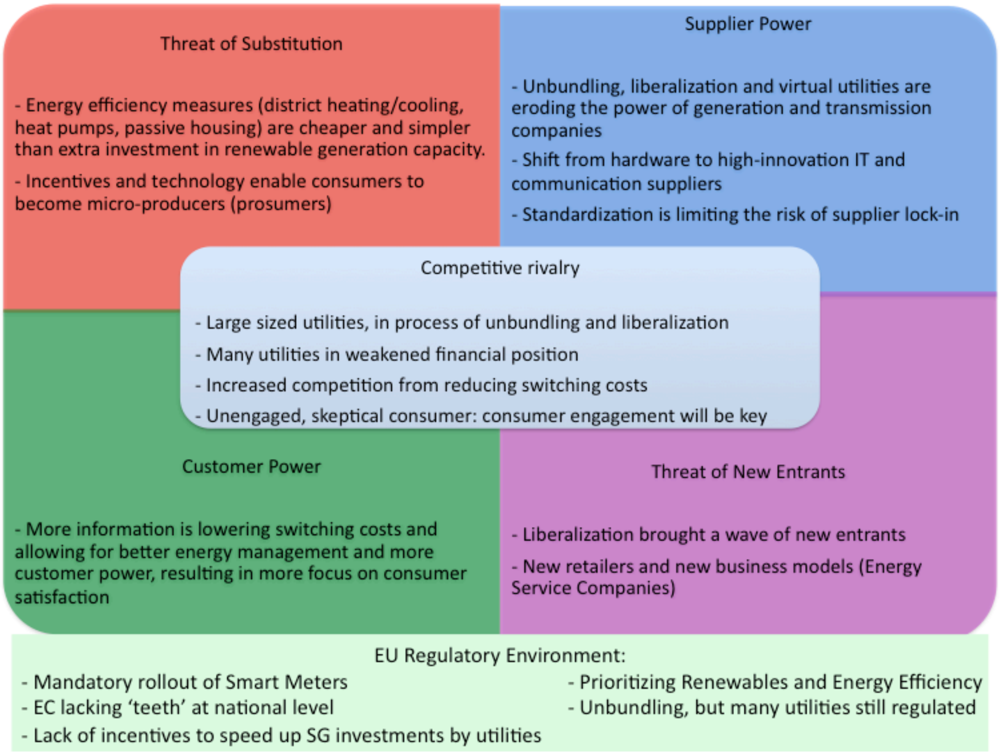
It should be underlined that demand response and AMI not only have the potential to generate savings, but play an important role for the EU in increasing energy efficiency and reducing CO2 emissions, as well as increasing security of supply. Increased price transparency will also increase the competitiveness and efficiency of the electricity markets, ultimately benefiting the consumers and society.

5.1 Theoretical explanations of consumer engagement

In marketing circles, 'consumer engagement' has been a buzzword for quite some time. Whereas one could say that marketing was traditionally centered around the paradigm of 'controlling and commanding' the consumer, better access to information and social network communication have driven consumer empowerment to higher levels. With increased empowerment, the focus of marketers changed from increasing 'reach and awareness' among consumers, to increasing consumer engagement. The Theory of Consumer Engagement describes consumer engagement as "a meaningful, lifelong, two-way conversation, continually learning and growing the relationship".

The Association of National Advertisers (ANA) sees a 'truly interactive dialogue' as the way to build consumer engagement. As can be seen from the (5+1)-Forces analysis of the power supply sector in Figure 21, electricity consumers are definitely becoming more empowered, but because of the history of non-transparency and lack of options in the relationship between utility and consumer, one could say that consumers are still very much 'controlled' by utilities. Forward-looking utilities and regulators will see the importance of engaging electricity consumers and will recognize the opportunity for value creation through changing consumer behavior.

Figure 21: (5+1)-Forces analysis of the electricity distribution sector.



Source: Van der Zanden, based on Porter's 5-Forces model with the addition of socio-eco-political influences

The challenge of increasing consumer engagement with smart grid technology is one of behavioral change. Consumers generally have been quite uninvolved with their electricity supply and consumption, because electricity was relatively cheap and because feedback was generally late, nonexistent or non-transparent. However, consumer involvement and change of habits are desired because they potentially have a very significant impact on the value of the smart grid, from a utility point of view, but especially from a societal point of view.

Most of the limited literature that is available on consumers' response to smart grid technology is based on empirical tests measuring individual's response to consumption feedback and pricing schemes. With the exception of Darby's (2010) reference to the theory of affordances, no insights from behavioral theory are sought, nor is much attention paid to the environmental and political-societal influences on the behavior of individual electricity consumers. This is why I decided to study the engagement of consumers with smart grid technology within the framework of behavioral change theories in the field of consumer and social psychology. To find relevant theories, a review of Aunger and Curtis' work "Consolidating Behavior Change Theory" (2007) is very useful. For this thesis, I decided to study several theories, some of which are single construct and others multi-level: the theory of regulatory engagement, the theory of affordances, transaction theory, social comparison theory and the theory of diffusion of innovation. A brief description of each of these theories follows, together with an assessment and conclusions of how each theory can be applied to the issue of engaging consumers with the objective of maximizing the value of smart grid technology.

5.1.1 Regulatory Engagement Theory

Regulatory Engagement Theory was developed by Higgins and Scholer (2006, 2009). It is based on the following assumptions:

1. Value can be conceptualized as a force that motivates an actor to act towards or away from an object.
2. This motivational force has two components: one determined by the hedonic quality of the component, which determines whether the actor feels attracted or repelled; and another one, an intensity component, that depends on both the hedonic quality and other unrelated forces.
3. Regulatory Engagement Theory focuses on these other forces, which are related to the process of goal pursuit itself and determine the strength of engagement: (a) opposition to interfering forces, (b) overcoming personal resistance, (c) regulatory fit, (d) the use of proper means and (e) high event likelihood.

Regulatory Engagement Theory claims that these other forces magnify the hedonic component of the motivational force and thus the perceived value.

The engagement concept has been described and applied to different fields, such as social psychology, educational psychology and organizational behavior (Saks, 2006) to explain superior student or employee performance. Translated to service marketing, consumer engagement would lead to increased customer satisfaction, customer value and loyalty (Bowden, 2009; Bove et al., 2009), but has more potential in highly hedonic categories of products/services, rather than highly utilitarian ones, as cited and investigated by Hollebeek (2010).

While a number of different definitions of consumer engagement exist, Hollebeek (2010) highlights the notion of two-way interactions between customer and service/product provider and the fact that customer engagement in a way reflects customer's levels of motivational (cognitive, behavioral and/or emotional) investments in their interactions with a product. Instead of a two-way interaction, Van Doorn et al. (2010) argue for a three-way interaction of a customer with a brand and with other customers, as is manifested in customers engaging in word-of-mouth activity, recommendations, blogging, etc.

In another research paper, Hollebeek (2010) investigates the relationship between customer engagement and co-created value (CCV), with CCV reflecting "the level of customer-perceived value arising from interactive and/or joint activities for and/or with actors in service processes". The interaction has utilitarian and hedonic facets that have the potential to enhance the CCV and thus the level of consumer engagement. Some utilities, like British Gas, have smartly exploited this mechanism by organizing energy efficiency competitions between neighborhoods.

Following the reasoning of the Regulatory Engagement Theory, the value of the smart grid would go up if:

1. The interest of the individual consumer is aligned with regulatory pressures.

2. It would be made easy for the consumer to engage positively.

3. The consumer has the right means to increase the likelihood of a positive outcome, i.e. a reduction in the cost of electricity.

4. Rather than underlining the functional benefits of smart grid technology, electricity utilities should underline the hedonic benefits, which have a higher potential for generation of consumer engagement.

The above also has important implications for power utilities in the sense that increased and improved two- or three-way interaction between clients and utility can build consumer engagement.

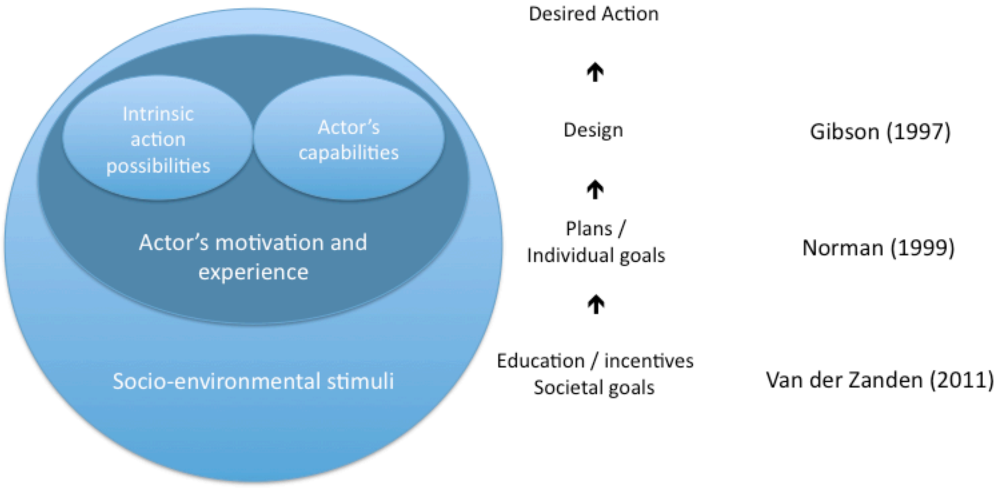
5.1.2 (Extended) Theory of Affordances

The Theory of Affordances was introduced by psychologist James Gibson and discussed in depth in his book "The Ecological Approach to Visual Perception" in the late 1970s. Affordances were originally defined as the quality of an object or environment that allows an individual to perform an action, e.g. a ball can be kicked, a button pushed, etc. Gibson described affordances as all action possibilities that are physically possible, independent of whether the actor is aware of the possibilities, but always dependent on the capabilities of the actor to perform the action.

Donald Norman later adapted the theory in his book "The Design of everyday things" (1988) in the context of human-machine interaction. Norman's definition of affordances was limited by the physical capabilities of the actor, but at the same time dependent of the actor's goals, plans, beliefs and experience, thus making the concept of affordances relational and situational, rather than intrinsic. This definition is highly applicable to 'design for interaction' issues. The theory supports the idea that people would perform desired or probable actions if the design of an object would facilitate the action, but at the same time if their goals and plans would support the action.

Many theories reviewed by Aunger and Curtis (2007) seem to focus on individual behavior and psychology, but in my opinion, studies of behavioral change should be broadened to include physical and socio-political environmental factors that shape the social interaction, lifestyles, norms and values, as well as external influences such as technology and policies. In the same way that Norman expanded Gibson's definition of affordances by including the factors that motivate the actor, Norman's definition could be expanded to include the factors that influence the actor's goals, plans, beliefs and experience. These factors would be the environmental and social stimuli that shape an individual actor's goals, plans and motivation. I believe that this is to a large extent driven by the education of the actor regarding societal goals and regarding the possibilities of action available, as well as efforts to align the individual actor's goals with societal goals. My definition of the Extended Theory of Affordances is presented in Figure 22:

Figure 22: Extended Theory of Affordances:



Source: Gibson (1997), Norman (1999), van der Zanden

Implications of the Extended Theory of Affordances on consumer engagement with the smart grid:

1. It should be made easy for consumers to become aware of action possibilities and which action possibilities are most effective in reaching desired goals (triggering perceptible affordance rather than hidden or false affordance);

2. Consumer interface should be designed to make it as easy and simple as possible for people to (re)act to feedback about their consumption;

3. Efforts to align consumer's goals, plans, values and beliefs with more general, societal energy efficiency objectives, would increase the likelihood of actors choosing the desired affordance, i.e. interacting in the desired way with electricity. This could happen through education and incentives.

5.1.3 Transaction Cost Theory

Ronald Coase developed the Transaction Cost Theory of the firm in 1937 to describe how imperfect information leads to the creation and growth of companies as long as the external transaction costs are higher than the internal transaction costs. If the external transaction costs are lower than the internal transaction costs, the company will be motivated to outsource activities and downsize.

Herbert Simon (1972) described decision makers' behavior in situations of uncertainty and argued that "people possess limited cognitive ability and so can exercise only 'bounded rationality' when making decisions in complex, uncertain situations."

Thus individuals and groups tend to 'satisfice'—that is, to attempt to attain realistic goals, rather than maximize a utility or profit function.

Applying the Transaction Cost Theory to individual smart grid consumers:

1. Faced with the uncertainty of a new technology or new tasks, consumers will outsource production (in the case of smart grid: demand response decision making) if the perceived benefit of internalizing the production or decision-making process is lower than the internal transaction cost. It is therefore interesting for utilities to find out for each type of consumer what the potential benefits of smart grid technology are to this consumer, what the perceived transaction cost to her/him is and design product/service offerings tailored to specific client segments.

2. Consumers have historically been unengaged with electricity. Unless the payoff is high enough, consumers do not want the extra task of having to interpret and digest information and actively manage their power consumption. This was shown in recent surveys in the UK (The Economist Intelligence Unit, 2011) and USA (Gohn, 2010).

3. Lowering transaction costs, which could be done through education, access to relevant information and instructions, and facilitating technology and devices, will increase consumer engagement. However, because of the limited cognitive ability described above, some demand response potential might be lost. This would be an argument in favor of developing technology that would take over the decision making for consumers, thus minimizing the issue of transaction costs to the largest extent possible, in line with Jung (2011), who argues that "a truely smart grid should require as little consumer participation as possible".

5.1.4 Social Comparison Theory

Social Comparison Theory was introduced by Festinger (1954) and is based on the idea that people tend to form opinions about themselves based on comparison with traits of other people in their reference group. Getting people to compare themselves to healthy models has proven to be an effective tool for behavioral change. Aunger and Curtis (2007) argue that the Social Comparison Theory provides a strong message in that people are intrinsically social beings and care about being socially accepted or respected, but that the theory can not be easily used for behavior change, because its message is broad and it does not give clear options for an intervention strategy. Perkins (2003) expanded the Social Comparison Theory to the Social Norms Theory, which shows that communicating what the norm or average behavior in a group is, tends to result in a convergence to the norm of the behavior of individual members of the group, while at the same time reducing misperceptions about normative behaviors.

The enormous amounts of consumer data that will become available through smart grid technology will enable application of the learning of the Social Comparison Theory. Comparison of individuals' consumption with their own historic patterns or with the consumption patterns of comparative households seems an effective way of increasing engagement and reducing consumption, as has been shown in several pilot tests, among which the award winning EnergiKollen in Växjö, Sweden. (Logica, 2009). US company Opower has built a successful business model around this concept.

5.1.5 Diffusion of Innovation Theory

The Diffusion of Innovation Theory (Rogers, 1995), as already referred to in section 2.2, argues that people differ with respect to their willingness to adopt unfamiliar behaviors or technologies. The population can thus be segmented into different groups, that can each be targeted with specific messages or programs. The contribution to behavioral change can be maximized if 'early adopters' can be motivated to adopt the target behavior and thus begin the diffusion of the behavior through other segments of the population.

The Theory of Diffusion of Innovation is especially relevant to the development of the smart grid on the basis of adoption by different consumer groups. Segmentation is commonly used by marketers and this theory clearly underlines the need for utilities to better understand and segment their customers and increase their engagement through the design of service/product offerings and communication, relevant to each customer segment.

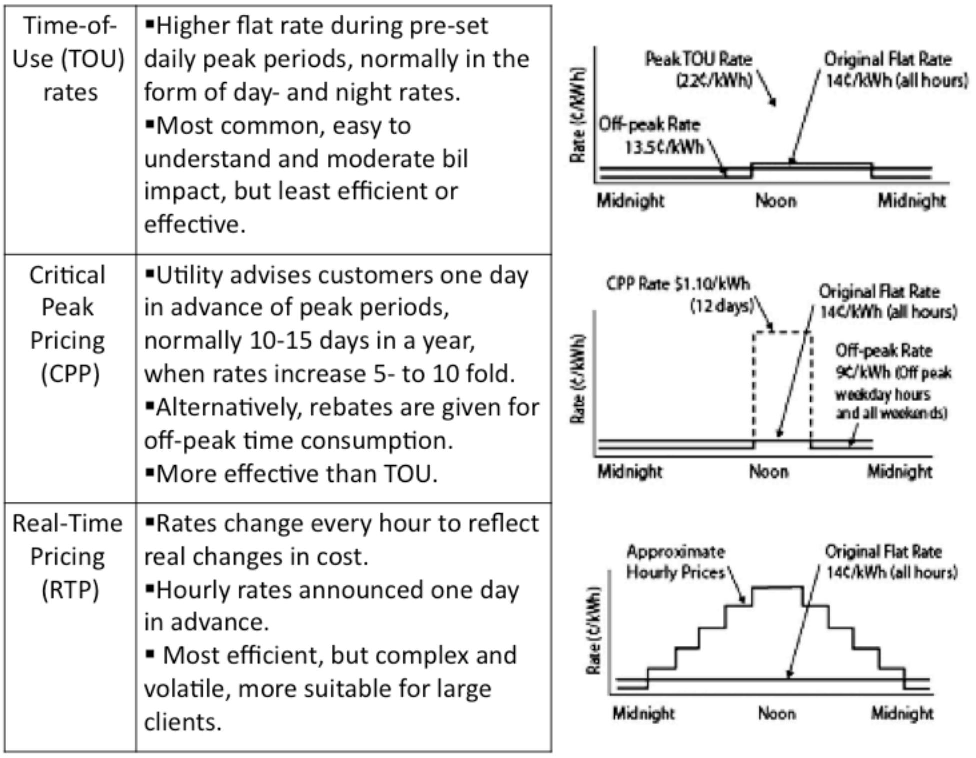
5.2 Empirical studies of consumer response to feedback on electricity consumption

To mirror some of the learning from the theories described in the previous chapter with the actual findings in pilot tests, this chapter reviews some of the main studies performed to date with respect to consumer response to smart technology, specifically smart metering. Most studies were performed in North America and Europe. Some of the most in-depth reviews to date were done by Ahmad Faruqui of the Brattle Group, Sarah Darby of the Environmental Change institute at Oxford University and Karen Ehrhardt-Martinez of the American Council for an Energy Efficient Economy (ACEEE). Because these three authors combined US and European pilot tests and my previous analysis of the European smart grid claimed that Europe has a lower potential for demand response than the US, I decided to review European-only pilot test results to come to an as accurately as possible analysis of the potential for demand response in Europe.

5.2.1 The impact of information feedback on energy consumption (Faruqui, 2009)

In an extensive study of various demand response tests around the world, Faruqui (2009) found conclusive evidence that households respond to higher prices by lowering usage. One of the most effective ways to stimulate consumers to shift their consumption is through dynamic pricing, such as time-of-use (TOU), real-time pricing (RTP), critical peak pricing (CPP) or peak time rebate (PTR) schemes. Figure 23 gives an overview of these pricing schemes.

Figure 23 Examples of time-varying electricity rates



Time-of-Use (TOU) rates	▪Higher flat rate during pre-set daily peak periods, normally in the form of day- and night rates. ▪Most common, easy to understand and moderate bil impact, but least efficient or effective.
Critical Peak Pricing (CPP)	▪Utility advises customers one day in advance of peak periods, normally 10-15 days in a year, when rates increase 5- to 10 fold. ▪Alternatively, rebates are given for off-peak time consumption. ▪More effective than TOU.
Real-Time Pricing (RTP)	▪Rates change every hour to reflect real changes in cost. ▪Hourly rates announced one day in advance. ▪ Most efficient, but complex and volatile, more suitable for large clients.

Source: Fox-Penner (2009), p. 41, as referred to by Faruqui

While all of these schemes shift consumption to some extent from higher-priced peak periods to lower-priced off-peak periods, important differences have been observed in pilot tests between different schemes, climatic contexts, communication methods and enabling technologies, such as smart thermostats and remotely controllable gateway systems. The studies, largely based on pilot tests in the USA, showed time-of-use rates to induce a drop in peak demand that ranges between 3% and 6% and critical-peak pricing (CPP) tariffs to induce a drop in peak demand that ranges between 13% and 20%. When accompanied with enabling technologies, the CCP tariffs resulted in a reduction in peak demand of between 27-44%.

Faruqui's main conclusions were:

1. The difference between tariffs at different times of day has a strong effect on demand response. Typically, high tariffs should be at least 5x low tariffs for consumers to show a significant response.
2. The "Paradox of choice" (Schwartz, 2004) seems to apply to electricity tariffs: more options means more confusion and higher transaction costs for customers. Research by Momentum Market Intelligence (2003) shows that the adoption rate is significantly higher (80%) when tariffs are 'opt out' (tariff scheme set by the utility), rather than 'opt in' (20%; utility offers a variety of schemes and the customer has to choose).
3. More sophisticated, often more expensive enabling technologies generate stronger demand response. Tests in California showed customers with smart thermostats reducing their peak load by twice as much as ones without, and over three times as much when a gateway system was in place (Faruqui and George, 2005)
4. Different segments of consumers react very differently to different price signals (Faruqui and Sergici, 2009). Consumers on prepayment schemes showed to reduce consumption twice (14%) as much as consumers buying on credit.
5. Demand response potential seems to be higher in areas with high central air conditioning penetration.

Faruqui (2010) estimates the total cost of installing smart meters in Europe at €51 billion. Based on data largely from the pilot tests in the USA and some in Europe, he estimates that consumers could generate savings for utilities of between €14 billion and €67 billion in peak power capacity, assuming a range of reduction of peak load of between 2% and 10%, depending on to what extent they can be convinced into shifting their consumption to lower cost time slots. The difference between the net present value of demand response under low-acceptance and high-acceptance scenario, €53 billion according to Faruqui, indicates the extra savings potential if EU consumers can be convinced to maximize their demand response.

Discussion of Faruqui's review

While the Faruqui study is very insightful, a number of questions arise:

1. Most of the pilot tests in the Faruqui study were performed in the USA, where the potential for peak load reduction and absolute reduction of consumption is significantly larger than in Europe. To assume that European consumers would achieve similar levels of reduction as US consumers, is in my opinion too optimistic.
2. The savings under a high adoption scenario would imply important additional investment in technology, reducing the return-on-investment on the total investment. A simple clip-on display unit costs approximately €25, with more sophisticated home automation systems costing up to €379 (RWE smart home). These extra costs have an important impact on the final value for the consumer.
3. Unless consumers can lower their electricity bill, there will be little interest in increasing their involvement, as shown in recent surveys in the USA (Gohn, 2010) and the UK (The Economist Intelligence Unit, 2011)
4. In his calculation of the business case for smart grids in Europe, Faruqui does not take into account the loss in revenue for utility caused by consumers'

lowering their electricity bills.

5. A longer-term question for utilities under dynamic pricing schemes is: What happens to price differentials if consumers start shifting the timing of significant amounts of their consumption? Shifting of load will automatically lower the price differentials between high- and low-price periods and thus eliminate the incentive for consumers to shift their consumption. Insufficient empirical evidence makes it impossible to determine what impact this could have on the overall business case.
6. Opt-out is much more effective than opt-in to get consumers onto dynamic pricing schemes. Regulated tariffs make it easier to introduce dynamic pricing by default, but market liberalization in most EU member states implies that customers have to actively choose a dynamic tariff. Without intervening in tariffs, regulators could help adoption of DR by making it obligatory for electricity providers to give their customers much more detailed information. Another way policy makers could intervene, according to Faruqui, is by mandating dynamic transmission and distribution (T&D) tariffs, which make up around 20-30% of household's electricity bills. While this measure will definitely increase the consumer's awareness of high- and low-price periods, it must be questioned if dynamic rates applied to only 20-30% of the electricity bill give enough of an economic incentive for customers to change tariff and behavior.

5.2.2 The Effectiveness of Feedback on Energy Consumption (Darby 2006, 2009)

Darby (2006, 2010) from the Environmental Change Institute at Oxford University also studied the potential for householder engagement. From a review of pilot tests from the USA, Canada, Scandinavia, the Netherlands and the UK, she concluded that:

1. Direct feedback (in-home displays giving real-time and historic usage feedback information) helps interested users achieve a permanent reduction of power consumption by 5-15% through changed habits and investment in efficiency measures.
2. Savings from indirect feedback (information that has been processed before reaching the consumer, usually via billing) are in the range of 0% to 10%, but are dependent on the quality of information given and the context.
3. Comparison with historic use seems more effective than comparison with other households or objectives.
4. Disaggregating feedback by end use is expensive and complicated, but accurate, frequent billing with general guidance on average home energy use disaggregated among end-uses can also be effective.
5. Pay-as-you-go systems seem to generate more savings than credit systems.
6. Online billing or feedback has the drawback that it requires consumers to pro-actively seek and engage with information about their electricity use.

Discussion of Darby's review

Darby argued that electricity consumers often lack the knowledge and information to correct their energy-use habits and underlined the importance of the communication that energy companies use over time to build up consumer engagement and structurally change consumer habits. Durable value creation through SG technology only happens if changes in consumer habits and routines over longer time period are achieved. Darby's findings of 5% to 15% permanent reduction are in line with claims made by Parsons (2008), but contrast with research at the Delft University of Technology in the Netherlands, which showed that the initial savings in electricity use of 7.8% in the first four months after installing home monitoring devices were lost over the medium to long term (Van Dam et al., 2010). More research in this area is essential for utilities to understand how to maximize consumer response. The Dutch researchers, however, concluded the same as Darby, that installing energy monitors alone will not necessarily reduce electricity consumption, but that attention should be given also to social science issues and contextual factors.

Using the Theory of Affordances, Darby (2010) studied the way consumption feedback, with and without smart meters, impacted the energy consumption. She concluded that little evidence exists to uphold the claim that AMI on its own brings about reductions in consumption. It is the feedback, depending on its form and context, which might change behavior. Darby argues that not only technology or economic incentives should be considered as drivers of consumer engagement, but also end-user perception and practices. AMI could thus be useful as a technology that facilitates home energy management and customer-utility relations. However, consumer perception and practices determine what interface, feedback, message and support will be most effective for influencing specific segments of consumers. For AMI to reduce consumption, Darby concludes:

1. The focus should not be on peak electricity demand reduction, but on overall demand reduction.
2. Customer interfaces should be designed that facilitate understanding
3. Consumers should be guided towards appropriate action through frequent and clear instructions

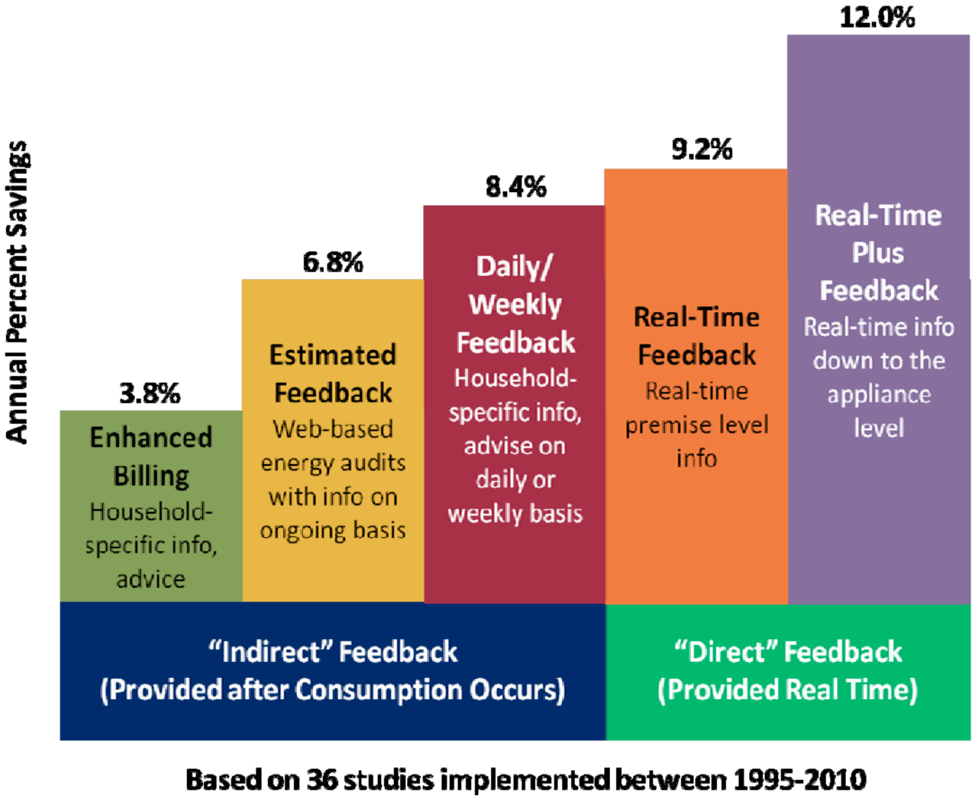
5.2.3 Advanced Metering Initiatives and Residential Feedback Programs (Ehrhardt-Martinez, 2010)

An overview by Ehrhardt-Martinez et al. (2010) of 57 studies from various continents showed average savings of up to 12%, as seen in Figure 24. It must be noted that only 13 of the studies included in the overview were European. Allthough most of the studies included in the Ehrhardt-Martinez review were American, a number of qualitative conclusions are insightful:

1. To maximize feedback related savings, useful technology must be combined with well-designed programs that inform, engage, empower and motivate consumers.
4. Daily/Weekly feedback and real-time, disaggregated feedback generate the highest savings.
5. Opt-out programs are significantly more effective than opt-in, because of higher participation rates.
6. Higher frequency of feedback (preferably real-time) and a higher level of detail (preferably down to appliance level), increase the likelihood of significant and persistent savings.
7. In the absence of expensive AMI, enhanced billing programs are a very cost effective feedback option. The new feedback mechanisms that come with smart metering will be useful as a complement to enhanced billing. The most effective feedback will include multiple feedback mechanisms.

8. Motivational elements, such as goal setting, competitions and social comparisons, for example as successfully done by US company Opower, can significantly influence behavior and generate significant additional savings.
9. Overall energy savings are much higher for programs focused on overall efficiency and conservation (10% in Ehrhardt-Martinez' sample) than for demand response programs focused on peak load shifting only (3%).

Figure 24. Average household electricity savings depending on type of feedback given.



Source: Ehrhardt-Martinez et al. (2010)

Discussion of Ehrhardt-Martinez review

According to Ehrhardt-Martinez, when limiting the study only to relatively recent data from the US, savings tend to be somewhat lower. This seems to be in contrast with my own expectation of the potential for demand response in the US being higher than in Europe, given the considerably higher per-household consumption level and the higher penetration of air-conditioning in the US. Caleno (2009) also claims that the energy savings (2-7% reduction versus 5-8%) and potential for peak reduction (3-8% versus 14-20%) are lower in Europe than in the US. This might indicate that the level of consumer engagement achieved in the European test programs was higher than in the US tests. Further research to verify this and to understand why consumer engagement in European programs may have been higher than in US programs would be very useful.

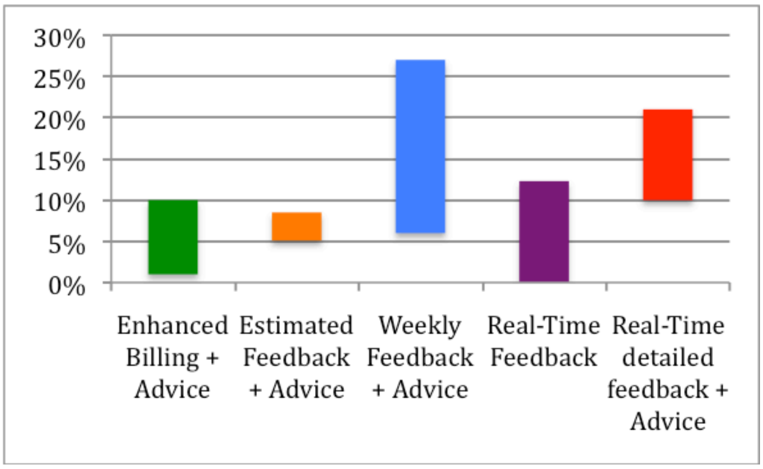
Moreover, the conclusions from Ehrhardt-Martinez should be interpreted carefully, because the data given in Figure 25 are the average savings achieved. These averages were calculated on the basis of the number of studies included in the review; they were not weighted for the number of households participating in each study and thus a study of 20 households has the same weight in the calculation as a study of 2000 households. For each of the feedback mechanisms, the range of savings varied widely. For example, the real-time aggregate (average 9.2%) results ranged from -5.5% to 32% savings.

5.2.4 Own findings

Appendix A shows the key information from 24 European studies of consumer feedback and demand response that I gathered. Some of these studies were also included in the Ehrhardt-Martinez and Darby reviews, but the size of the sample and focus on European-only studies makes an overview interesting.

The 24 studies vary widely in timing, size and profile of sample group, as well as type, frequency and medium of feedback used. The reported results also vary widely, from zero or negative impact of feedback, to reported reductions of over 20%. It must moreover be said that very few of these tests were real-life. Most were in small, selected communities and not-seldom plagued by low engagement from participants. This makes drawing specific conclusions difficult. More systematic, pan-European studies would give helpful insights. Despite these drawbacks, what seems clear is that solutions or best approaches to achieve reductions are situational and depend on the target consumer and context. Grouping the 24 studies into different categories of feedback type gives the following picture:

Figure 25. Ranges of reduction in consumption achieved through various feedback types in a sample of 24 European studies



Source: Van der Zanden (2011)

My general conclusions from reviewing the results from the 24 pilot tests are:

1. Real Time feedback is more effective if detailed to appliance level and if consumers are educated about what actions they can take to influence consumption. Without this, real-time feedback seems only marginally more effective than the more cost efficient option of enhanced billing.

2. Weekly feedback plus advice seems to generate more behavioral change and savings than continuous real time feedback through a monitor only.
3. Social feedback seems an effective driver for behavioral change. Staats' (2008) eco-teams achieved an 8% reduction, British Gas' Green Streets competition achieved 25% reduction (albeit with a prize of BP 50,000 as an incentive for the winning street) and Black's (2009) experiment with eco-meters and social marketing resulted in a 22% reduction in consumption.
4. Persistency of the effects of intervention seem strongly correlated to the length of the duration of a trial and the amount of information available to the customer, as was also concluded by Henryson et al. (2000). Regular reminders seem to contribute to habit formation.

It should be mentioned that almost all the European studies were performed in the north of Europe. Consumption levels in Central and Southern Europe are considerably smaller than in Northern Europe, making the potential and incentive for demand response smaller (Van der Zanden, 2011). It is therefore potentially incorrect to extrapolate these quantitative findings for all of Europe.

5.3 Implications

5.3.1 Recommendations for utilities and intermediaries

The pilot studies reviewed in this study clearly indicate that there is potential for reduction of peak load and reduction of overall electricity consumption through demand response. Both types of reduction seem to depend a lot on consumer engagement. Several of the studies showed that results were limited because of low engagement from participants. Whereas further pilot studies can help reduce the uncertainty in some of the quantitative conclusions from the pilot tests reviewed, there are valuable qualitative insights from the review of engagement theories and the results from demand response pilot studies, that have important implications for utilities:

1. Focus on technology or financials only is not going to generate engagement and might backfire. Put consumer response and getting consumer buy-in top of the agenda when introducing new technology or new rate schemes, to avoid the backlash observed in some US and European programs and to maximize consumer engagement.
2. The majority of today's electricity consumers are unengaged and uninformed. Lower transaction costs for the consumer, either through education and feedback, or preferably through set-and-forget technology or permission for the utility to directly control consumers' appliances.
3. Not all consumers are alike. Environmental benefits are important to one group, while convenience or price to another. Therefore, a one-size-fits-all solution is unlikely to be successful. Utilities should understand and target each consumer segment with tailor made price/product offerings, giving priority to 'early movers', because they will speed up the diffusion of innovations through other segments.
4. Give consumers easily understood feedback, actionable advice and insight into the bigger picture, not just data and information. The most effective feedback is accurate (based on actual consumption), frequent (ideally daily), detailed (broken

down by appliance), given over a longer period, invites the consumer to (inter)act and includes comparative and historic feedback.
5. Leverage social networks to help motivate consumers through the use of social norms, goal setting, community building and competitions.
6. Collaborate with third party providers to come up with engaging product/service-offerings and effective communication.
7. Maximize consumer participation through opt-out program designs rather than opt-in and other incentives, such as rebates and free technology.
8. Introduce pre-paid schemes alongside a choice of on-credit price schemes. Consumers on pre-paid schemes have shown to generate more savings through demand response than customers on credit.
9. Try to engage consumers by underlining hedonic aspects of electricity savings; make the learning process fun.
10. Stimulate two- or three-way interaction between utility and customers to build consumer engagement. Social media are an ideal vehicle for engaging consumers using existing channels, rather than trying to build new platforms.

5.3.2 Recommendations for regulators and public institutions

As shown in section 4.2, the business case for smart grids is more obvious for society than it is for utilities alone. This implies that regulators should be forward-looking and play an important role in driving the development of the smart grid. Regulators can influence the development not only through technology mandates or financial incentives, but also through the promotion and communication of social norms and objectives.

A survey by OECD (2011) concluded that the key policy influencers to greening household behavior are:

1. Providing the right economic incentive
2. Information and education
3. Supply side measures complementing demand side measures*
4. Using a mix of instruments
5. Recognizing variation and targeting specific groups

* This is in line with findings by Agarwal and Bayus (2002) that growth in supply, rather than price decreases, is a key driver of demand takeoff.

From this thesis' review of consumer engagement theories and practical demand response studies, the following recommendations for regulators can be formulated:

1. Clearly communicate societal goals and regulatory targets, and provide incentives and education to end consumers. This will contribute toward individual consumers' alignment with these goals and will increase consumer engagement.
2. Design policies that align utility goals with societal and consumer goals, i.e. focus on service quality rather than quantity, giving incentives for electricity savings, rather than electricity sales.
3. Rather than focusing on the mandatory installation of smart meters, make it mandatory for utilities to provide consumers with frequent, accurate, timely consumption data (real-time and disaggregated, if possible) and historic comparisons.
4. Allow or mandate utilities to use "opt-out" schemes for dynamic pricing rather than "opt-in" schemes.
5. Promote programs that focus on overall demand reduction, rather than reduction

of peak demand.

6. Invest not only in energy efficiency projects, but also in programs for behavioral change and formation of norms and values around energy efficiency, using instruments such as certification schemes and working together with energy intermediaries.
7. Promote, in order of potential impact, persistent changes in consumer behavior, energy efficiency retrofits, investment in energy efficient appliances.
8. Ensure clear, stable and supportive regulatory conditions
9. Apply the integration principle: adapt the program to the context and plan and time interventions for behavioral change in such a way that synergies are maximized with other ongoing energy efficiency initiatives, media coverage or regional/national activities.
10. Accelerate R&D and support evaluation efforts and sharing of results to ensure systematic learning and knowledge capitalization in this new area.

5.3.3 Smart meters for consumer engagement: to be or not to be?

Independent from these recommendations, this thesis has brought up questions regarding consumer engagement with electricity. European regulators and utilities have been largely technology focused in their approach to the smart grid and seem to have underestimated the potential impact of consumers on the value proposition that the smart grid represents. Regulators have mandated the rollout of smart meters, but smart meters alone do not change consumer behavior; instead, it is through relevant, frequent and actionable feedback that consumers adapt their behavior.

Many of the reductions in power consumption in the various tests reviewed by Darby (2010), Faruqui (2009) and Ehrhardt-Martinez (2010) were achieved not with smart meters, but through active meter reading by the consumer or through the utility or researchers giving detailed consumption feedback to the end-consumers. This underlines that it is not the smart meter (technology) that brought about the change in consumption, but rather clear, understandable and actionable information. The type of feedback that would generate action on behalf of the consumer would typically provide multiple options for the user to choose from, have an interactive element, be of high frequency, give a detailed breakdown of power usage by appliance and comparison to previous periods or other benchmarks, such as reference groups (Fisher, 2008 and Wilhite et al., 1999). Darby (2010) refers to various tests that show that consumers potentially had access to information, but did not know what to do with it. Smart meters, for example, might show the actual consumption and extrapolated cost, but not give any indications of what specific actions to undertake to lower consumption.

The studies reviewed seem to indicate that increased understanding and actionable knowledge can cost effectively be achieved through enhanced billing and advice. Now that the EC has mandated the rollout of smart meters in at least 80% of European households by 2020, utilities should be encouraged to take advantage of the opportunity to create value for consumers and society by providing detailed real-time feedback to consumers, together with advice and analysis.

The smart meter also has the potential to become the communication hub between utilities and consumers and thus become an instrument for the utility to increase consumer engagement. Wilhite et al (1999) recognized that more detailed feedback has the potential to increase consumer loyalty to the electricity supplier and increase consumer engagement with electricity use. Darby (2010) also concludes that the smart meter can act as a communications hub and thus improve customer relations, but that the effectiveness of smart metering for customer engagement, in line with the theory of affordances, to a large extent depends on how and for whom, the smart metering is designed.

The Transaction Cost Theory teaches us that unless the payoff is big enough, consumers do not want the extra task of having to interpret and digest information and actively manage their power consumption, which is what most smart meters, displays or consumer gateways today require. Online feedback might be cheap and flexible for the utility, but requires engagement and action from the consumer. Utilities must lower the transaction cost for customers by providing easy to understand, actionable information and advice, using effective communication channels or by providing technology and applications that require the minimum physical or intellectual investment from customers. Taking the transaction cost theory to the extreme, one could imagine a situation where transaction costs have been completely eliminated. Michael Jung (2011) advocates this view in Harvard Business Review, implying that service providers should develop smart grid technology that requires no or as little consumer participation as possible. While theoretically this may seem like an ideal situation, home automation and home energy management system providers have not been able to develop technology yet that effectively and efficiently takes over the complete decision-making from end-consumers. One could question to what extent they will ever be able to do so. Until then, it will be in the interest of consumers, utilities and society to maximize consumer engagement with existing smart grid technology.

6. Conclusions

Development of the smart grid is not only a necessity for the integration of distributed renewable electricity sources and the enabling of plug-in electric vehicles, it also represents an important opportunity for energy efficiency and reduction of CO2 emissions for the electricity sector. European directives for renewables, energy efficiency and CO2 reduction are in place, supported by funds for RD&D projects, many covering smart grid related technologies. While most member states have taken the CO2 reduction and renewable energy targets seriously, the enforcement of the EU's target for 20% higher energy efficiency has been weak. In fact, the European Parliament's Energy Committee (ITRE) failed to set mandatory legislation on this target.(Riley, 2010).

This thesis analyzed the driving and inhibiting factors for the development of the smart grid in Europe and determined ways to maximize the impact of one of these factors, consumer engagement, on the potential value created by the smart grid. In the process, a quantitative assessment was made of the economic value that can be generated through increased consumer engagement with smart grid technology.

During the research, it became clear that among European states, the smart grid is developing at very different speeds. Some governments and utilities have made important investments in the rollout of smart metering, but distribution automation, network management systems and home automation networks are generally still in early stages of development. The macro drivers and barriers identified apply to each individual member state, albeit in different measures.

This thesis demonstrates that the business case for smart grids is much more obvious for society than it is for utilities. Therefore, regulators play an important role in Europe realizing the full value potential of the smart grid. To facilitate investment in the sector, collaboration between regulators and utilities should be accelerated to develop a societal business case for the smart grid. A multi-stakeholder agreement on how the costs and benefits of smart metering, which represents the biggest area of investment, would be distributed amongst the actors, coupled with coherent regulatory measures and incentives, as well as the development of EU wide standards that facilitate interoperability of hardware and applications, will speed up the development of the smart grid.

In smart metering - a basic prerequisite for further development of the smart grid - there seems to be a correlation between the push generated by regulators and the pace of deployment of smart meters. The EC has made mandatory the rollout of smart meters in at least 80% of European households by 2020. Some countries have reached almost full penetration, while others have only just started pilot projects. This thesis argues that it is not the rollout of technology, but the maximization of consumer engagement that is the key to value creation. Most discussion and literature focuses on the roles of government and industry in the development and rollout of technology. However, without acceptance of demand response and home automation applications, and a willingness to change behavior on the part of end consumers, the smart grid is going to stay far from fulfilling its potential of bringing about significant increases in energy efficiency and CO2 reductions.

Most studies and theories of behavioral change seem to have too narrow a focus on individual behavior. It is useful to broaden the analysis to include social interaction, lifestyles, norms and values as well as technologies and policies - all enabling or constraining behavioral change. This thesis looked at the Theory of Regulatory Engagement, the Theory of Affordances, Transaction Theory, Social Comparison Theory and the Theory of Diffusion of Innovation. None of these single theories is complete enough to cover all aspects of behavioral change, but looking at multiple theories allowed me to put together a more complex picture. Using some of the insights from the Regulatory Engagement Theory and the Social Comparison Theory, I have expanded the Theory of Affordances, to include the socio-environmental stimuli in which the individual's motivation and experience are embedded. In my opinion, this makes the theory more complete and better applicable to the issue of consumer engagement with the smart grid.

Today's consumers are relatively uninvolved with electricity, because of the fact that for decades, electricity supply and invoicing has been largely non-transparent and because of the historically low cost of electricity. This makes any value created by the smart grid a relatively low value proposal for consumers. Utilities and regulators should dedicate much more attention and resources to understanding and improving consumer's relationship with electricity. Given the low level of involvement, it is recommendable for electricity providers to keep transaction costs as low as possible for consumers, by making consumer applications extremely user-friendly and offering 'opt out' rather than 'opt in' schemes.

The research into consumer response to different consumption feedback mechanisms was limited by a number of factors. Pilot tests studied have been performed over a period spanning more than 25 years, in different socio-environmental contexts, in different geographical locations, with widely ranging sample sizes, different households and widely varying feedback mechanisms and incentive schemes. Furthermore, response was often concentrated in a small percentage of participants. Whereas it is possible to draw some qualitative conclusions, these limitations make it very difficult to come to quantitative conclusions regarding the effectiveness of different feedback mechanisms.

Given the significant potential for value creation through consumer engagement, it should be useful and interesting to perform identical feedback tests in different parts of Europe, to identify regional differences in response. This type of pan-European test could easily be coordinated by JRC-SETIS or CORDIS. I would also encourage more research into the impact of communication of societal objectives, norms and values on individual motivation, participation and response levels, because the review of the theories identified this as a potential lever to increase response and in consequence, consumer engagement.

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Appendix A : Consumer feedback Studies

	Author, year	Country	Feedback	Mechanism	Sample Size	Overall Savings	Comments
1	Abrahamse et al. 2007	NL	est. Feedback	internet-based tool	189 hh	5.1% savings	
2	Benders et al. 2006	NL	est. Feedback	web-based	190 hh	8.5% savings	
3	Brandon and Lewis, 1999	UK	Daily/weekly, information materials	Written or via PC	120 hh	12% from PC feedback (gas + electricity)	Environmental attitudes and feedback relevant. "Visibility may be the key to change"
4	Haakana, 1997	Finland	Daily/weekly	Energy meters applied in 40 appliances; feedback given as video or printing	105 hh	6% savings in district heating; 17-21% decrease in electricity consumption	
5	Haakana, 1998	Finland	Daily meter reading by users; monthly feedback (comparative, historic, weather adjusted) by utility	Advice after feedback	105 hh	7%	Advice after feedback had no further effect.
6	Karbo and Larsen, 2005	Denmark	Real time and real time plus feedback	Electronic Energy Advisor plus feedback on HH energy consumption pattern	3000 hh with hh-level meters; 50 hh with appliance level feedback	10% expected savings	
7	Nielsen, 1993	Denmark	Enhanced billing	Meter reading	1500 hh	1% (flats)-10% (houses)	
8	Staats et al., 2004	NL	Enhanced billing	Monthly eco-team meetings	150 hh	5% immediately following test period; 8% 2 years later (no subsequent intervention	
9	Staats, Van Leeuwen and	NL	Daily/weekly		384 offices	6%	

	Wit, 2000						
10	Van Houwelingen, 1989	NL	Real Time feedback	The Indicator	325 (divided into FB type: displays, monthly external feedback, self monitoring chart, information about conservation)	Display 12.3%; monthly feedback 7.7%; self monitoring 5.1%; info only 4.3%	
11	Wihite et al., 1995	Norway	Enhanced billing	Two-monthly bills with text and historic comparison, temperature corrected	611 hh (part frequent bill; part feedback, part feedback+ advice)	10% after 3 years	Younger customers more likely to reduce consumption than older ones. Feedback helped identify and reduce wasteful habits
12	Wihite et al., 1999	Norway	Enhanced billing (historic feedback)	Customers sent meter readings to utility every 60 days	2000 hh	8% after 2 years	Increased energy awareness and customer satisfaction
13	Wood and Newborough, 2003	UK	Real Time Plus feedback	Energy Consumption Indicator	44	10-20%	
14	Gaskell, Ellis and Pike, 1982	UK	Info, feedback, weekly visits	Meter readings	80 hh	8% info alone; 9% feedback; 11% info + feedback	
15	Sluce and Tong, 1987	UK	Personal advice every 2 weeks	Meter reading	31 hhs	13% (gas + electricity)	Low income hhs; all received draught-proofing.
16	Staats and Harland, 1995	NL	Comparison with other members of 'eco-team'	Meter readings.	93	27%	Social factors and commitment key; savings persisted/ increased after programme ended.
17	NIE, 2002/3	UK	No bills, advice	Keypad display	26	11% by former pre-payment customers; 4% by	Pre-payment customers seem more sensitive to

						former credit customers	feedback and predisposed to change behaviour than credit customers.
17	Benders et al., 2006	NL	Information + feedback	Web-based tool with billing data	137	4.3%	High drop out rate, but those who continued were positive about the web-tool.
18	Arvola et al., 1994	Finland	Enhanced billing (historic feedback)		525	3% for feedback; 5% for feedback + advice	Billing frequency has mayor impact; hhs with lower-income and high base-line consumption more sensitive.
19	Garay and Lindholm, 1995	Sweden	Enhanced billing (historic and comparative)	Monthly billing	600	“tendency of reduction in electrically heated homes”, but increase in district heating	Positive attitude towards enhanced billing
20	NIE, 2005	UK	Price message (ToD bands and 3 tariffs)	Keypad display	200	11% reduction in evening peak when price signal is applied	Wet appliances and lighting proved best options for load management.
21	Pyrko, 2009	Germany	Online feedback	Real-time data		0%	Very low level of engagement
22	Midden, e.a., 1983	UK	Enhanced Billing	Weekly feedback	69	13%	
23	Black, 2009	UK	Display and advice	Eco-meter plus social marketing	200	20%	
24	Black, 2009	Ireland	Monthly and bi-monthly enhanced billing	TOU tariffs, monitor, fridge sticker and Overall Load Reduction incentive	5000+	Overall reduction of 2.5% and peak reduction of 8.8%	

Appendix B : Smart grid interview questions

General SG development

1. What is your general vision of the development of Smart Energy in Europe? What are for your company the main differences between the development of the SG in Europe versus the rest of the US? What are the main issues affecting its development?

2. Europe generally has more energy efficient housing than the USA and district heating/cooling as well as micro-RES generation is growing fast. How do you think this affects the potential for peak reduction in Europe through DR? Or is Peak reduction less of an issue?

3. Which utilities or countries do you expect to become the leaders in AMI, DA, RES integration and EVs? Do you expect these to be the small players or big players?

4. Which technologies and standards do you expect to prevail in Europe? PLC v wireless/mesh, IEC 61850 v DNP 3.

5. Which strategic alliances or M&A's do you see in the air?

6. What is your forecast of the SG market growth? On what basis do you calculate DA growth?

7. Where do you see most of your company's growth in the 2011-2020 period?

SG Investment

8. Key DA applications driving DA market growth will be distribution switchgear upgrades; Volt/VAR optimization (VVO); fault detection, isolation, and restoration (FDIR); and feeder protection systems and control. Is this also true for EU??

9. What is the appetite of utilities to invest in EU versus USA? Government or private money?

10. How do you expect SG investment over the coming 5 years in Europe to be distributed between:

• AMI	……%
• DA	……%
• Substation automation	……%
• DG/Renewables integration	……%
• EVs infrastructure	……%
• transmission upgrades	……%
• other?	

11. What specific hardware or technology and new solutions (where is communication being added) do you think will drive DA growth?

12. Do you think that the business case for AMI or DA in Europe differs significantly from the USA? In Europe generally about 100 end points are connected to one transformer, rather than 6 in the USA. How does this affect investment in DA?

13. Large scale AMI deployments in Europe tend to be cheaper than in the USA. Is this only because of cheaper PLC communication or do you see other reasons?

14. Where do you foresee penetration of EVs to happen quickest? How will this affect SG investments? Are EV's the 'tail wagging the dog'?

15. What are the challenges of massive RES integration onto the SG? What level of investment is required to meet this challenge? (In the US, RES is considered a big deal if solar penetration above 20% on a low voltage grid. How does this work in f.e. Germany? Is it also considered a complication?)

Regulation

16. How big do you estimate the chance that the EU will meet its goal of having 80% of households installed with smart meters by 2020?

17. Large differences between EU countries determine national regulations. F.e. Scandinavia's large hydro capacity provides a storage solution for intermittent RES and reduces the need for large price differentials between day and night electricity. Poland still has retail price regulation and thus utilities are limited in offering dynamic pricing. Which markets present the most favorable regulations for your company?

18. What should be the role of authorities/regulators in the development of the Smart Grid? What policies would be most effective?

Consumer engagement

19. Do you expect Smart Homes and beyond-the-meter services to take off in Europe? When and where?

20. How do consumers influence the speed of deployment of smart grid technology? What can vendors, utilities or regulators do to improve consumer acceptance?

21. Consumer engagement and reaction has been an important factor in the US AMI rollout. How do you foresee consumer reaction in Europe to be? What can European utilities or regulators learn from their US counterparts?

Further research

22. Top 5 countries for AMI, DA, RES, EV…

23. Do you have any white papers on SG technology that you could share with us?

24. Who else could you recommend us to talk to to get good insights into the SG development in Europe?

25. Apart from your big competitors like Siemens, Alstom, Areva, etc., which start-ups do you know of that are interesting and what solutions are they providing?