Supported by:

Renewable energy

Smart meters

Advanced Metering Infrastructure

Grid automation

Demand-side management

Customer Engagement

SUSTAINABLE ELECTRICITY SYSTEMS

SMART CITY LIGHTHOUSE CASES

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Index

1
Executive summary

1 Executive summary

This report, "Sustainable Electricity Systems – Smart City Lighthouse Cases", analyses 39 smart city projects which have implemented smart grid technologies in order to make their electricity generation, distribution and consumption more sustainable and efficient. 6 lighthouse cases out of the 39 smart city projects are analyzed in detail.

The purpose of this study is twofold:

1) To draw attention to the wide variety of smart grid related technologies available to improve electricity efficiency and grid performance in cities.
2) To serve as a basis from which key lessons can be disseminated and contribute to the growing number of smart grid projects in cities around the world.

The 6 lighthouse cases analyze 6 smart grid themes: smart meters and AMI, demand-side management, customer engagement, grid automation, renewable energy and the budget of each project. The following main findings can be highlighted:

Smart grid elements (excluding budget) analyzed in the lighthouse cases:

Smart meters	Customer engagement	Demand-side management	Grid Automation	Renewable energy

- Smart meters are the basic technology used in all smart city projects
  - Pilot studies should be carried out before massive roll-outs are planned to assure smooth implementation and functioning of the technology
- The different forms of Demand-Side Management have achieved reduction in electricity consumption of the participating consumers as well as a shift in the load, when structured and implemented correctly
  - Peak consumption reductions of up for 10% have been registered and average load shifts of up to 10%
- Customer engagement is an important factor which strongly influences the success of a smart city project, given that the technology itself cannot change the way energy is consumed
  - A large variety of initiatives for customer engagement exist
- Grid automation technologies are being used to monitor and control the infrastructure which is especially useful in outage situations
  - One case study registered a 55% of reduction in the duration of outages
- Existing and new renewable energy installations are being used to move generation closer to consumption and to increase the share of cleaner technologies in the generation mix
- Project budgets range from approximately 392 to 900.000 Euro (120.000 Euro when not considering Masdar City) per participating household depending strongly on the project's objective and reach

Apart from these topic-specific findings, more general conclusions were drawn from the analysis of the cases. These are related to smart grids in general as well as the organization of smart city projects:

- Smart grids can have positive effects on:
  - Final customers' electricity consumption and bill (with or without consumption reduction)
  - Reduced response time during supply interruptions
  - Cost savings for utilities (e.g. through remote meter reading)
  - Forecasting of generation by distributed renewable energy sources
- The objectives of smart city projects are diverse, even though an underlying focus seems to be emission reduction through energy efficiency; depending on the situation of each city the goal is more directed towards security, reliability, cost reduction or stimulus of the regional or national economy
  - Some projects aim to implement tested technologies like smart meters, other focus on demonstrating and fine tuning new smart grid technologies which will rather be implemented in the medium run
  - The majority of projects represent pilot or technology specific roll-out projects, few are part of an overall smart grid strategy (as for example Jeju in South Korea)
  - Some projects were carried out as a first phase for national technology roll-outs
- The projects should have a main focus and should not include too many technologies because this can lead to overall reduced effectiveness
  - In order to facilitate coordination, tasks should be structured in modules and work should be defined and specific
  - Structured projects and tasks allow to obtain statistically representative and comparable data which again facilitates the drawing of conclusions
- The implementation of smart city projects requires the participation of a large number of players (administration, utilities, consumers, equipment manufacturers, etc.)
- The economic profitability of smart grid projects seems to be very variable depending on the accompanying conditions.
  - A favourable cost-benefit relationship in the implementation of smart grid technologies usually requires a long-term commitment and a stable regulatory environment
  - In many cases, an important part of benefits are externalities which might be hard to measure as well as to allocate to a specific stakeholder

The lighthouse cases analysis has given further insight into the smart grid technology implementation in cities. The following lessons learnt could be identified:

- There is no typical smart city project. Each project is adapted to the requirements and objectives of each city.
- There are smart grid technologies which can already be implemented on a wide scale (e.g. smart meters); others still require further testing and development.
- Given the different requirements as well as the different development stages of the smart grid technologies, no clear conclusion can be drawn on the budget needed for a smart city project.
- A smart city project needs all shareholders to be involved (e.g.: authorities, regulators, utilities, equipment manufacturers), but in order to undertake a successful project it is a requirement that customers (end-users of the energy) are involved and engaged in the project process.

- Smart city projects are often the first step of a wider strategy to take smart grid implementation to a national level.

Further analysis should be focussed on making the results of smart city projects more comparable to better extract best-practices and lessons that other cities can benefit from. Establishing comparable "before" and "after" diagnostics of the cities that undertake smart city projects would also facilitate the thorough evaluation of projects and make it easier to draw conclusions that can help existing and future initiatives to focus their efforts on the those areas that are most relevant and effective for them.

2
Introduction

2 Introduction

Today more than half of the world's population lives in urban areas. This trend is growing as about 180.000 inhabitants are added to urban population each day. By 2030, the share will have reached 60% (double the share of 1950), by 2050 this figure may reach 70%.

Cities are the key engines of the global economy and responsible for the bulk of the world's energy consumption. Therefore, cities could be considered the largest "source" of global greenhouse gas (GHG) emissions. Indeed, estimates show that urban activity is associated with 80% of global energy consumption and CO^2 emissions[1] which will be exacerbated through the growing global urban population in the future. Being the hubs of economic activity and the main contributors to economic growth, when looking at GHG reductions, one must therefore consider the cities' role in driving change and implementing new technologies.

In order to manage cities and make them more liveable, as well as sustainable, authorities and regulators as well as companies have started working on making cities smarter. Smart cities have been defined by the European Commission as *"systems of people interacting with and using flows of energy, materials, services and financing to catalyse sustainable economic development, resilience, and high quality of life; these flows and interactions become smart through making strategic use of information and communication infrastructure and services in a process of transparent urban planning and management that is responsive to the social and economic needs of society."*[2]

Sustainability touches a large number of daily life aspects and is especially related to the field of energy. Reducing greenhouse gas (GHG) emissions is near the top of the political agenda and at the heart of climate change discourse. Many countries have pledged to reduce their GHG emissions through a variety of measures including increasing investment in renewable energy resources and energy saving strategies. All of the members of the European Union, for example, have made a commitment to reduce overall greenhouse gas emissions by 20% by 2020, compared to 1990 levels. Australia has committed to cutting its emissions by at least 5% below 2000 levels by the same year. President Barack Obama also outlined his Climate Action Plan[3] where he pledged to reduce carbon emissions from power plants and invest in renewable energy.

As countries embark on GHG reduction policies, attention will inevitably be drawn to how important parts of the energy system, like electricity generation and grids, can be adapted to better serve our current needs. Despite technological advancements in harnessing new and clean forms of energy, electricity generation still largely depends on GHG emitting fossil fuels. In the United States, electricity accounts for 33% of the country's GHG emissions, compared with 28% from transportation and 20% from industry[4]. This trend mirrors what happens at the global

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[1] "Global Energy Assessment, Toward a Sustainable Future" IIASA, 2012

[2] European Commission, Smart Cities and Communities

[3] Climate Change and President Obama's Action Plan, Whitehouse.gov, 2013

[4] Environmental Protection Agency, 2013

level, with electricity generation contributing 41% of the world's CO_2 emissions in 2010.[5] Curbing GHG emissions caused by electricity generation becomes even more of a pressing issue when considering that, according to the World Energy Outlook, demand for electricity in 2035 will be over 70% higher than current demand.

The key challenge that governments and cities need to face is how to meaningfully cut GHG emissions from electricity generation while maintaining a reliable supply of electricity. Integrating renewable energy on a large scale will require a significant change in how we supply electricity due to their intermittent nature and how to apply that electricity generation to meet demand. In addition, the electricity grid is currently designed to be able to supply peak electricity demand, even though this peak demand is concentrated in only a few hours of the year, causing huge inefficiencies and incurring high costs both to utilities and society in general.

The solutions needed to meet these challenges will not be found in piecemeal measures, they require a fundamental rethink of our electricity system. At the heart of this revolution is the smart grid.

2.1 Smart grid – a key enabler

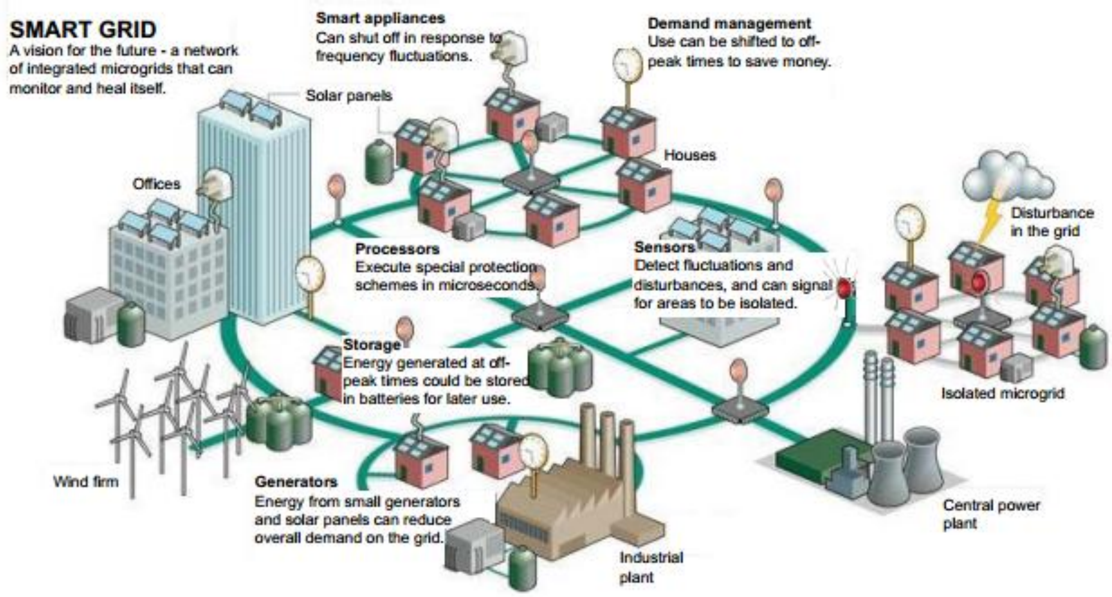
The smart grid is a broad concept which has different definitions to different people. It is easier to understand as a vision or an ideal rather than one specific thing. The term generally refers to a modernization of the whole electricity system where interconnected elements and devices help improve efficiency, reliability and reduce overall consumption. According to this vision, the smart grid will lead us to a cleaner and ultimately sustainable electricity system. Copied below are the key characteristics of a smart grid according to the Electric Power Research Institute (EPRI):[6]

1. Enables informed participation by customers through demand-side management (DSM) initiatives.
2. Accommodates all generation and storage options.
3. Enables new and improved products, services and markets.
4. Optimizes asset utilization and operating efficiency.
5. Addresses disturbances through automated prevention, containment and restoration.
6. Operates resiliently against all hazards.

[5] CO2 Emissions and Fuel Combustion, IEA, 2012

[6] "Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects" EPRI, 2010. p. 4-5.

Figure 1: Smart Grid illustration[7]



As the above illustration shows, the smart grid encapsulates a vision that will not be achieved without a holistic and long-term strategy altering the way we produce, distribute and consume electricity. According to the smart grid vision, the current centralized generation structure will be transformed into an interconnected and interactive system enabling communications between all actors in the grid. The benefits of implementing smart grid technology are felt by all stakeholders along the electricity value chain. For example, utilities will be able to better manage their electricity supply and coordinate more efficiently with individual consumers and businesses, they in turn will have greater control over their usage and save on electricity bills. Pollution as a result of electricity generation will decrease as the grid gains in efficiency and is able to allocate resources more effectively. More importantly, renewable energy resources will be able to be integrated on a much wider scale on the smart grid as it can accommodate intermittent production through better communication infrastructure.

However, we are still a long way from realizing this ideal. Technological and above all budgetary obstacles mean that smart grid projects have so far tended to focus on one specific area, either to test the viability of implementing certain technologies on a wider scale or to fix reliability problems on the distribution network. Key stakeholders therefore need to be coordinated and engaged in long-term, multifaceted city-wide and nationwide projects with the ultimate objective of realizing the smart grid vision.

This study focuses on smart grids as a "key enabler" to reduce electricity consumption throughout the grid and ensure reliable electricity supply. It is important to consider the smart grid not as a solution in itself but more for the possibilities it allows. It is part of the process of implementing sustainable electricity systems in cities and will play a fundamental role in the transition to a low-carbon economy.

"Smart Grids will play a fundamental role in the transition to a low-carbon economy"

[7] Image taken from Smart Grid 2030 Research Associates

2.2 Focus of this study

There is still a lot of uncertainty around the tangible benefits of smart grids. Performing assessments of smart grid technologies poses specific challenges in measuring physical impacts and estimating economic benefits. This is partly because smart grid technologies have some of their benefits in the capabilities they enable rather than the technology itself. This provides its own unique problems for researchers and there is currently no industry agreed methodology for comprehensively assessing the cost-benefit relationship of smart grid technologies. For example, applying grid automation technology along the distribution network provides improvement in customer outage duration, but there is no established procedure for converting this improved reliability to direct monetary benefits (although the U.S. Department of Energy (D.O.E.) has attempted to fill this gap with its Interruption Cost Estimate Calculator). Smart meters can also have many benefits for both customers and utilities, although the ways these are measured also differ according to which methodologies and assumptions are applied.

It has also been argued by some investigators that because of the numerous learning curves involved, demonstration projects alone cannot provide sufficient information to support major decisions on the full-scale implementation of smart grid applications.[8] However, this document takes the view that demonstration projects do provide opportunities for gaining necessary experience and establish a base of impact data that can inform analysis for smart grid installations of broader scale and scope. [9]

Another aspect of the evaluation of smart grid projects is their contribution to GHG reduction. Both the Electric Power Research Institute (EPRI)[10] and the U.S. DOE[11] have attempted to establish a methodology to establish the relationship between smart grid technologies and GHG reductions. However, these studies are fraught with assumptions and estimates rendering the quantification of potential GHG reductions through smart grid deployments extremely difficult. For example, the study by the DOE admits that the uncertainties in estimating GHG reductions are "relatively high" with the individual reduction estimates typically judged to be uncertain in a range of ±50%, and in some cases larger.

It can therefore be stated that the methodology landscape for assessing the GHG reduction potential of smart grid technologies is still insufficiently mature for these projects to be assessed on a GHG-centric basis. Moreover, some of the projects selected for the study were not directly aiming to reduce GHG emissions. For example, E-DeMa in Germany focused on testing sophisticated communication technology that, if implemented on a wider scale, would expand the grid's operational capacity and efficiency. The two projects in the USA in Chattanooga and Houston sought primarily to improve reliability in the network by limiting the effects of seasonal storms. These projects were therefore not designed with that end in mind and they do not quantify GHG impact, making an assessment on that basis unviable.

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[8] EPRI, "Methodological approach for estimating the benefits of the smart grid", 2012 p.11

[9] EPRI, "Methodological approach for estimating the benefits of the smart grid", 2012 p.11

[10] EPRI. "Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid." (2009)

[11] U.S. DOE. *The Smart Grid: An Estimation of the Energy and CO_2 Benefits.* 10 Jan. 2010.

Having said this, it is important to consider that almost all improvements that smart grid technologies bring about (whether in efficiency, reliability or enabling energy saving technologies) do inevitably cause a reduction in GHGs. For example, although the E-DeMa project did not set-out to reduce emissions, the electricity savings that were achieved would have the same end result.

The multifaceted nature of smart grids demands a variety of deployment strategies depending on the objectives set by project managers during the development phase. Despite these different approaches, smart grid projects do tend to be characterized by common themes. This study identifies 6 themes that cover the technical, economic and organizational aspects of smart grid related deployments:

- Smart Meters
- Demand-Side Management
- Customer Engagement
- Grid Automation
- Renewable Energy
- Budgets

These themes are deployed to benchmark 39 smart city projects from around the world that have implemented a variety of smart grid initiatives and technologies. Out of these 39 smart city projects, 6 have been analyzed in detail ("lighthouse cases"). The study does not attempt to employ benchmarks as a means to evaluate the projects; rather it aims to establish these projects as benchmarks in their own right.

The 6 lighthouse cases have been selected in order to cover diverse technologies and solutions within the study and due to the availability of data, for this document aims to contribute to the analysis of smart city projects through the quantification of costs and benefits.

The purpose of this study is therefore twofold:

3) To draw attention to the wide variety of smart grid related technologies available to improve electricity efficiency and grid performance in cities.
4) To serve as a basis from which key lessons can be disseminated and contribute to the growing number of smart grid projects around the world.

Before presenting the analysis and the findings of this study, it should be made clear that the majority of data and information used comes from public sources. Interviews were conducted to gain more insight only for the lighthouse cases, as well as a couple of other specific topics of other smart city projects. We take this opportunity to thank all those that collaborated in the elaboration of this study.

3
Definition of smart city themes

3 Definition of smart city themes

Smart city projects implement a large number of smart grid technologies in order to make their city smarter. The following subsections shall provide definitions and descriptions of 5 of the smart city themes ("budget" requires no definition) that will be used in this study to establish smart city project references (benchmarks).

3.1.1 Smart Meters

Smart meters, and the accompanying Advanced Metering Infrastructure (AMI), are the platform upon which most other smart grid technologies and initiatives operate. A smart meter is an electrical meter that records real-time electricity consumption and communicates consumption data to the utility.

This technology has several advantages over traditional meters. On the one hand they offer consumers and utilities the possibility to use other technologies. For example, a special tariff to persuade consumers to use electricity during off-peak hours (Time-of-Use) can only be optimally implemented if customers have access to real-time electricity costs through a smart meter enabled In-Home Display (IHD). Likewise, all grid automation on the distribution network depends on the AMI communication framework to send fault messages to the utility.

On the other hand, smart meters offer more benefits to consumers and utilities than simply enabling other technologies. For example, they help reduce electricity theft as well as enable the utility to conduct remote readings so a worker does not need to be sent to take the reading manually, saving the utility operational costs and reducing CO_2 emissions from truck journeys. Customers, for their part, benefit through being provided with more accurate electricity billing and reduced waiting times for electricity to be switched on and off after moving homes.

3.1.1.1 Advanced Metering Infrastructure (AMI)

All successful smart meter solutions must be based on effective and reliable communication links between smart meters, consumers, the utility and all of the components in between. This communication is provided through Advanced Metering Infrastructure (AMI). AMI is the term given to the system that employs the communication capabilities to monitor, measure and deliver real-time smart meter data to the utility company. The goal of an AMI is to provide the utility with the necessary information on electricity consumption to help manage and control their resources more effectively whilst also enabling them to help customers make informed choices about their energy usage.

The definitions of the three key components that make up AMI are listed in the table below:

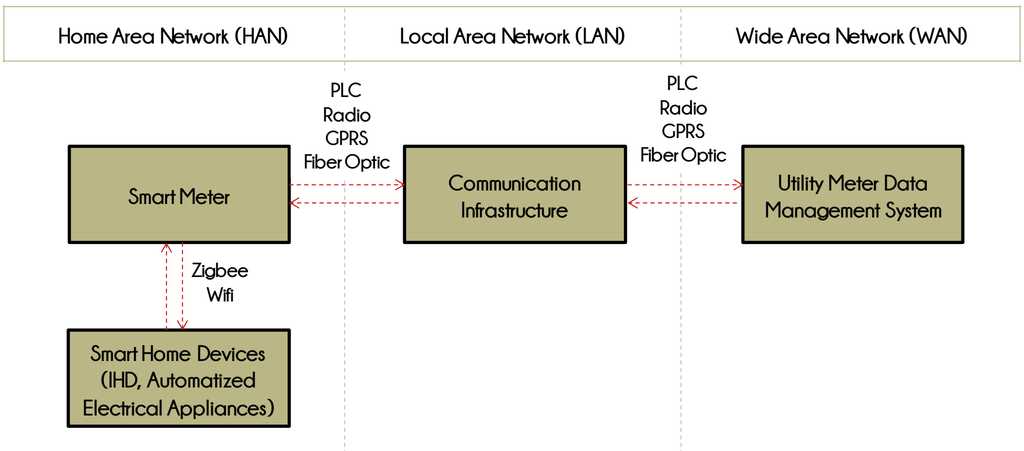
Table 1: AMI technology definitions[12]

[12] Smart Grid Information Clearinghouse, Technologies, 2013

Advanced Metering Infrastructure components	Definition
Smart Meters	Featuring two-way communications between consumers and utilities to automate billing data collection, detect outages and dispatch repair crews to the correct location faster.
Communications	Required by all other smart grid technologies, allowing the system to communicate and interact with the intelligent electronic devices in an integrated system.
Meter Data Management (MDM)	Manages the smart meter data and performs analysis to provide meaningful information to the utility.

A typical AMI set-up is illustrated in the diagram below. The smart meter is set-up in the household where a Home Area Network (HAN) is installed allowing the smart meter to communicate with other devices such as In-Home Displays or automatized electrical appliances through Wi-Fi or ZigBee communications. The smart meter also connects to the Local Area Network (LAN) and Wide Area Network (WAN). This can be done through a variety of communication methods such as PowerLine Communications, Radio and Fiber Optic. These communications allow the smart meter to send information to the utility's Meter Data Management (MDM) system where data analysis and heightened monitoring of consumption trends can be implemented. The MDM then processes and manages the data which customers have access to for billing and analysis of their own electricity usage. It is of the utmost importance therefore that this system is robust, reliable and secure due to the confidential nature of the data being transferred.

Figure 2: Typical AMI set-up



3.1.2 Demand-Side Management

Demand-side management (DSM) is the name given to a set of initiatives aimed at changing electricity consumption trends through methods such as financial incentives, automation of electrical appliances and promoting energy efficiency awareness. It is not a technology in itself but rather a concept which combines technologies as well as pricing mechanisms and consumer education. In this chapter, time-of-use tariffs, in-home displays and automatized electrical appliances will be presented.

DSM takes a step further towards the smart grid than smart meters. It aims to change the way energy is consumed and how demand is managed.

The different elements of DSM only function well if they are combined. For example, the consumers need to have access to information about time-of-use tariffs through in-home displays in order to make use of them effectively.

3.1.2.1 Time-of-Use (TOU)

TOU programs are a type of DSM which focuses on shifting electricity consumption from peak-hours to off-peak in order to reduce the strain on the grid and mitigates against large-scale future utility costs. Utilities encourage customers to do so through special, time-based tariffs providing customers a price incentive to shift their non-essential electricity usage to off-peak hours of the day. Although smart grid technologies are not necessary to implement TOU programs, studies have shown that providing customers with an In-Home Display, enabled through a Home Area Network (HAN), allows them to better adhere to the given tariffs. In addition, by analyzing data from the smart meter, utilities can better advise customers on their electricity usage.

3.1.2.1 In-Home Displays (IHDs)

IHDs connect automatically with the smart meter through the Home Area Network (HAN) and present information in a user-friendly way. Although designs do vary, displays normally present consumption in three formats – electricity consumption in kWh, €/kWh and CO_2 emissions. In addition, IHDs are normally portable or can be fixed to walls or fridges so that customers can have them in places where they are most likely to be using electricity.

Although IHDs are a necessary part of the TOU trials, they may also, in themselves, be considered a form of DSM because they provide customers with heightened insight into their electricity usage and costs in real-time. Customers can view electricity prices before they turn on an electric device, helping them alter their behavior for non-essential loads such as dishwashers and clothes washers. Indeed, households generally suffer a lack of real-time visibility into their electricity usage which limits their ability to effectively manage their consumption. In saying that, the projects that attempted to measure customer reaction to being provided with an IHD were also combined with other initiatives such as TOU or energy efficiency education. It is difficult therefore, based on the results, to conclude that IHDs can bring about electricity consumption changes on their own. It is recommended instead that projects in the future consider IHDs more of a companion to DSM programs rather than a DSM program on their own.

3.1.2.1 Automatized electrical appliances

One of the biggest loads for utilities from residential customers is summer air conditioning usage. Demand for electricity is greater during hot weather, and peaks in demand correlate strongly with maximum daily temperatures. The increase in peak demand, which must be supported by costly network augmentation, has resulted in the less efficient use of existing network resources. Networks are specifically built to cater for these spikes in peak demand at a high cost and these peaks only occur during a few days in summer when air conditioner usage is at its highest.

Automatizing electrical appliances requires the full collaboration of customers because they essentially have to renounce full control over their electrical devices. The objective of implementing automatized electrical appliances is the same as TOU initiatives which is to shift peak loads to times when electricity prices are lower.

3.1.3 Customer Engagement

As mentioned throughout the previous two sections, it is not sufficient to simply implement technology. Technology itself does not change the way energy is being used by significant levels. A real change is being achieved when the consumer is made aware of the potential and the benefits of adapting energy consumption and educated to increase efficiency and the technology is used as an "enabler".

Electricity customers are generally not interested in their electricity until they encounter an outage or a higher bill than usual. For their part, utilities have traditionally tended not to engage with their customers, focusing instead on building and maintaining infrastructure and meeting grid requirements from "behind the stage"[13]. Engagement until now has typically been limited to administrative tasks such as service activation or de-activation requests, sending out monthly or quarterly bills to households and tracking payments.

Marketing, education and innovation are one way of involving the customer. Rewards and incentives can be used to achieve participation.

3.1.4 Grid Automation

As most smart grid discussions tend to focus on consumer-facing technologies such as smart meters and IHDs, the distribution tiers of the electricity grid can sometimes be overlooked. However, one of the key benefits of implementing smart grid technology is to allow real-time communication between grid components to identify faults and voltage imbalances that allow utilities to operate more efficiently and minimize outages or interruptions. Indeed, one of the key challenges that utilities face is that they lack sufficient visibility of the distribution network to identify faults and take decisions that will ensure reliability of electricity supply. This is important because even a short disruption can have a huge effect on businesses and economic activity. In the United States, the electricity system is 99.97% reliable, yet the power outages and interruptions cost an estimated$150 billion each year.[14]

There a number of enabling technologies known collectively as Grid Automation technologies which help utilities analyze conditions in the grid and then help take appropriate action to eliminate, mitigate, and prevent outages and power quality disturbances. Grid automation should be thought of as essentially taking the same concept as AMI and applying it to the distribution network. Two of the main methods are described in the table below:

[13] The Es of End User Engagement, IEEE Smart Grid, 2013

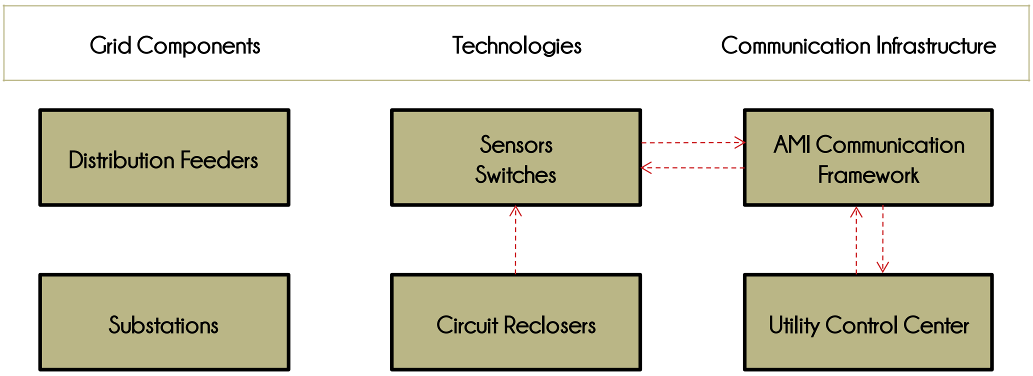
[14] The Smart Grid, US Department of Energy, 2009

Table 2: Advanced Control technologies definitions[15]

Advanced Control Technology	Definition
Distribution automation (DA)	Distribution automation (DA) enables utilities to remotely monitor, coordinate and operate distribution components (such as feeders) in real-time from remote locations.
Substation Automation (SA)	Substation Automation (SA) enables utilities to remotely monitor, control and coordinate the distribution component installed in a substation. SA comprises of smart sensors with integrated communication technologies and control of substation equipment.

Although there certainly are more technologies and systems to mention, the two listed above are the most common and established in current smart grid projects. The below diagram illustrates how a typical DA and SA system operates. Smart technologies are fitted on distribution feeders or substations throughout the distribution network. These smart technologies include sensors and switches that are fitted with communication devices which send reports to the utility control centre through the existing AMI communication infrastructure. When there is a fault or if the loads are too high, the utility is notified immediately and can take preventive action. In addition, if there is a fault, the smart switches are able to isolate the disturbance so fewer customers are affected.

Figure 3: Typical DA System



3.1.4.1 Distribution Automation (DA)

Distribution Automation (DA) is broadly defined as any type of automation which is used in the operation of the electricity grid, including communication between all grid components and automated interfaces with customers. However, it is important to consider that today the "automation" element in DA is more about providing utilities with the necessary information so they can act in a timely and appropriate manner. In saying that, DA as it is can still provide utilities with significant cost savings through improvements in operational efficiency and reliability.

3.1.4.1 Substation Automation (SA)

Substation Automation (SA) allows the utility to control and monitor the substations in their distribution network through smart technologies. As mentioned above, SA can improve electric service reliability by ensuring rapid reactions to unpredictable events in the network while also

[15] Smart Grid Information Clearinghouse, Technologies, 2013

reducing operations and maintenance costs. Smart sensors installed at substations can detect when and where there is a voltage imbalance or voltage level issue. It is estimated that with the help of SA, substations can reduce their losses of up to 10%.

3.1.5 Renewable Energy

Today, the majority of electricity still tends to be generated at central power stations (located far away from populated areas) and distributed along high capacity power lines to urban zones. The challenge facing utilities today is that the operation of these power lines has become the main driver of their costs. Indeed, as stated in the previous section, estimates show that transmission and distribution losses along power lines account for approximately 7% of total electricity generated.[16] A potential solution to this problem would be to produce electricity closer to end-consumers. This will see the increasing integration of distributed generation, especially from renewable sources, in urban areas. However, integrating renewable sources, either from distributed generation or from large-scale solar or wind farms, provides a new challenge for today's electricity grid. It is these challenges which the smart grid vision aims to meet.

Due to their intermittent nature, the increased integration of renewable energy sources requires the improved use of control elements. Although this can be provided in the form of storage capabilities, the costs involved mean that it is still not a viable option to implement on a large-scale. However, it is expected that as distributed generation becomes more pervasive, energy storage technologies will proliferate.

3.1.5.1 Home PV Integration

Home PV Integration refers to photovoltaic installations that are located near or on the consumers' property. Usually the installation is set up and directly connected to the house allowing for self-consumption of the generated energy. Depending on the regulation of a country self-consumption is legally permitted or not.

3.1.5.2 Virtual Power Plant (VPP)

A Virtual Power Plant (VPP) combines the energy produced from various distributed generation installations whose energy is collectively managed by a central control entity or "control room". The control room aggregates, monitors and controls the energy flows from the various installations, operating similarly to "traditional" power plants. VPPs can therefore play a role in driving the smart grid vision towards decentralized electricity production. Indeed, in the short-term this type of energy management system has great potential as utilities seek to further develop new ways in which renewable energy and distributed generation sources can be effectively utilized.

3.1.5.3 Micro-Combined Heat and Power (CHP)

Micro-Combined Heat and Power (Mirco-CHP) is the small-scale generation of heat and electricity from a single fuel source such as natural gas, biomass, biogas etc.). Today, Micro-CHP generally involves domestic gas water heaters that can simultaneously generate heat (for

[16] U.S. Energy Information Administration, 2012

radiators and showers, for example) and electricity. It must be noted that although Micro-CHP boilers do emit CO_2, by burning natural gas, the devices reduce the carbon footprint of a typical household because electricity is being taken from the heater rather than from the grid.

This section has only presented a small part of smart grid technologies, even if, according to the case studies at hand, they represent the common areas. The "list" should therefore not be seen as extensive but rather as an introduction to the smart grid topic.

4
Lighthouse cases

4 Lighthouse cases

Six lighthouse cases have been selected to show how cities implement smartness in their electricity grid or related applications. They are located in different geographical areas of the world and have different approaches, complexities and objectives. Before presenting the analysis of the smart grid themes and related conclusions of the lighthouse cases, they will be quickly presented in this chapter.

4.1 Perth, Australia

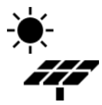
SMART GRID TESTING GROUND

Project Name: Perth Solar City
Project Manager: Western Power
Population: 1,740,000
Participants: 16,283
Start date: 2009
End date: 2013

Objective: Western Power, the Western Australian network operator, set out to test over 30 smart grid and energy efficiency technologies in order to establish a framework to support a network-wide roll-out.

Description: Perth Solar City developed their field tests within Perth's Eastern Region including demand-side management and renewable energy initiatives. Western Power gathered a consortium of 7 companies and organizations that reached over 16,000 households who participated in the program through one or more of the trials.

Smart Grid Elements:

Smart meters	Customer engagement	Demand-side management	Grid Automation	Renewable energy
				

4.2 Évora, Portugal

NATIONAL ROLL-OUT PILOT

Project Name: InovGrid
Project Manager: EDP
Population: 41,159
Participants (households): 32,000

Start date: 2007
End date: 2013

Objective: EDP, Portugal's electricity company, established the Évora pilot with the objective to test and preview smart grid technologies in preparation for a national roll-out. Évora was selected because its demographic was deemed a reasonable representation of the whole of Portugal.

Description: EDP tested the benefits and public response to heighted supervision and control of the electricity network. As part of the project, EDP implemented monitoring technologies at substations and installed smart meters in all 32,000 households as well as fitting efficient lighting technology in all public street lights.

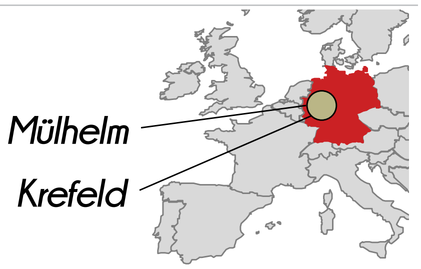
Smart Grid Elements:

Smart meters	Customer engagement	Demand-side management	Grid Automation	Renewable energy

4.3 Mülheim and Krefeld, Germany

INNOVATIVE LOAD-SHIFTING INITIATIVES

Project Name: E-DeMa
Project Manager: RWE
Participants: 656
Start date: 2009
End date: 2013



Objective: E-DeMa set out to test how much electricity customers would save by having greater control over their electricity consumption and spending. The project aimed to test the viability of implementing this initiative on a wider scale.

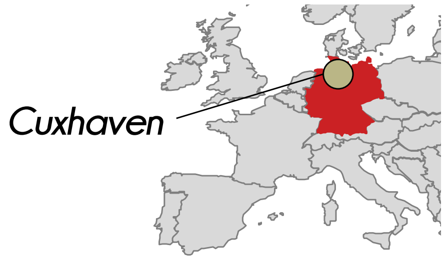
Description: E-DeMa, like eTelligence below, was part of the national E-Energy project in Germany which was part-funded by the government and private sector. Consumers tested various demand-side management initiatives through two ICT (Information and Communications Technology) platforms, known as "gateways" that connected them to an online marketplace that helped them prioritize their electricity consumption according to market prices.

Smart Grid Elements:

Smart meters	Customer engagement	Demand-side management	Grid Automation	Renewable energy

4.4 Cuxhaven, Germany

CONSUMERS, RENEWABLE ENERGY AND VIRTUAL POWER PLANTS



Project Name: eTelligence
Project Manager: EWE
Participants: 650
Start date: 2008
End date: 2012

Objective: eTelligence sought to explore the relationship between energy produced from renewable resources and commercial and private consumption and how the amount of fossil fuels used in electricity production could be reduced.

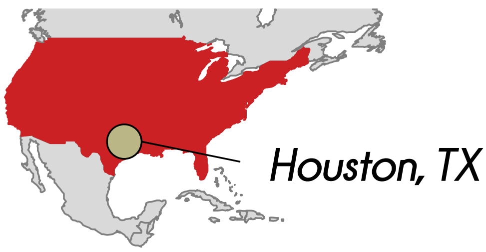
Description: eTelligence implemented a local energy market to explore and demonstrate various approaches to improve the current energy supply system and to integrate renewable energy sources like wind, photovoltaic and biomass. Virtual Power Plants were created for the aggregation of various consumers and renewable generation units as well as to reduce the deviations between forecast and actual production.

Smart Grid Elements:

Smart meters	Customer engagement	Demand-side management	Grid Automation	Renewable energy

4.5 Houston, TX

STRATEGICALLY IMPROVING NETWORK RELIABILITY



Project Name: Energy Insight
Project Manager: CenterPoint
Participants: 2.1 million
Start date: 2009
End date: 2013

Objective: CenterPoint, a Houston electricity provider, began their smart grid to improve network reliability and help consumers better manage their energy consumption. The added incentive came from the fact that Houston experiences electricity interruptions from seasonal hurricanes and storms.

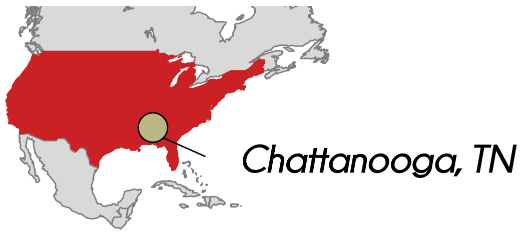
Description: The first phase of CenterPoint's project began with the deployment of more than 2 million smart meters which was followed by the installation of smart devices throughout the grid that allowed the monitoring of network performance in order to help restore service more quickly in the event of a failure or outage.

Smart Grid Elements:

Smart meters	Customer engagement	Demand-side management	Grid Automation	Renewable energy

4.6 Chattanooga, TN

FIBER OPTICS AND THE "LOW HANGING FRUIT" OF THE SMART GRID



Project Name: Chattanooga Smart Grid
Project Manager: EPB
Participants: 172,000
Start date: 2002
End date: 2012

Objective: EPB, Chattanooga's electricity and telecommunications company, wanted their smart grid to improve reliability by reducing the number and length of outages customers were experiencing, especially after storms.

Description: The Chattanooga smart grid project sought to integrate their electricity system with the already installed high-speed fiber optic network. The first part of the smart grid project was designed "under the bonnet" where customers would reap the benefits without witnessing any changes in their homes. The second part saw EPB deploy smart meters to all their customers after the initial strategy had paid dividends and public support for the smart grid was established.

Smart Grid Elements:

Smart meters	Customer engagement	Demand-side management	Grid Automation	Renewable energy

5
Analysis of lighthouse cases

5 Analysis of lighthouse cases

The presented lighthouse cases have been analyzed according to the selected smart grid themes. The chapter will close with a conclusion via lessons learnt from the lighthouse cases.

The lighthouse cases will be used as examples for smart city projects which have implemented or used each theme. For the same technology or theme, two projects might have used a different approach because each city's situation is different and the objectives of the project are not always the same.

Table 3: Main objectives of each lighthouse case

		Main objectives
Perth Solar City, Australia	Smart grid testing ground	• Test over 30 smart grid and energy efficiency technologies in order to establish a framework to support a network-wide roll-out.
InovGrid, Évora, Portugal	National roll-out pilot	• Carry out pilot to test and preview smart grid technologies in preparation for a national roll-out. • Identify benefits and public response to heithed supervision and control of the electricity network
E-DeMa, Mülheim and Krefeld, Germany	Innovative load-shifting initiatives	• Test how much electricity customers would save by having greater control over their electricity consumption and spending. • Test the viability of implementing this initiative on a wider scale.
eTelligence, Cuxhaven, Germany	Consumers, RES and VPP	• Explore the relationship between energy produced from renewable resources and commercial and private consumption and how the amount of fossil fuels used in electricity production could be reduced.
Energy Insight, Houston, USA	Strategically improving network reliability	• Improve network reliability and help consumers better manage their energy consumption.
Chattanooga Smart Grid, USA	Fiber optics and the 'low hanging fruit" of the smart grid	• Improve reliability by reducing the number and length of outages customers were experiencing, especially after storms.

5.1 Analysis of smart grid themes

5.1.1 Smart Meters

All of the initiatives that formed part of the 6 projects in this document either directly depended on or were facilitated by smart meter infrastructure.

5.1.1.1 Smart Meter roll-outs

Project	Description	Smart meters
Perth Solar City, Australia	Smart grid testing ground	✓
InovGrid, Évora, Portugal	National roll-out pilot	✓
E-DeMa, Mülheim and Krefeld, Germany	Innovative load-shifting initiatives	✓
eTelligence, Cuxhaven, Germany	Consumers, RES and VPP	✓
Energy Insight, Houston, USA	Strategically improving network reliability	✓
Chattanooga Smart Grid, USA	Fiber optics and the 'low hanging fruit" of the smart grid	✓

All 6 projects implemented smart meter roll-outs, although to varying degrees. As shown in the table below, the number of smart meters installed ranged from 650 (eTelligence) to over 2 million (Houston, TX).

As stated in this chapter later on, this difference is attributed to the varying objectives of each project. Whereas Houston and Chattanooga were city-wide deployments, the projects in Germany were pilots to test innovative technologies enabled by smart meters and to investigate the viability of implementing these new methods on a larger scale.

Table 4: Smart Meter installations by project

City	Smart Meters installed	Timeframe
Perth (Perth Solar City)	9,276	2009 – 2012
Évora (InovGrid)	35,000	2009 - 2012
Mulheim + Krefeld (E-DeMa)	656	2011 – 2012
Cuxhaven (eTelligence)	650	2011 – 2012
Houston, TX	2,000,000	2009 - 2012
Chattanooga, TN	172,000	2009 - 2012

The most successful smart meter deployments found that conducting smaller trials before a wider roll-out was beneficial in ironing out potential technical issues with the smart meters and communication technology. For example, before the roll out in the rest of the city, EPB in Chattanooga implemented a 1,000 meter pilot to ensure that the Tantalus technology could deliver maximum performance to customers.

In addition, best practices show that engaging with customers and providing them with information before the smart meter deployment has a more positive effect on how customers react. For example, CenterPoint in Houston had an integrated customer outreach strategy to assuage any potential opposition to a citywide smart meter roll-out and extra costs that would be incurred by customers. The different examples of customer engagement encountered in the 6 projects are spoken about in more detail in the Customer Engagement section.

5.1.1.2 Advanced Metering Infrastructure (AMI)

The table below outlines the different technologies and technology providers in each project. This illustrates the variety of technology providers and communication methods that may be utilized in an AMI. As shown, the projects that were designed for a wider deployment (Chattanooga, Houston, Perth and Évora) only utilized 1 smart meter provider whereas E-DeMa and eTelligence in Germany contracted different providers to test various technologies.

Table 5: AMI installed by project

City	Smart Meter providers	Communication technology (providers)	MDM providers
Perth (Perth Solar City)	Landis and Gyr	Radio, 3G (Silver Springs Networks)	Silver Springs Networks
Évora (InovGrid)	EDP	PLC, GPRS (Efacec)	Logica
Mulheim + Krefeld (E-DeMa)	RWE Metering + SWK	PLC, GPRS (Siemens)	RWE Metering
Cuxhaven (eTelligence)	Landis and Gyr + QNE + ITF Fröschl + EasyMeter	PLC, GPRS (BTC + EWE)	EWE
Houston, TX	Itron	Radio (GE)	eMeter
Chattanooga, TN	Tantalus	Fiber Optic (Tantalus)	Alcatel-Lucent

Western Power in Perth set-out to implement a reliable AMI which would eventually be used as a platform to execute a wider roll-out. Over 9,000 Landis and Gyr smart meters were installed which communicated wirelessly to the Meter Data Management (MDM) system, supplied by Silver Springs Networks, via a radio frequency mesh. During the 1 year test period, the MDM experienced just 3.5 hours of total down time, or 0.04% of total operating hours, exceeding the performance benchmark set before the project began. This was important to demonstrate because most of the benefits obtained through the AMI are down to the heightened ability to receive and analyze network data, which depends on the functionality of the MDM. In addition, if customers experience problems such as errors in their billing, the likelihood of them losing confidence in a relatively untested technology will increase. As it was, Perth Solar City recorded 81% of participants being “supportive” of a wider roll-out and only 5% as “unsupportive”.

EDP in Évora installed 32,000 smart meters or “EDP boxes” which provided readings every 15 minutes as well as other functionalities such as remote tariff configurations for Time-of-Use (TOU) trials. The smart meters were enabled through Logica's *Sm@rtering* platform, which was chosen in part because it could integrate the new smart grid processes with EDP’s existing systems for: Asset Management, Work Force Management and Customer Information. Similarly, CenterPoint in Houston also utilized an MDM system (provided by eMeter) that could integrate enterprise-wide information. This aspect was important to both EDP and CenterPoint because they envisaged their MDM system to add value across the entire enterprise by centralizing information that previously had been siloed in different departments.

In both projects in Germany, eTelligence and E-DeMa, ICT (Information and Communications Technology) platforms, known as “gateways”, were developed to monitor, manage and in some cases control smart grid components including smart meters, In-Home Displays and electrical devices. For E-DeMa, two different “gateways” were tested. The first “gateway” was set-up in 549 households where customers could consult an In-Home Display and smartphone app to see when electricity was cheapest and thus an optimal time to consume energy. The second “gateway” was implemented in 107 households and involved the installation of automatized home electrical devices such as dishwashers. These appliances were fitted with communication devices that could delay the machine switching on if electricity prices were high. For the 650 customers taking part in eTelligence, an AVM Fritz!Box internet router was connected to all smart meters. The router known as the “multibox” was fitted with extra software to process smart meter data, which it could then transmit to the MDM. The multibox also enabled demand-side management devices such as In-Home Displays so customers were provided with more control and visibility over their electricity consumption.

In all of these “gateways”, households were connected to an online energy marketplace which communicated automatically with data from the utility and would allow customers to view electricity prices in real-time. This was an important area to test because one of the facets of the smart grid ideal envisages all customers will become active participants in the electricity market, and the E-DeMa and eTelligence online energy marketplace was implemented as a step in that direction. The innovative approach taken by both projects was therefore in contrast to the other projects which implemented mostly proven technologies such as distribution automation and In-Home Displays.

EPB’s smart meter roll-out in Chattanooga followed a different pattern to the other projects as it focused primarily on leveraging the already installed fiber optic network as much as possible to deliver further benefits to the city. Fiber optic networks enable high-speed, two-way communications which now allow EPB to transfer and store near unlimited amounts of data. This means that the network will not be at risk of becoming congested when smart meter and smart electrical device communication become more frequent. In this sense, EPB considers that they have "future proofed" their grid as fiber optic provides them with the necessary strength to seamlessly integrate further loads which future technologies may require.

5.1.1.3 Smart Meter financial benefits

Any smart meter roll-out will involve an initial investment by the utility to pay for installation and the smart meters themselves. In the case of CenterPoint in Houston, customers were required to pay a monthly surcharge to subsidise the roll-out. In both cases it is therefore fundamental for any large-scale deployment to demonstrate quantifiable benefits as a result of installing smart meters. Although it has been discussed earlier that conducting cost benefit analysis of smart grid technologies can be problematic[17], the table below shows that 4 out of the 6 projects recorded financial benefits as a direct result of installing an AMI. ETelligence and E-DeMa did not record any particular monetary benefits because the objectives were not to specifically test smart meter benefits as much as they were to test the technologies enabled by them.

"Smart meters can provide considerable monetary benefits in their own right."

Table 6: Smart meter financial benefits by project

City	Measured benefits	Estimated € savings
Perth (Perth Solar City)	-	€104 million (estimated over 20 years in wider roll-out)
Évora (InovGrid)	96% real-time consumption invoices 60% remote operations	€2.2 million (per year)
Houston, TX	99.5%+ remote reading accuracy rate	€33 million (per year)
Chattanooga, TN	TBC	TBC

As part of their analysis, Western Power in Perth found that the average time to complete a manual service request was 5 days for a disconnection and 1.5 days for a reconnection. However, during the smart meter trial, connect and disconnect timeframes were slashed to less than 1 minute thanks to remote controlling. In addition, the trial enabled 1,255 unscheduled remote meter readings to be conducted. Meter readings are requested by clients when a billing is being queried or when a customer is moving in or out of a property. In a citywide roll-out, Western Power has estimated that these benefits along with the improved reliability of the network will equal €104 million over 20 years.

EDP and CenterPoint in Évora and Houston respectively are now basing the vast majority of invoices on real-time consumption meaning that estimates have been effectively eliminated for customers. This makes operations more efficient as the number of customers questioning their electricity bill decreases. In addition, EDP is conducting over 60% of operations remotely allowing them to save on operational costs through not having to send a worker to make a manual reading. CenterPoint is now electronically reading all meters daily at a 99.5%+

[17] EPRI has conducted various cost/benefit studies of smart grid technologies. Their latest study can be found by following this link.

accuracy rate (going from 26.4 million reads a year to 219 million meter reads a day in the process). In addition, CenterPoint has performed 20,000 remote connect/disconnect service orders in a single day, which has saved $8 million (€6.2 million) per year bringing the total yearly savings to an estimated €33 million.

Although the figures above are based on estimates, the results demonstrate that smart meters can provide considerable monetary benefits in their own right. Although, as mentioned earlier, it is not the purpose of this document to provide a cost-benefit analysis of smart grid technology, the data shows that there are a variety of benefits of installing smart meters if utilized to their full potential. In saying that, utilities and governments will still need to ensure that there is a compelling business case for deploying smart meters on a wide-scale and present these findings to the public.

The following potential benefits of smart meter and AMI were identified in the 6 lighthouse cases:

- Extensive data recollection, measuring, and monitoring of consumption data for utility
- Precise and remote meter-reading
- Meter and tariff configuration and remote (dis-)connection
- Fault detections
- Information on real-time electricity costs for consumers

It seems important to conduct smaller trials before massive roll-outs in order to assure successful smart meter deployment.

5.1.2 Demand-Side Management

All lighthouse cases have implemented some sort of DMS initiatives; the majority focusing on load-shifting (i.e. encouraging consumers to move their energy from peak hours to off-peak, thus reducing the strain on the electricity grid). It should be explained that certain projects have achieved success in decreasing total energy consumption through behavioural changes.

Project	Description	Demand-side management
Perth Solar City, Australia	Smart grid testing ground	✓
InovGrid, Évora, Portugal	National roll-out pilot	✓
E-DeMa, Mülheim and Krefeld, Germany	Innovative load-shifting initiatives	✓
eTelligence, Cuxhaven, Germany	Consumers, RES and VPP	✓
Energy Insight, Houston, USA	Strategically improving network reliability	
Chattanooga Smart Grid, USA	Fiber optics and the "low hanging fruit" of the smart grid	✓

In its current state, the grid does not possess the capability to store electricity on a large scale. This means that as electricity demand has grown, utilities have had to employ expensive "peaking" power plants to increase power generation to meet peak demand. DSM can be valuable for a utility because, if implemented on a wide scale, it potentially allows them to save on the costly operation of peaking power plants and also on new constructions and maintenance. Customers, for their part, are empowered to control their electricity consumption which enables them to cut their electricity bills and contribute to GHG reduction efforts.

5.1.2.1 Time-of-Use (TOU)

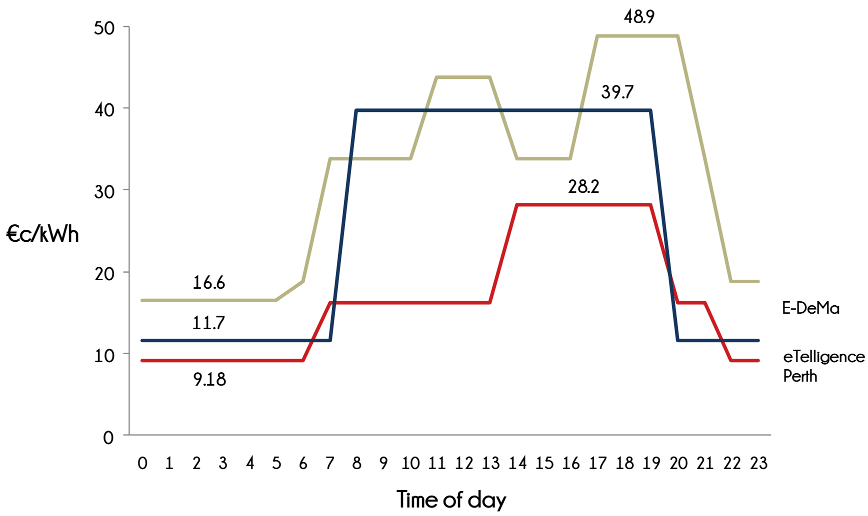
The table that follows outlines the different tariffs utilized in the projects that implemented TOU initiatives:

Table 7: TOU tariffs by project (€)

City	Peak Tariff	Off-Peak Tariff
Perth (Perth Solar City)	28.20 c/kWh	9.18 c/kWh
Évora (InovGrid)	N/A	N/A
Mulheim + Krefeld (E-DeMa)	48.90 c/kWh	18.96 c/kWh
Cuxhaven (eTelligence)	39.79 c/kWh	11.67 c/kWh
Houston, TX	N/A	N/A
Chattanooga, TN	12.71 c/kWh (Summer)	3.17c/kWh (Summer)

Below is a graphical depiction of the different tariffs, illustrating that lower prices were offered to customers during the morning and late evening with the highest prices coming in the afternoon/early evening. E-DeMa offered customers the most complex tariff with various peaks and shoulders before lulling between midnight and 5 am. The eTelligence project managed by EWE aimed to simplify tariff prices for participants and this is demonstrated through the only two prices offered throughout the day.

Figure 8: TOU tariffs by project



The results of the trials are listed in the table below.

Table 9: TOU results by project

City	Participants	Avg. peak hour load-shift
Perth (Perth Solar City)	424	13.1%
Évora (InovGrid)	TBC	TBC
Mulheim + Krefeld (E-DeMa)	549	3%
Cuxhaven (eTelligence)	650	11%
Houston, TX	TBC	TBC
Chattanooga, TN	22 (large manufacturers)	$2.3 million savings/year (projected)

In Perth, Western Power introduced a TOU tariff known as "PowerSmart". The 427 participants who took part could view their electricity cost in real-time via an In Home Display (IHD). Analysis showed that participants reduced their electricity consumption during peak hours an average of 13.1% demonstrating that households are open to changing their consumption behavior when financial incentives are present. As mentioned above, the trial concluded that providing customers with an In-Home Display improves the results of TOU programs. Western Power demonstrated this by setting up a control group with customers who volunteered for the tariff but did not have access to an In-Home Display. Analysis showed that the control group reduced their consumption during peak hours 8.9%. It is therefore important that customers have access to an In-Home Display if TOU programs are going to reach their full potential.

In the E-DeMa project, the 549 participants in the ICT platform known as "gateway 1" were provided with access to their electricity consumption in real-time, either through an online web portal or a smartphone app. Participants were then able to consult their usage in relation to the tariffs and adjust their consumption accordingly. Analysis found that they reacted more positively to viewing their electricity consumption in colors instead of by prices (i.e. dark red for expensive electricity and light green for cheap electricity). As well as testing a variety of different tariffs with different peaks, RWE tested real-time tariffs where customers would be informed when there was excess energy in the grid (during very windy or sunny days for example) and therefore an optimal time to consume electricity because the price was cheaper. It was found that, on average, customers shifted their loads by 3%. However, it was concluded that overbearing customers with information and real-time tariffs can result in confusion and be counter-productive. It was therefore recommended that tariffs are designed in a simple year-round format (like the tariff introduced by EWE in eTelligence for example) so customers can be reassured by a stable structure to help reduce their consumption.

In eTelligence, the load shift potential of participants was investigated in 650 households. On average, electricity consumption was reduced by 11% during peak time while saving €100 during the 12-month test phase. Although this rate is significantly higher than E-DeMa's and Perth's, it should be noted that this is because the time defined as "peak" in eTelligence lasted much longer than the other projects. Indeed, as the graph above illustrates, E-DeMa's peak only lasted a few hours in the early evening whereas both Western Power and EWE implemented longer peak tariffs. This suggests that for utilities to obtain the optimal load shifting results, it may be preferable to ensure that peak tariffs last for longer than a few hours.

In addition, eTelligence sought to further test customer's reactions to higher and lower electricity prices through "events" where they would alert customers of a period where prices would be at exaggerated levels (0.00 €/kWh - 0.80 €/kWh). Although EWE didn't notice the same customer confusion as E-DeMa, analysis did show that during the instances of very high prices, there was a shift of around 20%. However, when electricity was at very cheap rates, there was an increase in consumption of up to 30% within the period of the event. This suggested that the incentive to use more electricity when the prices are low is more effective than the incentive to refrain from using electricity when prices are high.

Lastly, both eTelligence and E-DeMa found that the load-shifting behavior strengthened over the entire test period and continued after the trial had finished. In saying that, the projects also saw that the use of monitoring solutions such as smartphone apps decreased over the duration of the trials, although this did not have any discerning impact on consumption. These discoveries go some way to proving that if combined with electricity consumption education, customers are more than willing to permanently alter their consumption behavior. However, it should be stressed again that in both projects, participants were volunteers motivated by a desire to help the environment which means that they may not be entirely representative of the average electricity customer.

5.1.2.2 In-Home Displays (IHDs)

The table below presents the projects that measured the effects of having IHDs in the home.

Table 10: IHD results by project

City	Participants	Avg. electricity consumption reduction	Avg. peak hour load-shift
Perth (Perth Solar City)	1,137	1.5%	5%
Évora (InovGrid)	1,000	3.9%	-
Mulheim + Krefeld (E-DeMa)	549	-	3%
Cuxhaven (eTelligence)	TBC	TBC	TBC
Houston, TX	TBC	TBC	TBC
Chattanooga, TN	TBC	TBC	TBC

In Perth, IHDs provided real-time electricity consumption information to 1,137 participants, allowing them to view the change in electricity consumption and cost immediately after switching appliances on and off. In parallel to energy saving coaching sessions, participants reduced their total electricity consumption by an average of 1.5% and shifted their peak usage by 5%. The lasting effects of the trial were that 81% of participants said they are now more aware of day-to-day energy usage. In addition, the fact that customers shifted their load from peak hours implies that providing households with IHDs can be a solution to reducing the strain on grids with peak demand constraints.

In Évora, 1,000 participants took part in the IHD trial. Their IHDs took energy consumption readings every two seconds and the information could also be viewed on a computer or smartphone. The IHDs were also fitted with a control function which allowed customers to switch smart plugs on and off remotely. A study monitored electricity consumption of customers in Évora and compared it to a control group in a nearby municipality with similar socioeconomic conditions that were not provided with IHDs or energy efficiency education. The results observed a consumption reduction in the first year of 3.9% vs. the control group, showing that IHDs can be an effective means of reducing electricity usage. However, as was noted above, the 1,000 participants in Évora were also provided with education on how to reduce their consumption. This education took the form of focus groups as well as SMS messages and emails to participants with personalized information on their consumption.

It is therefore important to consider these results within the context of how the projects were managed. Participants were provided with IHDs as part of a wider project to encourage energy saving behavior. In addition, participants in Évora were able to check their consumption on smartphones and computers. This means that although the results were obtained without intervention from TOU tariffs or automatized electrical appliances, it should be considered that the effectiveness of IHDs as a DSM method depends on the amount of education participants are provided.

5.1.2.3 Automatized electrical appliances

As mentioned before, one of the biggest loads for utilities from residential customers is summer air conditioning usage. Demand for electricity is greater during hot weather, and peaks in demand correlate strongly with maximum daily temperatures. The increase in peak demand, which must be supported by costly network augmentation, has resulted in the less efficient use of existing network resources. For example, in Perth, Western Power research shows that 10% of peak electricity supply is used less than 0.5% of the time meaning that their grid is built to meet a capacity that only happens a few hours a year. Networks are specifically built to cater for these spikes in peak demand at a high cost and these peaks only occur during a few days in summer when air conditioner usage is at its highest.

For their implementation, customers need to give their full collaboration for automatized electrical appliances because they essentially have to renounce full control over their electrical devices. The objective of implementing automatized electrical appliances is the same as TOU initiatives which is to shift peak loads to times when electricity prices are lower.

There were only 2 projects out of 6 which implemented automatized electrical appliance initiatives. The project information and results are provided in the table below:

Table 11: Automatized electrical appliances results by project

City	Participants	Appliances	Average peak hour load-shift
Perth (Perth Solar City)	202	Air conditioners	20-25%
Krefeld + Mulheim (E-DeMa)	107	Dishwashers, Washing machines	4.4%

Western Power in Perth tested the feasibility and cost-effectiveness of reducing electricity consumption at times of peak demand through air conditioner demand management. 202 participants agreed to have their air conditioners remotely controlled through a Demand Response Enabling Device (DRED). The DREDs received signals from the smart meter allowing the air conditioner to be controlled via remote signals from Western Power operators. At times of peak demand and hot weather, the DRED would receive a signal to switch the air conditioner on/off in determined cycles. As the participants in the trial were willing volunteers, it is not clear how customers would react on a wider scale. However, analysis showed that the average reduction ranged between 20-25% of peak demand of participant households.

In E-DeMa, the 107 households that were selected for the ICT platform known as “gateway 2” were equipped with smart appliances from Miele, an electrical appliance manufacturer. The appliances automatically chose the lowest tariff for their operating cycles by means of a communication module developed by ProSyst, a software company, which connected the household to the intelligent marketplace. The appliances were only switched on when power was readily available and at a low price. Analysis showed that on average the trial achieved a load shift of 3%.

The reason for the significant divergence between the load shifts of Perth and E-DeMa is that summer peaks are much more extreme in Perth owing to the heightened usage of air conditioners. Temperatures can rise to above 35°c during the day, meaning that air conditioner usage is quite high, especially when compared with Germany. In fact, it could be argued that automatizing electrical appliances is best suited to grids that have to support high air conditioner loads, as the potential for load-shifting from dishwashers and washing machines is limited to an estimated maximum of 5%.[18] It is therefore suggested that in the future, projects develop further technological alternatives involving domestic electrical appliances such as utilizing refrigerators as storage units which was tested in the eTelligence project. This is spoken about in more detail in the section on Renewable Energy.

Demand management, in its different forms, has principally three benefits:

- Increase consumers' insight into their electricity usage
- Achieve load-shifting by application of TOU tariffs
- Adapt/ plan consumption of appliances according to level of electricity tariffs through implementation of automation mechanisms

Demand management needs collaboration of the consumers to function well. It is important that they have access to easily understandable and visual information in order to be able to adapt their consumption.

5.1.3 Customer Engagement

Utilities have been known to consider smart grid deployments almost solely in terms of technology, while neglecting their outreach strategies.[19] Involving customers in smart grid projects therefore requires a mindset change for utilities. This is because customers will play a fundamental role in the success of the smart grid (e.g. the usage of smart meters and TOU tariffs). Customers need to be informed of the costs and benefits and how to make the most of these benefits. Surveys taken before the deployments in Évora, Perth and Germany showed that many customers were not aware of the associated benefits of having a smart meter. However, this changed once they were informed and understood the benefits that a

Project	Description	Customer engagement
Perth Solar City, Australia	Smart grid testing ground	✓
InovGrid, Évora, Portugal	National roll-out pilot	✓
E-DeMa, Mülheim and Krefeld, Germany	Innovative load-shifting initiatives	✓
eTelligence, Cuxhaven, Germany	Consumers, RES and VPP	✓
Energy Insight, Houston, USA	Strategically improving network reliability	✓
Chattanooga Smart Grid, USA	Fiber optics and the "low hanging fruit" of the smart grid	✓

[18] Expert Interview, Dr. Michael Laskowsi. Interview by E-DeMa. 24 May 2013

[19] Interview with Avnaesh Jayantilal, IEEE Smart Grid, 2013

wide scale roll-out could bring. Providing customers with the opportunity to lower their electricity bills through a Time-of-use initiative, for example, will not bear fruit unless they fully understand the concept of peak hours and what are the main contributors to their electricity bills. Likewise, if customers are required to contribute to smart grid deployments through an increase in their electricity bills (as in Houston), they will have to be "on-boarded" in interactive engagement campaigns to understand how the costs outweigh the benefits.

"Involving customers in smart grid projects necessarily requires a mindset change for utilities"

The 6 lighthouse cases in this document were chosen partly because of their successful customer outreach programs. Although smart grid initiatives can be met with some opposition from a certain section of society (whether for privacy or cost concerns), these case studies show that taking the initiative and engaging with customers has allowed them to mitigate against these risks and on-board customers through a variety of channels.

5.1.3.1 Marketing, Education and Innovation

All of the 6 projects recognized the importance of customer engagement programs. For example, CenterPoint in Houston identified that strong public opposition could have arisen from a 12 year monthly surcharge payable by customers which was approved by the Public Utility Commission of Texas to recoup part of the investment in the smart grid project. For the first 24 months, the surcharge for residential customers was $3.24 (€2.43) per month but was later reduced to $3.05 (€2.29) per month. In addition, the potential pain points for the utility in this case were not only the surcharge, but also public opposition to smart meters in general. Public Q&A forums were set-up so concerned customers could voice their opinions, whether about costs or other issues to do with smart meters. In addition, phone staff at CenterPoint was trained in how to deal with customer questions about smart meters, establishing a direct contact for customers when they had doubts. This transparent and helpful process of presenting the costs and benefits to customers allowed the surcharge to be passed with minimal public resistance. Although customers involved in the 5 other projects did not have to pay for their smart meters (in Portugal, for example, national regulation states that customers do not have to pay for their smart meters), the CenterPoint model shows that preempting customer complaints by identifying the potential pain points early in the deployment process can ensure a smooth smart meter roll-out.

Similar to CenterPoint, Western Power in Perth focused on educating participants, although their campaigns aimed to get customers to understand their own electricity consumption and what was contributing to their electricity bills. Through the Perth Solar City project, the Western Australia Department of Transport implemented phone-based eco-coaching to support 6,000 participants in reducing their energy, water, and car usage. The project was envisaged to test the effectiveness of engaging households in behavioral change through setting simple and measurable targets and explicit benchmarks as well as encouraging participants to join the other projects that were part of Perth Solar City. Results showed that participating households who also took part in other smart grid trials, achieved an average of 7.5% reduction in total electricity use.

"Broad-reaching marketing campaigns were less successful when not complemented with a well planned direct marketing or community engagement strategy."

Another key part of Western Power's effort to engage customers was their grassroots community engagements. Social media was an effective, low-cost method of reaching out to potential participants. The effectiveness of such a method was demonstrated by the fact that 35% of project referrals were generated online (rather than via phone or in-person). EPB in Chattanooga also utilized social media as an interactive tool where customers were encouraged to ask questions and learn more about EPB's plans. Online interaction was designed so that customers could voice their opinion and concerns and interact with a member of the EPB customer service team. Although not all social media engagements are effective, Perth and Chattanooga demonstrated that utilities can find success if they share interesting information and operate a two-way communication channel that will engage customers.

Western Power found that campaigns were less successful when not complemented with a well planned direct marketing or community engagement strategy. An example of this was the In-Home Display (IHD) Trial, where only 56% of households who received a device paired it to their smart meter. If an IHD was not paired to the smart meter the customer was not counted as an "active participant". Reasons cited for not pairing the device were technical issues that were not resolved as well as customer's not being provided with enough information about the device. A closer engagement with customers in this respect would surely have increased the number of active participants.

Similarly in Évora, EDP viewed customer engagement as a prerequisite to changing behaviors and achieving energy savings. As part of this effort, key stakeholders (such as schools, business leaders and energy professionals) were identified and multiple initiatives were designed to target specific customer groups. These initiatives included showrooms where people in the city could learn about the smart grid as well as public Q&A sessions with EDP representatives. Demonstration zones were also set-up around the city where customers could learn firsthand about some of the initiatives. One of these demonstrations was set up in a popular coffee shop where an In-Home Display showed changes in consumption in real-time as coffee was being made. This served to inform the public about the projects that were being implemented and how best to take advantage of their functionalities to achieve energy savings.

EDP also installed innovative public lighting technology enabled by the smart grid. The lighting was fitted with communication modules which were designed to fit in with the aesthetic of Évora (a UNESCO World Heritage Site). Each LED lantern contained a set of sensors that, together with a centralized management system, had dimming capabilities that increased energy efficiency. As an example of the improved lighting capacity, street light working periods were automatically adjusted in order to adapt to film projection schedules during a summer film festival. After analyzing data for the whole city after all of the new lights had been fitted, EDP saw an energy reduction from 2,451 kWh/ month to 726 kWh/ month, a decrease of around 70%.

5.1.3.2 Rewards and Incentives

For the E-DeMa project, RWE contacted approximately 5,000 households to take part, with 656 eventually being selected. To drive interest and customer participation, RWE offered up to €25,000 to spend on energy-efficiency and social projects in both Mülheim and Krefeld. Each customer received a monthly bill along with information on their energy consumption compared with the previous year. If there had been a reduction in their consumption during peak hours, then RWE would contribute to the donation to the community. It should be noted that E-DeMa operated with fictional prices and monthly bills that showed how much they would have saved in comparison with their normal electricity costs. Participants were therefore volunteers whose sole motivation was their concern for the environment, something which possibly could have resulted in above average energy saving results. This should be taken into account for all pilots that utilize volunteers because their motivations may not be reflective of the average person.

Customer engagement is necessary to carry our any smart grid project in any smart city that involves energy consumers. It contributes the benefit of consumers actually making use of the technology the way it was foreseen. There are a large number of ways to carry our customer engagement (Marketing, Education and Innovation initiatives like workshops and showrooms or Rewards and Incentives like donations).

5.1.4 Grid Automation

Four out of the six lighthouse cases have implemented some grid automation measure.

Project	Description	Grid Automation
Perth Solar City, Australia	Smart grid testing ground	✓
InovGrid, Évora, Portugal	National roll-out pilot	✓
E-DeMa, Mülheim and Krefeld, Germany	Innovative load-shifting initiatives	
eTelligence, Cuxhaven, Germany	Consumers, RES and VPP	
Energy Insight, Houston, USA	Strategically improving network reliability	✓
Chattanooga Smart Grid, USA	Fiber optics and the 'low hanging fruit" of the smart grid	✓

5.1.4.1 Distribution Automation (DA)

Before they started the Distribution Automation project, EPB in Chattanooga estimated the annual cost of outages in Chattanooga at \$100 million (€75.5M). It was estimated therefore that if customer outages could be reduced by 40% the utility would save €30.2m (\$40m) each year. To help achieve this target, EPB invested €37m (\$49.1m) in 1,200 S&C Electric's IntelliRupter automated switches to be installed on the low voltage distribution system. These switches utilize a new brand of technology known as PulseClosing which verify that lines are clear of faults before initiating a close operation. For their part, CenterPoint's DA project integrated a variety of platforms which enabled a series of technologies including smart sensors, switching devices and transformer monitors that helped detect, locate and isolate faults automatically.

The benefits of this technology in Chattanooga were evaluated during a summer storm in 2011, where EPB managed a 55% reduction in duration of outages, with the early restoration saving \$1.4 million. After analyzing data over the course of 2011, EPB's System Average Interruption Duration Index (SAIDI) has dropped 24%, from 109 minutes to 82.5 minutes. In Houston, CenterPoint managed to achieve a 21% improvement in outage response in 2012 compared to 2011.

EPB has also implemented DA technology on their high voltage network. A Schweitzer Electronic Labs (SEL) platform was implemented and the system's functionality was proven in January 2013 after a storm that affected over 11,000 customers. 10,800 customers were restored automatically in less than one minute. The remaining 200 were switched on remotely by dispatchers in 7 minutes.

It is important to note that the business case for Distribution Automation technology becomes especially compelling when the grid suffers from seasonal storms like in both Houston and Chattanooga. However, utilities will need to conduct thorough research to evaluate the value that grid automation technology can bring to their grid. Indeed, as demonstrated in the example below, grid automation also entails the operational improvement of grid components.

5.1.4.2 Substation Automation (SA)

The only project to implement SA out of the 6 projects was the national roll-out pilot in Évora. A technology known as Distribution Transformer Controllers (DTCs) was installed at 340 MV/LV substations to centralize the data that was being sent by all of the 35,000 smart meters. The DTCs became known as the "brain" of EDP's smart grid as they provided remote control and monitoring capabilities along the whole grid. These capabilities were valuable because it allowed EDP to increase efficiency in electricity usage through optimizing line currents and changing the off-load power transformer tap to increase voltage levels.

Seeing as the LV grid accounts for a significant portion of losses along the distribution grid, it is necessary for utilities to invest in smart infrastructure that can help minimize these losses. In placing these losses into context, EDP estimated that their total distribution grid losses accounted for 3.5 TWh or 7.4% of total generated energy in Portugal. This huge potential of savings can therefore be enabled through the implementation of SA on a national scale.

As seen in this section, grid automation is focused on the upstream part of the distribution grid. There are several benefits to be gained from implementing technologies that make the grid more automatized:

- Provides utilities with visibility through information and data about the distribution infrastructure to react faster in case of faults or operational difficulties
- Detects, locates and isolates faults automatically
- Controls and monitors substations and other grid infrastructure
- Reduces operation and maintenance costs

5.1.5 Renewable Energy

As presented in an earlier section, due to their intermittent nature, the increased integration of renewable energy sources requires the improved use of control elements. This can be provided in the form of storage capabilities, but the costs involved mean that it is still not a viable option to implement on a large-scale. It is expected, however, that as distributed generation becomes more pervasive, energy storage technologies will proliferate. The eTelligence project integrated a control capacity through a refrigeration warehouse which would consume electricity when there was a surplus of supply (during windy or sunny days for example) and then be able to go without electricity when electricity prices were high for up to a few days.

Project	Description	Renewable energy
Perth Solar City, Australia	Smart grid testing ground	✓
InovGrid, Évora, Portugal	National roll-out pilot	✓
E-DeMa, Mülheim and Krefeld, Germany	Innovative load-shifting initiatives	✓
eTelligence, Cuxhaven, Germany	Consumers, RES and VPP	✓
Energy Insight, Houston, USA	Strategically improving network reliability	
Chattanooga Smart Grid, USA	Fiber optics and the 'low hanging fruit" of the smart grid	

As another example of the challenges utilities face in integrating renewable resources into the grid, Western Power in Perth investigated the effects of a high penetration (30%) of 35.5kW solar Photovoltaic (PV) systems on their low voltage network. The trial studied the potential for problems such as localised power quality issues and found that voltage rises outside of upper voltage compliance limits can occur. It was recommended that in instances of high urban PV density, smart grid enabled mitigation strategies be put in place such as voltage regulators which can control voltage imbalances at times of high electricity production from PVs.

It should be noted that in some of the 6 projects in this study, integrating renewable energy resources has not gone hand-in-hand with smart grid trials. Both utilities in the USA, for example, have implemented their renewable energy projects separately from their smart grid roll-outs. This has been because these utilities have preferred to focus on attainable benefits in the short-term such as achieving greater efficiency and energy savings. On the other hand, Western Power, E-DeMa and eTelligence all considered integrating renewable energy sources as a central part of their smart grid trials.

The table below demonstrates which projects integrated renewable energy sources as part of their smart grid initiatives along with the generation potential.

Table 12: Renewable Energy technologies

City	Type of renewable resource	# installed
Perth (Perth Solar City)	PV	659 (average size of 2.30kW)
Évora (InovGrid)	TBC	TBC
Mulheim + Krefeld (E-DeMa)	Cogeneration (CHP)	14 (average size of 1 kW)
Cuxhaven (eTelligence)	PV and Wind	8 Wind Farms (600 kW total) 19 PV Systems (80 kW total)
Houston, TX	TBC	TBC
Chattanooga, TN	TBC	TBC

5.1.5.1 Home PV Integration

In Perth, the residential solar PV program incentivized households to generate their own electricity by providing a discount on residential solar PV systems. Project partner, SunPower, installed 659 solar PV systems at an average size of 2.30kW, for a total installed capacity of 976kW. Analysis showed that the average participant household used 41% less electricity from the network, or 8.15kWh per day. It was also shown that north-west facing solar PV systems produce approximately 50% of their summer maximum output at the time of network peak. It was therefore concluded that north-west facing solar PV should be considered as a demand management tool to reduce peak electricity consumption on appropriate parts of the network.

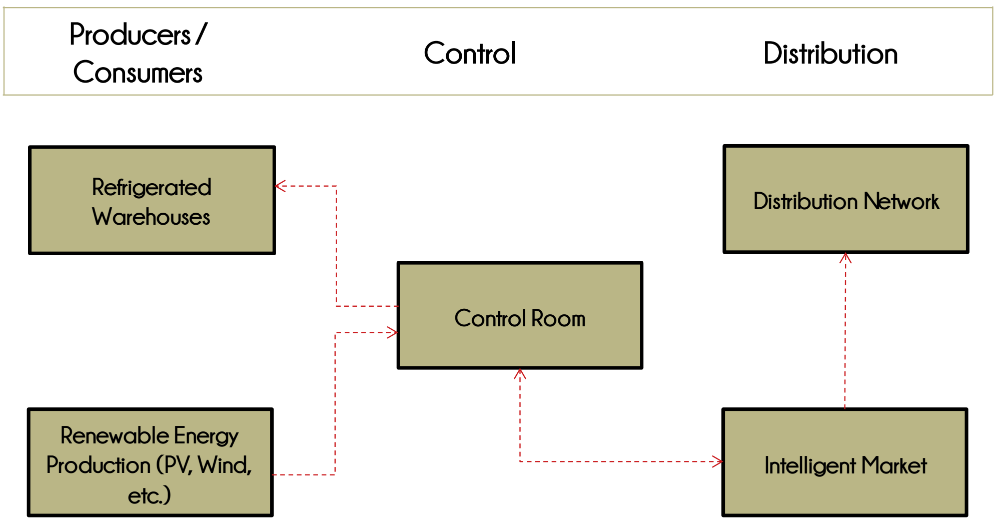
Perth Solar City was the only project out of the 6 which deployed home PV systems. As stated above, this is attributed to the fact that utilities tend to pursue smart grid and renewable energy projects separately. Furthermore, utilities tend to prefer to lay the foundation for customers to invest in PVs and other renewable resources. For example, EDP in Évora sought to encourage home PV systems through implementing Distribution Transformer Controllers (DTCs) in substations to better monitor and control grid performance (something which can be become affected with a higher density of renewable resources). It is yet to be seen how utilities will define their role in developing renewable energy resources, although the example given below could provide a promising indication.

5.1.5.2 Virtual Power Plant (VPP)

The only project out of the 6 in this study to test VPP technology was the eTelligence project which aimed to test a complex control system to balance fluctuating wind and solar power and integrate it into the grid. The core component was a regional electricity "marketplace" which brought together renewable energy producers, consumers with shiftable loads, energy service providers and grid operators.

The eTelligence VPP operated for 1 year. The main generating systems were wind and PV systems, while the "consumers" were refrigerated warehouses. These warehouses would be utilized as a type of storage facility, where it could consume excess electricity and store it in the form of cooler temperatures meaning that it could go without electricity for a few days in moments when there was a greater need for electricity. As the image below illustrates, the VPP system in eTelligence utilized a "control room" which aggregated all of the production from the renewable energy sources, sending excess electricity to the refrigerated warehouses. The control room would then trade its energy with the intelligent marketplace which would then coordination with the distribution network. The aim was to coordinate these operations just as reliably as a conventional, centralized power station.

Figure 4: eTelligence VPP System



Among the results which eTelligence demonstrated was that facilities like the refrigerated warehouse, can be used very effectively as energy storage facilities, achieving savings of up to 8% of their normal electricity costs. When a lot of wind is available, the cold storage depot lowered its temperature, creating a cold buffer for itself, allowing it to go without electricity when electricity prices were high. The depot could run on the cold buffer for as long as a few days, thereby reducing its demand and in turn its electricity costs. Although there are complexities in setting up such a system on a wide-scale (especially in terms of software and ICT), utilities can refer to the achievements in eTelligence has a reference.

5.1.5.3 Micro-Combined Heat and Power (CHP)

As part of E-DeMa's project, 14 households were fitted with micro-CHP units which would produce electricity as a by-product from the heat produced by the boiler. However, this element of the project proved to be the most challenging for RWE. The CHPs were integrated into the online market place or "gateway" that was being tested to prove that customers and their electricity consumption could be integrated into a holistic system. This was a significant achievement considering the complexities involved of aggregating customer demand and generation capability of other energy sources. However, the 1 kW capacity of each micro-CHP unit meant that the effect on the grid was marginal and the project was unable to draw any definitive analysis from the results.

This suggests that, while the technology is available, the application of energy efficient water heaters to shift loads from the grid still requires some development before it becomes a viable option for consumers and utilities alike. For example, one of the issues at the moment with this particular type of micro-CHP technology is that the device is designed to be operated only when heat is required, meaning that the benefits are focused on colder months when central heating is being used.

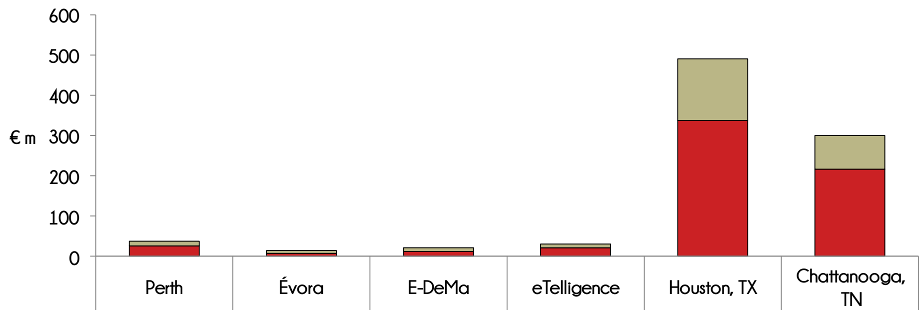
Renewable energy technologies which are generally appropriate for distributed generation can be implemented effectively and efficiently if smart grid infrastructure exists. Further, if generation is located closer to consumption the overall grid infrastructure might not have to be extended or might even be reduced.

5.1.6 Budgets

The budget section does not cover any specific smart grid theme but aim to give general information on smart city projects.

Effectively analyzing the budgets of smart grid projects presents its own unique challenges. As demonstrated in the table below, the budgets allocated to the 6 projects varied considerably. It may be striking to see such differences in the funding quantities; however, this simply illustrates the diversity of smart grid projects and their range of budgeting requirements. For example, the projects in Germany aimed to test the viability of integrating new and innovative technologies as part of a national strategy in the medium to long term. The projects in the USA, on the other hand, targeted the "low hanging fruit" of the smart grid where benefits in reducing customer outages could be demonstrated relatively quickly through established and proven technologies.

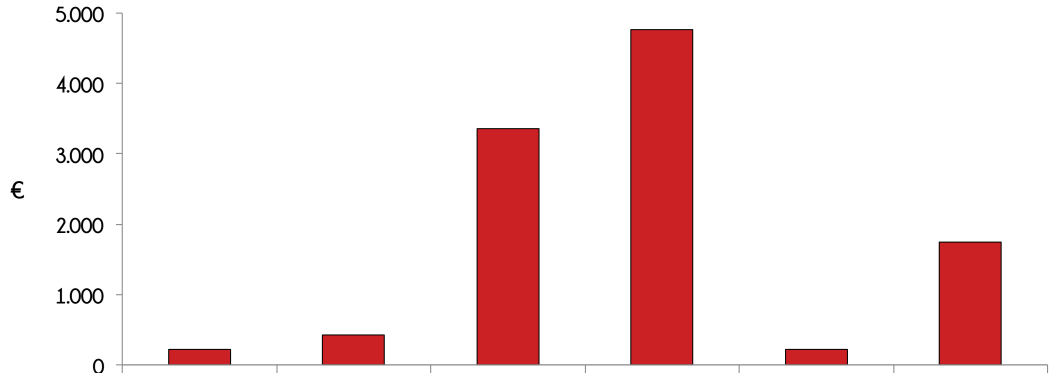
Table 1: Total Budget per project (€, m)



	Perth	Évora	E-DeMa	eTelligence	Houston, TX	Chattanooga, TN
Public	10,7	7,5	10,0	10,0	153,8	85,4
Private	25,7	7,5	12,0	21,0	337,6	215,4

It should be noted that the projects in Germany were significantly more costly if analyzed on a per participant basis (see table below). This is because the projects were run as pilots to test new methods that are currently more complex than the already established technologies utilized in the USA. In addition, the projects in Germany implemented "customer facing" technologies that did not benefit from economies of scale like the projects in the USA who mainly invested in upstream grid technology. It should also be noted that many participants in Perth did not actually take part in the most expensive stages of Perth Solar City, participating instead in less expensive initiatives such as eco-coaching and energy audits that were offered as part of the program, thus reducing the cost per participant overall.

Table 13: Budget per participant (€)



	Perth	Évora	E-DeMa	eTelligence	Houston, TX	Chattanooga, TN
€ per participant	219	429	3.354	4.769	223	1.744

5.1.6.1 Public-Private Cooperation

Due to the high costs involved, national and local governments will play a necessary role in the funding, development and evolution of smart grid technologies. Indeed, governments and public institutions have contributed to all 6 of the projects surveyed. Governments have many political and economic reasons for supporting smart grid initiatives, varying from stimulating economic growth to promoting environmentally-friendly technologies. However, these projects also demonstrate that the smart grid requires a unified effort from various sectors within governments and private sectors.

The Perth Solar City project received AUS$13.9 million (€10.73M) in funding from the Australian Government's Solar Cities initiative and a further AUS$33.3 million (€25.71M) of funding was contributed by the Perth Solar City Consortium which included Western Power and 7 local companies. EDP in Évora also established partnerships with several local companies such as INESC Porto, Efacec, JANZ & Contar as well as their technology partner Logica. The public-private split in Évora was more even than Perth, with the project budget split 50/50 between EDP and public funds.

E-DeMa and eTelligence were part of the German government's E-Energy programme, which ran from 2009-2013 and was funded by the Federal Ministry of Economics and Technology (BMWi) in collaboration with the Federal Environment Ministry (BMU). Six projects across Germany were selected for funding with an overall budget of €140 million. E-DeMa cost €22m, with €10m being provided by the government and €12m by the participating companies. On the other hand, eTelligence cost €31m, with €10m coming from the government and €21m from private participants. Both projects counted on the contribution of a wide variety of players, with 9 companies taking part in E-DeMa and 19 in eTelligence. RWE and EWE partnered with these companies because they both set-out to test new technologies and demand-side management techniques which required a wide range of expertise. It is thought that while this structure is necessary in pilots of this kind, a wider-scale deployment of these technologies will involve a more traditional set-up like the projects in the U.S.

Indeed, in both Chattanooga and Houston, EPB and CenterPoint were the project leaders and neither formed a consortium like the 4 other projects. This was primarily because the technologies they were implementing were already established products that could be purchased "out of the box" by various providers. Both projects therefore did partner with technology companies, although these partnerships matched the more traditional mould of client-provider relationships than the other 4 projects in the study. Both Chattanooga and Houston were supported with sizeable federal grants from the U.S. Department of Energy (DOE). CenterPoint received a DOE grant for approximately 30% of their total investment while EPB counted on a grant of $111 million (28% of total investment) to support their smart grid project.

5.2 Conclusions of lighthouse cases

The projects of all 6 lighthouse cases have been carried out to make the cities smarter with respect to energy generation, consumption, transmission and distribution. The overall objective is therefore the same for all, even though each project focuses on a different aspect depending on the current situation and circumstances of each city. The cities in the US, for example, concentrated their efforts on reducing problems which arise from outages, among other problems. For this they used more established technologies. The German projects focused on consumption reduction and the integration on renewable energies. They used newer methods and technologies. The project in Perth and Évora had a more general approach which aimed at testing smart grid technologies later to be deployed on a wider level.

As presented throughout the previous sections, each project had a different reach and covered different smart grid elements. A summary of the theses can be found below:

Table 14: Themes covered by each lighthouse case

		Smart meters	Demand-side management	Customer engagement	Grid Automation	Renewable energy
Perth Solar City, Australia	Smart grid testing ground	✓	✓	✓	✓	✓
InovGrid, Évora, Portugal	National roll-out pilot	✓	✓	✓	✓	✓
E-DeMa, Mülheim and Krefeld, Germany	Innovative load-shifting initiatives	✓	✓	✓		✓
eTelligence, Cuxhaven, Germany	Consumers, RES and VPP	✓	✓	✓		✓
Energy Insight, Houston, USA	Strategically improving network reliability	✓		✓	✓	
Chattanooga Smart Grid, USA	Fiber optics and the "low hanging fruit" of the smart grid	✓	✓	✓	✓	

All project but one (Solar City Perth) we led by utilities which seem to have understood the need for smart grids in smart cities in order to cope with the need for energy efficiency and emission reductions, increased demand and costs.

Smart meters

Smart meters are the most widely employed smart grid technology. They are a well tested technology and the most basic element that all smart city projects use. They seem to be fairly easy to deploy and depending on their model, allow for customer engagement, as well as the recollection of basic information and a better operation of the relationship between consumers and the utility. Benefits like more accurate billing and faster and cheaper service (e.g. connection and disconnection of a customer point) are common.

They are a clear example of an enabler on which the deployment of other technologies can be based. According to the case studies at hand, it seems to be more effective to undertake smaller smart meter roll-outs before massive deployment.

Other AMI technologies have been less tested and there is not such a wide experience on deployment. There are different technologies which have different functions. Depending on the project's objective and its reach one technology might be more adequate than another. Advanced technologies are used to take smart meters benefits even further.

Smart meter and AMI deployment in the present lighthouse cases have recorded direct financial benefits.

Demand-side management

The objective of demand-side management (DSM) is to adapt the demand in order to improve energy efficiency. The majority of DSM initiatives in the 6 projects focused on load-shifting (i.e. encouraging consumers to move their energy consumption from peak to off-peak hours, thus reducing the strain on the electricity grid). Technologies like In-Home Displays (IHD) overcome the problem which households generally suffer because of a lack of real-time visibility into their electricity usage which limits their ability to effectively manage their consumption.

Load-shifting seems to have been effective in the cases at hand. If consumers are provided with information, training and tools necessary to change their consumption, they will most likely do it. On the other hand the consumer should not be overloaded with information in order to avoid confusion. A clear tariff structure is important. One has to bear in mind that the projects were undertaken with volunteers and it is not clear how the general public would react in a similar case.

Customer Engagement

Customer engagement seems to be an important factor in the success of the projects. Consumers involved in the activities have to be informed on the objectives of the study and have to understand why certain actions are being taken in order to get involved properly. An example of customer engagement is providing information on the costs and the benefits for the individual as well as the city as a whole. As mentioned before, one objective of the smart grid is the participation of consumers in the electricity market. In order to participate, the consumer has to know how it is possible and what consequences and benefits the participation brings along.

An article in IEEE Smart Grid states that "customers must be told what is to be gained from and how to make use of variable pricing, advanced metering, smart appliances and home energy management systems, to name just the most obvious innovations being introduced (. . .). Only a meaningful customer experience of enablement, empowerment and education will produce the fully engaged end user who fully exploits what the smart grid has to offer and paves the way to the smart city and a smarter planet."

As mentioned before the projects in this report have generally had very well functioning customer engagement mechanism, which is why, among other factors, they were chosen. The lighthouse cases have presented different approaches (e.g. campaign, hotlines, social media, and customer trainings) and it seems like customer engagement in whatever form can contribute significantly to a successful implementation and completion of a smart city project.

Grid automation

Technologies used for grid automation allow real-time communication between grid components. This way, utilities can implement preventive as well as reactive measures when problems in the grid occur.

The case studies have shown that grid automation technologies have improved operational efficiency and reliability significantly. For example, the reaction time during outages was reduced and related costs cut by important shares.

This type of technologies is especially interesting for cities which suffer from problematic weather conditions like storms.

Renewable energy

The approach for integrating renewable energy sources (RES) has been different in each analyzed project. Some considered RES to be a central element of their smart city project, others did not include RES as an integrated technology. Four out of the six implemented some RES technology, but to a very different extent.

The RES technologies can be installed and managed separately or integrated in Virtual Power Plants (VPP). In either case a more distributed generation is achieved, reducing losses which occur during transmission and distribution as well as reducing the need for grid infrastructure. The projects showed that RES could help reduce consumption of energy from the grid and that combined with storage solutions they can help reduce the need for large central generation plants.

Budgets

The lighthouse cases do not allow drawing any general conclusion on budgets because each project is of a different nature and extension. Companies are involved in all of the cases and bear important shares (> 50%) of the budgets to cover. Nevertheless, public support and funding is needed to push and complete the projects.

Depending on the technology deployed and the size of the project, the overall budgets vary significantly but in general, smart grids and smart cities demand for large monetary investments, not only for the investment in the technology itself (purchase, development, etc.) but for a successful implementation (installation, training, etc) and completion of the whole project.

The budget is linked to the type of project and its objectives. Pilot projects which test technologies might be cheaper overall than massive roll-out projects because they have a smaller reach but are probably more expensive when rated on their number of participants.

Lessons learnt

Considering the conclusions of the lighthouse cases, the following lessons can be learnt considering smart grid projects for smart cities:

- There is no typical smart city project. Each project is adapted to the requirements and objectives of each city.
- There are smart grid technologies which can already be implemented on a wide scale (e.g. smart meters); others still require further testing and development.
- Given the different requirements as well as the different development stages of the smart grid technologies, no clear conclusion can be drawn on the budget needed for a smart city project.
- A smart city project needs all shareholders to be involved (e.g.: authorities, regulators, utilities, equipment manufacturers), but in order to undertake a successful project, especially the consumers have to be involved and engaged in the project process.
- Smart Cities seem to be the first part of a project which is later taken to a national level of smart grid implementation.

6
Further analysis

6 Further analysis

The 39 cases covered in this study are found across several geographic regions (Europe, North and Latin America, Asia, Middle East and Australia) and range from small specific pilot projects to larger and more generally orientated roll-out projects.

On the following two pages, a summary of the analyzed smart city cases can be found with data on:

- Project name, city and country
- Participants and households
- Total budget and budget per household
- Smart grid themes included in project, where the following code represents the extent of implementation
  - ✓✓ (extensive implementation of technology or theme during project)
  - ✓ (existing but reduced implementation of technology or theme)
  - ✓ (existing but extent unknown)
  - \- (not included in project)

Table 15: Analyzed smart city cases

Country	City	Project name	Partici-pants	House-holds	Ratio	Budget (MEUR)	EUR/ house-hold	Smart meters	Demand-Side Management			Customer engagement	Grid Automation		Renewable Energy		
									TOU	In-Home Displays	Automatized electrical appliances		DA	SA	Home PV	VPP	CHP
Australia	Perth	*Perth Solar City*	35,680	16,000	2.2	36.40	2,275	✓✓	✓	✓	✓	✓✓	✓		✓		
Austria	Graz Mitte	*Reininghaus (barrio inteligente)*	343	143	2.4	4.20	29,371	✓				✓✓			✓✓		✓
Austria	Viena	*Aspern "Smart Urban Lab"*	20,000	10,500	1.9	40.00	3,810	✓			✓	✓			✓	✓	
Austria	Salzburg	*Smart Grids Model Region Salzburg*	720	300	2.4	1.00	3,327	✓			✓	✓	✓		✓	✓	✓
Austria	Upper Austria	*Linz 2050*	N/A	N/A	2.4	0.19		✓		✓		✓			✓		
Brazil	Búzios	*Cidade Inteligente Búzios*	27,701	11,542	2.4	13.68	1,185	✓✓		✓	✓	✓✓	✓✓		✓		
Chile	Santiago	*Smart city Santiago*	30,000	12,500	2.4	N/A		✓✓			✓	✓	✓✓		✓		
France	Lyon	*Greater Lyon Smart City II (Lyon Confluence urban development*	660	275	2.4	N/A		✓✓		✓✓		✓✓			✓		
France	Lyon	*Greater Lyon Smart City III (Linky Smart Grid)*	420,000	175,000	2.4	69.00	394	✓✓		✓✓		✓✓	✓✓				
France	Lyon	*Greater Lyon Smart City I (Hikary Project)*	3 mixed-used types	3 mixed-used	2.4	N/A		✓		✓	✓	✓			✓✓		
Germany	Aachen	*Aachen model region, Smart Watts*	1,500	391	3.8	20.00	51,151	✓	✓	✓	✓				✓		
Germany	Cuxhaven	*eTelligence*	650	271	2.4	31.00	114,462	✓✓	✓✓			✓✓				✓	
Germany	Mannheim	*MoMa*	2,400	1,000	2.4	20.00	20,000	✓✓		✓✓	✓✓	✓✓	✓✓		✓✓		
Germany	Mülheim and Krefeld	*E-DeMa*	656	273	2.4	22.00	80,488	✓✓	✓✓	✓✓	✓	✓✓					✓
Japan	Yokohama	*Yokohama Smart City Project*	N/A	N/A	2.5	533.00		✓✓			✓	✓✓	✓		✓		
Latvia	Riga	*Promotion of Energy Efficiency in Households*	1,200	500	2.4	N/A		✓✓		✓		✓✓			✓		✓
Netherlands	Amsterdam	*Amsterdam Smart City*	1,200	500	2.4	60.00	120,000	✓✓		✓	✓	✓✓	✓		✓		
Netherlands	Breda	*Easy Street / Meulenspie*	590	246	2.4	N/A		✓✓		✓✓	✓✓	✓✓	✓		✓✓		
Netherlands	Hoogkerk	*The power-matching city*	101	42	2.4	N/A		✓✓			✓✓	✓✓	✓✓		✓✓	✓✓	✓✓
Netherlands	Meppel	*Nieuwveense Landen Meppel*	8,160	3,400	2.4	5.00	1,471	✓			✓	✓	✓		✓		✓
Netherlands	Zwolle	*Muziekwijk*	792	330	2.4	N/A		✓✓		✓✓	✓✓	✓	✓		✓✓		
Norway	Steinkjer	*Demo Steinkjer*	2,400	1,000	2.4	4.83	4,830	✓✓		✓		✓	✓	✓	✓		
Portugal	Évora	*InovGrid*	76,800	32,000	2.4	15.00	469	✓✓		✓		✓✓		✓	✓		
South Korea	Jeju	*Smart Grid Test-bed*	4,984	2,000	2.5	152.00	76,000	✓	✓	✓	✓	✓	✓		✓		

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Country	City	Project name	Partici-pants	House-holds	Ratio	Budget (MEUR)	EUR/ house-hold	Smart meters	Demand-Side Management			Customer engagement	Grid Automation		Renewable Energy		
									TOU	In-Home Displays	Automatized electrical appliances		DA	SA	Home PV	VPP	CHP
Spain	Barcelona	*Price*															
Spain	Corredor de Henares	*Price*	200,000	83,333	2.4	34.00	408	✓✓		✓✓	✓✓	✓✓	✓				
Spain	Málaga	*Smart City Malaga*	12,200	5,083	2.4	31.00	6,098	✓		✓		✓	✓		✓		✓
Sweden	Gotland	*Smart City Gotland*	4,800	2,000	2.4	28.00	14,000	✓			✓	✓				✓	
Sweden	Malmo	*Hyllie*	19,200	8,000	2.4	22.00	2,750	✓✓		✓✓	✓✓	✓✓	✓		✓✓	✓	
Sweden	Stockholm	*Stockholm Royal Seaport*	24,000	10,000	2.4	18.00	1,800	✓			✓	✓	✓		✓		✓
UK		*Energy Demand Research Project*	144,000	60,000	2.4	23.60	393	✓		✓✓		✓✓					
United Arab Emirates	Abu Dhabi	*Masdar*	40,000	16,050	2.5	14440.00	899,669	✓		✓		✓	✓		✓	✓	
US	Boulder	*SmartGridCity*	97,385	39,077	2.5	100.00	2,559	✓✓		✓	✓✓	✓✓	✓		✓		
US	Chattanooga	*Chattanooga Smart Grid*	172,000	69,017	2.5	300.80	4,358	✓✓	✓			✓✓	✓				
US	Fort Collins	*Fort Zed and SGDP*	7,000	2,809	2.5	27.51	9,795	✓✓	✓✓	✓✓		✓	✓		✓✓	✓	
US	Houston	*Energy Insight*	2,100,000	842,644	2.5	491.40	583	✓✓				✓✓	✓				
US	Naperville (datos del 2011	*Smart grid Initiative*	143,684	57,654	2.5	22.00	382	✓	✓	✓		✓	✓				
US	San Diego	*Ecoluxury Apartments*	284	114	2.5	N/A		✓✓		✓✓	✓✓	✓✓			✓✓		
US	San Diego	*SDG&E RDSI Demonstration Project*	N/A	N/A	2.5	11.55		✓✓				✓	✓		✓		

An overview of the 39 smart city projects throws further light on the 6 smart grid themes analyzed in this study.

Smart meters and AMI (Advanced Metering Infrastructure)

Smart meters are the most widely employed smart grid technology. All analyzed smart city projects have implemented smart meters (ranging from deployment in several buildings or households to the whole city), although the objective to fulfil in each project as well as the technology chosen might have been different. In some cities smart meters were mainly installed to simply improve the meter reading, in others more advanced smart meters were used or they were combined with other technologies to give the consumers more information about their consumption and other important elements like electricity tariffs.

Smart meters are a well tested technology and the most basic element that all smart city projects use. They are a clear example of an enabler on which the deployment of other technologies can be based.

As suggested by the Smart Watt project carried out in Aachen, the implementation of smart meters alone is not yet economically attractive for clients (economic savings were limited to 10 to 15 Euro a year for households and businesses).

In many cases the smart meter implementation has been completed with the deployment of AMI. Smart meters and AMI can lead to more efficient consumption, as has been shown by the e-Telligence project in Cuxhaven where a reduction of peak demand was achieved through smart meter deployment, attractive tariffs and consumer information systems. This is beneficial for the consumers as it reduces their electricity costs, as well as for the grid operator because of the reduced peak demand which leads to a more efficient grid use and lessens otherwise necessary investment for grid extension.

For utilities, smart meters and AMI have several benefits: automation of meter reading which eliminates the need for estimations as well as physical visits by utility employees, remote connection and disconnection of consumption points, improved client service by providing more information on consumption as well as the before mentioned services.

According to the case studies at hand, it seems to be more effective to undertake smaller smart meter roll-outs before massive deployment. In Naperville, for example, the smart meters which had been installed in 99% of the households since 2010 have to be replaced. The smart meters are not compatible with the old metering infrastructure, leading to fires due to overheating. If a smaller pilot had been carried out to identify any (technical) problems, the need for replacement might have been avoided.

In Chile, for example, a pilot project was started to test the functionalities of CERM1 meters in the conditions of the electrical grid and to confirm the benefits for clients as well as identify necessary regulatory changes which would permit a massive roll-out.

Demand-side management

Demand-side management concentrates on influencing demand to reduce energy consumption or make it more efficient. In the smart cities analyzed for this study, demand-side

management has taken different forms, but many projects focus on load-shifting. All of the initiatives have shown positive results, given that they were well structured and implemented.
Load shifting can be achieved by incentivising consumption during off-peak hours through specific tariff structures (time-of-use, TOU). Variable tariffs were introduced during the pilot project in Jeju, and although a reduced consumption was only noted by a small share of participants, they reduced their consumption on average by 3% and 5%.

The tariff structure should not be too complex though. During the E-DeMa project, the utility RWE introduced real-time tariffs (which were based on energy supply surpluses during windy or sunny days, for example) and concluded that a system with more than five different tariffs was considered too complex by consumers.

In-Home Displays are another innitative used by several smart city projects. They are used to inform the consumers about their consumption. As explained by the Lyon project: "Setting up a residential energy monitoring system involves carrying out detailed measurement of electricity, gas and water use – and then sharing this information with those most directly concerned: the residents themselves."[20] In the Malmo project, a screen was installed in the hallway of households so the participants could monitor their energy consumption and the associated cost.

Apart from TOU and IHD, intelligent electrical appliances are used to shift loads. In Breda and Zwolle, the participating households received a smart washing machine equipped with special software which allows them to set washing programmes according to their preferences, based on cost and/or sustainability. The washing machine automatically starts the washing cycles at the selected moments. This system is similar to that used in the E-DeMa project in Mülheim and Krefeld (Germany) where intelligent home appliances like washing machines and dishwashers were installed in households which only started functioning when electricity supply was high. On average consumption was reduced by 3% in participating households, while through the demand response initiatives the peak demand was shifted by an average of 5% and a maximum of 10%. The results are similar to those of the Smart Watts projects which concluded that a load shifting of 3% to 10% can be achieved in households.

<u>Customer engagement</u>

As explained in the two previous sections, the implementation of different technologies can lead to consumption reductions and increased efficiency, but generally their implementation requires the implication of the consumer. Customer engagement is essential for the success of a smart city project because the technology itself cannot change the way electricity is consumed. As explained by the Fort Collins project: "Smart Grid will benefit from technologies integration but to realize its full potential the users have to embrace it." Therefore a major focus point in smart city projects is the integration of the smart consumer in the system.

Mannheim's MoMa project came to the conclusion that customers on average showed a price- elasticity of 10-18% whereas the most engaged customers reached 30-35%. Consumers therefore have to be informed and engaged in order to achieve better results. Through the visualization of data like consumption and prices, users become aware of the benefits of environmentally friendly habits and assume personal responsibility for their energy consumption.

[20] Lyon Smart Community, Media Kit, June 2013

With more insight and awareness of their energy habits, consumers can make informed decisions regarding their energy costs.
Consumers have to be educated and the population has to be actively involved. This can be done through various initiatives based on marketing and education tools or rewards and incentives.

In the e-telligence project in Cuxhaven, Germany, the reduction of electricity consumption was directly translated into a reduction in the electricity bill which helped amortize the equipment investment. In order to achieve better results, awareness and follow-up campaigns were used. This translated into average electricity savings of 11% as well as strong awareness of the participants.

In Búzios, Brazil, "customers become the main players: they can manage their consumption, reduce spending and even protect the environment. They can choose to consume or sell the energy produced according to their needs."[21] In order to involve the customers, various techniques of awareness creation were used, among them lectures, travelling cinema, training for teachers and school staff, workshops with students and parents, all carried out during the three years of the project.

Several projects provide the participating consumers with mobile apps which offer consumption information. For example, in the Smart Watt project in Aachen the extensive use of the app (three quarters of the participants accessed the app several times a week) showed how important information and transparency are for the consumer. Furthermore, Smart Watt showed how incentives for the consumer influence the success of a project.

At the beginning when installing intelligent appliances, no monetary incentives were given to consumers to change their consumption, but when these were implemented, significant load shifts because of tariff changes were recorded.

Jeju on the other hand seems to have not made use of customer engagement initiatives or at least has not implemented them successfully. According to a study conducted by the University of Hong Kong, a general mistrust towards the government and KEPCO, the national utility, limited the potential of variable tariffs because they could be perceived as hidden price increases. Further, the participants did not have enough knowledge about the implemented technologies to use them properly.

Grid automation

On the supply side of electricity, the transmission and distribution grid plays an important role. The smart city projects have implemented different technologies to automate the distribution infrastructure and substations.

In Búzios, Brazil, control elements were implemented on both transmission and distribution lines which will control the flow of energy, improving service quality and avoiding the need to expand grid capacity.

[21] Buzios Smart City video

Other examples are Jeju and e-telligence where the grid was made smarter by monitoring and controling technology which informs constantly on the state of the grid, as well as improves quality of supply and grid efficiency. In Jeju, further:

- An open grid was installed for different interconnections between supply and demand points,
- A fault prediction system with automatic recovery was implemented.

In Chattanooga, thanks to distribution automation EPB managed a 55% reduction in duration of outages during a storm, with the early restoration saving $1.4 million. The utility's SAIDI dropped by 24% because of the technology implementation.

Renewable energy

Renewable energy sources (RES) technologies have been installed in several smart city projects allowing to move generation closer to consumption and increasing the share of cleaner technologies.

In the cities at hand, the integration of existing or the installation of new installations of the following renewable energy as well as storage technologies has been carried out:

- Photovoltaic
- Solar thermal
- Wind
- Biogas
- Combined heat and power systems (CHP) and combined heat, power and cooling (CHPC) generation
- Thermal and battery storage systems

Cities have opted for installing RES installations on public and/or landmark buildings or directly in the consumers' houses. In Hoogkerk, for example, all houses have been connected to PV panels for electricity supply. Additionally a 2.5 MW wind turbine has been installed, whose output is scaled to match the energy demand of the households.

In Cuxhaven, e-Telligence used RES to create Virtual Power Plants (VPP) with the following results:

- Positive experience thanks to development and operation of management platform for generators
- Increased benefits from renewable generation through reduced errors in prediction
- Implementation of communication system between market stakeholders (VPP, CHP and market players) based on international communication protocols (IEC 61850)

More specifically through the aggregation of CHP plants, industrial energy consumption could be reduced.

The project in Perth showed how far distributed PV can be used to bring generation closer to consumption. Households were able to reduce their electricity demand from the grid on average by 41% thanks to installed residential PV installations.

The implementation of RES was combined with electric vehicles in several occasions. One example is the Smartcity Santiago which will convert all vehicles of public transport into electric ones, as well as encourage the purchase of electric vehicles by individuals.

Budget

The budget depends strongly on the project scope and objective. Testing new technologies requires more investment than implementing existing and tested elements. The present case studies range from approximately 392 Euro per household to 900.000 Euro per household (or 120.000 Euro if we leave Masdar City out of the ranking).

Budgets vary significantly depending on the city's situation, technologies used, year of implementation and the objective, e.g. pilot project versus citywide roll-outs, for this reason it is very difficult to compare this parameter. The projects which have been included in this analysis range from simple smart meter roll-out to the designing and construction of a whole new city. For example, Graz has only carried out the implementation of smart meters, with a budget of 4,2 million Euro. Masdar City, on the other hand, has a significantly higher budget (14 billion Euro) as the city is being developed from scratch, meaning that the Masdar City project creates a 100% self-sufficient and sustainable city.

Further, it is also important to establish who is covering the investment costs. In some cases the consumer has to pay for parts of the smart meter installation whereas in other cases the investment is covered by the utility or public authorities. The budget of Corredor de Henares for example, does not include the cost of smart meters.

In those cases where the budget per household is very high it is often because the technologies used in these projects are very innovative and therefore more expensive, as are the case of Amsterdam or Yokohama.

Most projects in the United States are very mature projects (e.g.: Chattanooga, 2002), meaning that they started several years back, but at that time were innovative projects and the technologies used then (e.g.: smart meters) were not all developed. However current projects like Búzios (started in 2012) use smart meters which are now fully developed and tested, which makes the budgets decrease.

7
Annex: contacts

7 Annex: contacts for lighthouse cases

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